# COMMERCIAL OFF THE SHELF (COTS) FLIGHT DATA MONITORING (FDM) SOLUTION FOR BUSINESS AVIATION

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# Executive Summary

The business aviation sector within the UK environment encompasses a diverse range of aircraft types operating across both commercial air transport (including cargo) and private sectors. NBAA statistics for the period 1990 to 2013 suggest that accident rates (accidents per 100,000 flying hours) for corporate/executive aviation (aircraft flown by two-person professional crew) are comparable with commercial airlines. However, air taxi and business aircraft (flown by a single pilot) are less favourable and present an opportunity for improvement. In 2013, the accident rates for corporate/executive, business, air taxi and commuter air carriers all increased, while commercial airlines continued to decline.

Flight data monitoring - the collection of real-time flight data for continuous safety improvement - has been routinely used by commercial airlines over the past 50 years. FDM facilitates the assurance of operational standards, traceable feedback into training and continuous improvement, supports safety management systems and a reporting culture to reduce risks. The adoption of FDM by the business aviation sector in the UK has been limited to date due to lack of legislation, the size and diversity of fleets, lack of digital data-bus installations and financial considerations.

If flight data can be recorded and analysed economically for smaller Business Aviation operators or operators utilising a range of aircraft sizes/models then a more complete and balanced view of flight operations, risks and mitigating actions can be achieved. This project reviews potential COTS solutions in support of an FDM programme for Business Aviation operators of lower weight category aircraft.

Three typical examples of data collection devices (Quick Access Recorders, independent Flight Data Recorders and EFIS) have been reviewed and the number, frequency, precision and accuracy of recorded flight data parameters has been established. Each device type has been successfully emulated using a desktop study and flight simulation.

Simulator check rides (LPC/OPCs) were conducted by four commercial pilots using the Gulfstream G450/550 full flight simulator in four separate sessions. These sessions generated useful flight data and safety events due to the nature of the required flying tasks. A software 'plug-in' was developed to enable analysis of the data and safety events using a commercial FDM analysis solution.

For the given devices and scope of tests using the FDM analysis solution, it has been shown that iFDRs are capable of detecting up to 50% of safety events in the take-off & climb phases of flight. The extension of the basic parameter set (16 parameters) by using derived data parameters may increase the number of detectable safety events.

EFIS systems, where installed offer broad capability, detecting at least 50% of safety events in ALL phases of flight by using additional parameters such as air data and weather information etc.. The addition of configuration and warning information to EFIS systems could further enhance capabilities in support of FDM programmes for Business Aviation.

A high-level review of the technical installation requirements for the devices has shown that under current EASA regulations, QARs require minor modifications, iFDRs require STCs and EFIS systems (with a data recording capability) require no additional installation or modification.

With regard to methodology, it has been shown that flight simulation using LPC/OPC data can be used as an effective means in the evaluation of COTS technologies in support of an FDM programme. This method has potential to reduce the time required to complete a manual desktop evaluation of a new aircraft introduced to the fleet and a practical means by which to evaluate the newly defined LFLs using simulated flight data representative of that which will be present in normal and abnormal flight operations.

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## Glossary of Terms & Nomenclature

| Symbol | Description (Units of Measure) |
|---|---|
| A/T | Auto Throttle |
| AAIB | Air Accident Investigation Branch |
| AAL | Above Airfield Level |
| $a_c$ | lateral acceleration (g) |
| AGL | Above Ground Level |
| AHRS | Attitude, Heading & Referencing System |
| Airprox | air proximity |
| Alt | altitude (ft.) |
| $a_n$ | normal acceleration (g) |
| ANO | Air Navigation Order |
| APP | approach |
| ARINC | Aeronautical Radio Incorporated |
| ASC | Air Safety Central |
| ATC | Air Traffic Control |
| ATM | Air Traffic Management |
| $a_x$ | longitudinal acceleration (g) |
| BOS | Bristol Online Survey |
| C of A | Certificate of Airworthiness |
| CAA | Civil Aviation Authority, the CAA is the statutory corporation which oversees and regulates all aspects of civil aviation in the United Kingdom. The CAA is a public corporation of the Department for Transport. |
| CAP | Civil Aviation Publication |
| CAS | Calibrated Airspeed (kts) |
| CASE | The Corporate Aviation Safety Executive was formed in 2008 by a group of Safety Managers to collate data and monitor trends over the whole business aviation community with the express purpose of improving aviation safety. |
| CAT | Commercial Air Transport |
| CFIT | Controlled Flight Into Terrain |

