Example Application
of
The Aviation Performance
Measuring System
(APMS)

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Preface

This example application has been prepared by the NASA AMES Research Center in conjunction with the Global Aviation Information Network (GAIN) Working Group B (Analytical Methods and Tools) (WGB) as one of a number of such examples of the use of analytical methods and tools described in the "*Guide to Methods & Tools for Airline Flight Safety Analysis*". The intent of these example applications is to illustrate how various tools can be applied within an airline flight safety department, and provide additional information on the use and features of the tool and the value of such analysis. GAIN WG B hopes that these example applications will help increase the awareness of available methods and tools and assist the airlines as they consider which tools to incorporate into their flight safety analysis activities.

Each example application of an analytical method or tool is posted on the GAIN website (*www.GAINweb.org*). Readers are encouraged to check the website periodically for a current list of example applications, as further examples will be added as they become available.

Aviation Performance Measuring System (APMS)

1 Introduction

The Aviation System Monitoring and Modeling (ASMM) Project of NASA's Aviation Safety Program is developing a set of automated tools to enable efficient, comprehensive, and accurate analyses of data from large, heterogeneous databases within the National Aviation System. APMS is a project sub-element developing the next generation of tools for flight data analysis and interpretation. Work began with workload-reducing tools for exceedanced-based FOQA analyses, and has progressed to sophisticated multivariate statistical analyses. This example application will focus on a tool designed to identify multivariate statistically extreme flights, characterize what made them atypical, facilitate understanding of associated contextual conditions, and prompt broad and deep evaluation of potential safety risks these flights represent.

1.1 OVERVIEW OF THE TOOL FUNCTIONALITY

Airlines, military units, corporate operators, and others analyze aircraft flight data to identify contributing factors and corrective actions for situations in which aircraft performance parameters exceed prescribed limits during a phase of flight. APMS implemented several key tools over the past eight years to advance the science of flight data analysis. Each of these new tools has been picked up and implemented in some form by commercial vendors as enhancements to exceedance-based FOQA analyses. But these are only first steps, facilitating the processing and understanding of predefined exceedances. The limits of this approach are obviously high sophisticated data collection with modest analysis. Exceedance processing examines only a portion of the data. It scans to extract and understand a few predefined events. Unless we specify in advance what we are looking for, we cannot find it. Further, exceedances may or may not be normative. That is, they may occur routinely at some locations – we do not know in advance anything about their distribution.

There is far more potential information in these datasets that can help operators understand and improve the safety, reliability, and economics of their flight operations. The challenge is finding and understanding key information from the mass of data generated by aircraft and collected by data recorders. Flight data may identify precursors of incidents and accidents and the contextual factors such as weather and air traffic that might make consequences of deviations more and less likely. Extracting this information is extremely difficult by manual analysis or calculation -- searching for key values through terabytes of data or calculating values over dozens to hundreds of parameters measured many times per second. Machine processing is necessary to reduce the human labor required, or normative and contextual analyses are unlikely to be undertaken in a commercial environment. These analyses will complement the information from exceedances, providing greater insight into their operational significance and enabling the discovery of unexpected events.

Advanced tools look beyond events within individual flights to identify systemic problems through statistical analyses of many flights. APMS development of advanced tools has three major thrusts that moving beyond exceedance-detection to routine analysis of all the data for:

1. Safety and efficiency,
2. Providing focused analysis of higher risk phases of flight,
3. Mining for atypical, potential precursors of incidents and accidents.

Our goal is to focus the limited time of domain experts on analyzing the most operationally significant events, while broadening and deepening their analyses.

1.2 OVERVIEW OF MORNING REPORT FUNCTIONALITY

The *Morning Report of Atypical Flights* uses multivariate cluster-analysis to group flights by similarity along flight signatures derived from parameter values, calculates an atypicality score for each flight, and provides a plain-language description of what makes targeted flights atypical. (Statler, et al, 2004). The distribution of atypicality scores – a measure of difference from average values over many parameters – is used to identify flights for examination each day that data are uploaded. This focuses analyst attention on flights likely to be outside the norm, whether they contain predefined exceedances or not. The analyst works through this listing of flights, examining the characteristics that made them atypical, assessing their operational significance, and determining the need for follow-up action. Atypical flights are potential precursors of exceedances, incidents, or accidents, but are identified without *a priori* analyst knowledge or specification of search criteria -- the flight is statistically extreme by multivariate criteria. Atypical flights may or may not capture exceedances, and will complement, or possibly displace, exceedance analysis as a primary FOQA activity.