| | |
|---|---|
| CLIMB | climb phase of flight |
| COTS | Commercial Off The Shelf: Products, components, or software that is readily available through normal commercial channels, as opposed to custom-built units that would achieve the same functionality. |
| CSV | Comma Separated Value: An ASCII format file where each column in a row of data is separated by a comma. Many tools, such as Microsoft Excel, recognise this format. |
| CVR | Cockpit Voice Recorder |
| dd.mm.ss | degrees/minutes/seconds |
| deg | degrees |
| deg/s | degrees per second |
| DES | descent phase of flight |
| DFDR | A Digital Flight Data Recorder is a device used to record specific aircraft performance parameters. The purpose of a DFDR is to collect and record data from a variety of aircraft sensors onto a medium designed to survive an accident. |
| DfT | The Department for Transport is the government department responsible for the English transport network and a limited number of transport matters in Scotland, Wales and Northern Ireland that have not been devolved. The department is run by the Secretary of State for Transport. |
| EASA | EASA is a European Union agency with regulatory and executive tasks in the field of civilian aviation safety. The main activities include: strategy & safety management, certification of aviation products & the oversight of approved organisation & member states. |
| EGPWS | Enhanced Ground Proximity Warning System |
| FAA | Federal Aviation Administration: The agency under the US Department of Transportation tasked with the regulation and promotion of air commerce. |
| FDA | Flight Data Analysis (see FDM) |

| | |
|---|---|
| FDM | Flight Data Monitoring is the proactive and non-punitive use of digital flight information from routine operations to improve aviation safety. |
| FDR | Flight Data Recorder |
| FFS | Full Flight Simulator |
| FLT MAN | flight manual |
| FMS | Flight Management System |
| FOQA | Flight Operational Quality Assurance (see FDM) |
| ft | feet |
| ft/min | feet per minute |
| g | acceleration due to gravity (ft/s$^2$) |
| G/S | glide slope |
| GPS | Global Positioning System |
| GPWS | Ground Proximity Warning System: Also referred to as Ground Collision Avoidance System, GPWS provides aural and visual warnings of an impending ground collision based on an aircraft's actual dynamics and recovery capability. GPWS prevents the incidence of Controlled Flight into Terrain. |
| GSHi | high ground speed (kts) |
| GSLo | low ground speed (kts) |
| GSPD | ground speed (kts) |
| HDG | heading (degrees) |
| HEMS | Helicopter Emergency Medical Services |
| Hi | High |
| Ht | height above ground level (ft) |
| IAS | indicated airspeed (kts) |
| ICAO | ICAO is a United Nations specialised agency, working with its 191 member states & global organisations to develop international standards and recommended practices which states reference when developing their legally-enforced national civil aviation regulations. |

| | |
|---|---|
| iFDR | An iFDR is an 'Independent Flight Data Recorder', a completely stand-alone unit with built-in sensors (AHRS + GPS) capable of recording data to removable media and may use an internal or external power supply. In the USA, these devices are referred to as 'LARS' or Lightweight Aircraft Recording Systems. The device maybe crash-resistant but not usually crashworthy since their primary purpose is to collect data in support of an FDM programme. |
| IMN | indicated Mach number (Mach) |
| INITCLB | initial climb |
| KIAS | knots indicated airspeed |
| knot | nautical miles per hour |
| LATA | lateral acceleration (g) |
| LDG | Landing |
| LFL | Logical Frame Layout: A data map that describes the format used to transcribe data to a recording device. This document details where each bit of data is stored. Even though standardized by aircraft manufacturers, the LFL may change in response to new regulatory requirements, resulting in different LFLs on aircraft of the same type. |
| LNGA | longitudinal acceleration (g) |
| Lo | low |
| LoC | Loss of Control |
| LOC | Localiser |
| LPC | Licence Proficiency Check |
| LVR | lever |
| m | metres |
| Mach | mach number |
| MEMS | Micro-electro Mechanical System |
| MOR | Mandatory Occurrence Reporting |
| MQAR | Mini/Micro Quick Access Recorder |
| NBAA | National Business Aviation Association |
| N/W | nose wheel |