Flights identified by the Morning Report represent recurring operationally interesting groups of flights, which may identify a developing issue or problem, and unique individual flights of interest.

1.3 INTRODUCTION TO THE EXAMPLE APPLICATION

The APMS team worked with three airline customers of one FOQA vendor to develop the Morning Report. These airlines provided access to over 30,000 flights over a two-year period. Aircraft models represented in these datasets included B-737-400 to –900 and B-757-200 aircraft. In this example application, the Morning Report was applied to 16,493 flights operating to and from airports with sufficient numbers of flights in each database to allow statistical analyses (at least 100 departures and arrivals).

Flights were submitted to the Morning Report analysis within each sample, resulting in lists of the most statistically extreme 5% of flights. The APMS team examined all of these flights in which at least one flight phase was in the most extreme 1% of its comparison sample (airport, carrier, aircraft, and flight phase). All flights were deidentified, but an encrypted correspondence file created at the time the data was downloaded to allow access to weather information for the departure and arrival airport of each flight at the time of takeoff or landing.

2 Input Data

Input data consisted of 16,493 flight data files in engineering units output by the FOQA vendor's software and the logical frame layout for each aircraft model. Thirty-nine operations-focused parameters measured from one to eight times per second on all included models were selected through experimentation during tool development. Individual parameters are screened for data quality by the airline's commercial FOQA vendor's analysis ground station, and further by APMS filters for empirically improbably minima, maxima, and rates of change.

3 Analytical Process

Using a user-selectable list of operations-focused parameters, the program calculates flight signatures within each flight phase – 18 parameter values per phase accounting for the parameter trace through the phase, consisting of start and end-of-phase values, and the mean, standard deviation, minimum, and maximum values of each parameter, its slope, acceleration, and noise. Principal components analysis is used to derive a reduced number of uncorrelated dimensions. Cluster analysis is applied within each

phase. An atypicality score is calculated for each flight using the distance from multidimensional (principal component) centroid, and relative frequency of cluster membership. Analyses are conducted within arrival and departure airports when the aircraft is below FL180. All flights are included in single analyses when the aircraft is above FL180. Atypicality analysis of previously processed data takes about 2 hours per 10,000 flights. As new data are uploaded each day, complete processing, calculation of flight signatures, and atypicality analysis is accomplished overnight.

4   Tool Output

The Morning Report produces output in a graphical format consisting of a list of atypical flights, alerting the analyst or FOQA Monitoring Team (FMT) to the most extreme 5% of flights. The FMT judges whether they are operationally relevant.

5   Application of the Analysis Results

The analyses identifies recurring operationally interesting groups of flights, which may identify a developing issue or problem, and unique individual flights of interest. The former include high-energy arrivals, turbulence and accommodation, go-arounds, landing rollout anomalies, atypical climbs on departure, takeoff anomalies, TCAS resolution advisories with escape maneuvers, and unusual arrival paths. Individual flights of interest have included auto-approaches and landings, reduced flap landings, abrupt corrective maneuvers, unusual level-offs during arrival and approach, and unusual control inputs. Most of these atypical events were not detected by predefined exceedances. Similarly, the program was not specified to look for any of these categories of events, but only multivariate statistically extreme phases and flights.

Let us consider each frequently occurring category in turn.

- **High-energy arrivals** were well above the desired glide path between 10,000 and 2500 ft. afe. and/or entered the approach phase at an atypically high airspeed, resulting in 10-30% more kinetic and/or potential energy that must be dissipated before landing than required by a three-degree arrival path. Importantly, while unstable approaches (a primary industry focus identified through exceedances) almost always began as high-energy arrivals, more than half of the identified high-energy arrivals were brought under control within stabilized approach criteria and others abandoned the approach before violating those criteria. A focus on atypical flights would call attention to high-energy arrival precursors of unstable approaches, just as analyses of approach and landing accidents brought attention to unstable approaches as potential accident precursors. This would shift attention to earlier and higher phases of flight that set the stage for unstable approaches, and potentially, accidents. An exceedance associated with an unstable approach may be a symptom of a systemic problem that has its genesis in the causal factors of high-energy arrivals, which may result from airspace constraints. A focus on understanding the causal factors of high-energy arrivals may provide the insight for formulating more effective interventions than those that treat the symptom.

- **Turbulence and accommodation** were detected on many flights. Turbulence was observable in pitch, airspeed, and vertical speed accompanied by lateral and vertical acceleration. However, acceleration parameters appeared to be too noisy to be useful in turbulence detection. Accommodation was observed in reduced airspeeds during affected phases of flight. These flights were identified only occasionally through exceedances.

- **Go-arounds** were readily identified as atypical. These flights descended to altitudes appropriate to the final approach phase, then climbed back to altitudes appropriate to low speed descent (above 2,500 ft. afe.), and had high-power settings and positive vertical speeds not typically observed in either phase. Many of the identified go-arounds resulted from high-energy arrivals. Most of these flights were identified through exceedances, but the exceedance criteria mistakenly labelled many flights as going around that did not.

- **Landing rollout anomalies** included atypical use of reverse thrust or application of elevator or rudder during landing rollout. Those with reduced or late reverse thrust were accompanied by lower deceleration rates; higher reverse was associated with higher deceleration rates. Atypical elevator application suggested unusual landing or rollout technique; atypical rudder, crosswind or gusty conditions encountered on landing. Very few of these flights were identified by exceedances.

- **Atypical climbs** on departure appeared to be associated with light gross weights. These aircraft climbed and/or accelerated rapidly after takeoff. They were not associated with exceedances.

- **Takeoff anomalies** included flights using reduced power and flights rotating and lifting off at atypically high airspeeds. The former are economically desirable applications of approved techniques. The latter may represent a problem the airlines may wish to monitor or correct. Interestingly, flights with atypically high speed on the runway were at speeds lower than detected by exceedances currently in use by the airlines. They may choose to lower alerting speeds as a result of these analyses.

- **TCAS resolution advisories with escape maneuvers** represent appropriate responses to abnormal traffic situations alerted by a warning system. These flights were not detected by exceedances, but could be by monitoring the "up" and "down" advisory parameters recorded in most FOQA programs.

- **Unusual arrival paths** described flights whose path to the landing runway was outside the path flown by most aircraft. This could be a simple as using a runway not used for landing in most weather situations, or as complex as avoiding weather in the terminal area. The former could be observed directly in flight data, the latter inferred from ATIS in effect at arrival time. Most of these flights involved rather short downwind and final approach segments keeping the aircraft in atypically close proximity to the landing runway. These flights were detected by exceedances only when the path deviated from the localizer at low altitude or produced high descent rates because of a shortened approach path.

Linkage to weather conditions for atypical flights was accomplished through the Automated Data Integration System (ADIS, Kulkarni, et al, 2003). ADIS allows the linkage of a flight to the weather or air traffic data within the flight, while screening from the display time and date information that would reidentify the flight to the analyst. This information is immediately useful to examining the context of a flight identified as atypical or having an exceedance. Atypical flights were found most often to occur in daylight, visual conditions, just like most other flights in the sample. This, on the one hand, reassures that we are less concerned, based on accident rate information, with an unstable approach in day visual conditions than in night instrument conditions. However, weather parameters were not included in the list of parameters identifying atypicality. As ceiling, visibility, wind direction and speed, temperature, and precipitation variables are captured and stored as numeric or categorical data, they may be included in the analysis. This will make capture of multivariate statistically extreme maneuvers in the context of multivariate statistically extreme weather conditions more likely.

The methods described in this report can become routine analyses in FOQA programs. The APMS team has applied for patents for both Morning Report and ADIS and NASA has completed licensing agreements with at least one vendor. For example, carriers might recognize the high number of atypical high-energy arrivals as precursors to unstable approaches. An analyst could develop and apply a pattern search to look at past data or an exceedance measure to monitor for future situations. The analyst or monitoring team might also consider calculating kinetic and potential energy directly; comparing it to values expected from a three-degree descent path and linear deceleration from 250 kts. at 10,000 ft. afe. Either approach would allow the airline to assess and respond to high airport or runway rates of high-energy arrivals, as they now do for unstable approach exceedances. This "discovered" phenomenon could be incorporated into trend analysis just like any other exceedance. We would envision an effective long-term incorporation of atypicality analysis to generalize this process to other alerted issues.

References

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Statler, I., et al, (2004). Identification of atypical flight patterns. Patent Application. NASA Ames Research Center.