| | |
|---|---|
| N1 | engine spool rpm (%) |
| NMLA | normal acceleration (g) |
| OAT | Outside Air Temperature (degrees C) |
| OPC | Operator's Proficiency Check |
| OQAR | Optical Quick Access Recorder: A QAR that stores data on an optical disk. |
| p | roll rate (degrees/s) |
| PALT | pressure altitude (ft) |
| Parameters | Measurable variables that supply information about the status of an aircraft system or subsystem, position, or operating environment. |
| PAX | passengers |
| PCMCIA | Personal Computer Memory Card International Association |
| PRATE | pitch rate (degrees/s) |
| q | pitch rate (degrees/s) |
| QAR | A Quick Access Recorder is an airborne Digital Flight Data Recorder designed to provide quick and easy access to raw flight data, through means such as USB or cellular network connections and/or the use of standard flash memory cards. |
| r | yaw rate (degrees/s) |
| RALT | radio altitude (ft) |
| RPM | revolutions per minute |
| RRATE | roll rate (degrees/s) |
| RTO | rejected take off |
| S Shaker | stick shaker |
| SD | secure digital |
| Sig-7 | CAA Significant '7' Safety Outcome: The most common lethal outcomes (accident types) that could cause a catastrophic loss in aviation (e.g. loss of control in flight, controlled flight into terrain, runway excursion etc.). |
| SOP | Standard Operating Procedures are detailed written instructions to achieve uniformity of the performance of a specific function. |

| | |
|---|---|
| STC | Supplemental Type Certificate: An STC is a National Aviation Authority approved major modification or repair to an existing type certified aircraft, engine or propeller. As it adds to the existing type certificate, it is deemed “supplemental” |
| SS | side stick |
| SSFDR | Solid-State DFDR: A DFDR that utilises solid-state memory for recording flight data. |
| T/O | take off |
| T/R | thrust reverser |
| TAT | Total Air Temperature ($^{0}$C) |
| TC | Type Certificate |
| TCAS | Traffic Collision Avoidance System |
| TD | touch down |
| T-O | take off |
| USB | Universal Serial Bus |
| $V_2$ | take off safety speed (kts) |
| $V_3$ | flap retraction speed (kts) |
| $V_{GND}$ | ground speed (kts) |
| $V_{REF}$ | landing reference speed (kts) |
| VSIHi | high vertical speed indicator |
| VSILo | low vertical speed indicator |
| $V_{VERT}$ | vertical speed (ft/min) |
| WT | weight (kg) |
| YRATE | yaw rate (degrees/s) |
| μQAR | Micro Quick Access Recorder |
| $\phi$ | roll angle (degrees) |
| $\psi$ | yaw angle (degrees) |
| $\Theta$ | pitch angle (degrees) |

# 1 Introduction

The business aviation sector within the UK environment encompasses a diverse range of aircraft types operating across both commercial air transport (including cargo) and private sectors. It includes rotary wing aircraft used by police, ambulance and search & rescue, piston prop and turbo prop aircraft used for aerial survey and air ambulance, as well as business jets and helicopters used for executive/VIP transport, chartered or privately owned/operated.

## 1.1 Safety Statistics

Accident rates for the business aviation sector need to be considered in the context of a diverse range operations and aircraft types across different sectors. Within the United States of America, the NBAA collects data from a number of sources to present annual statistics (1). The Business Aviation sector within the UK environment can be considered as a combination of air taxi, corporate/executive and business operations as defined by NBAA.

The US statistics for the period 1990 to 2013 (Figure 1) suggest that accident rates (accidents per 100,000 flying hours) for corporate/executive aviation (aircraft flown by two-person professional crew) are comparable with commercial airlines. However, air taxi and business aircraft (flown by a single pilot) are less favourable and present an opportunity for improvement. In 2013, the accident rates for corporate/executive, business, air taxi and commuter air carriers increased, while commercial airlines declined.

The five year totals for accident rates by phase of flight for Business Aviation aircraft (2) show that for business jets, 19.1% of accidents take place in the take-off & climb and 66.4% in the approach & landing (Figure 2). Similarly for turboprops 18% occur in the take-off & climb and 64.3% in the approach & landing.

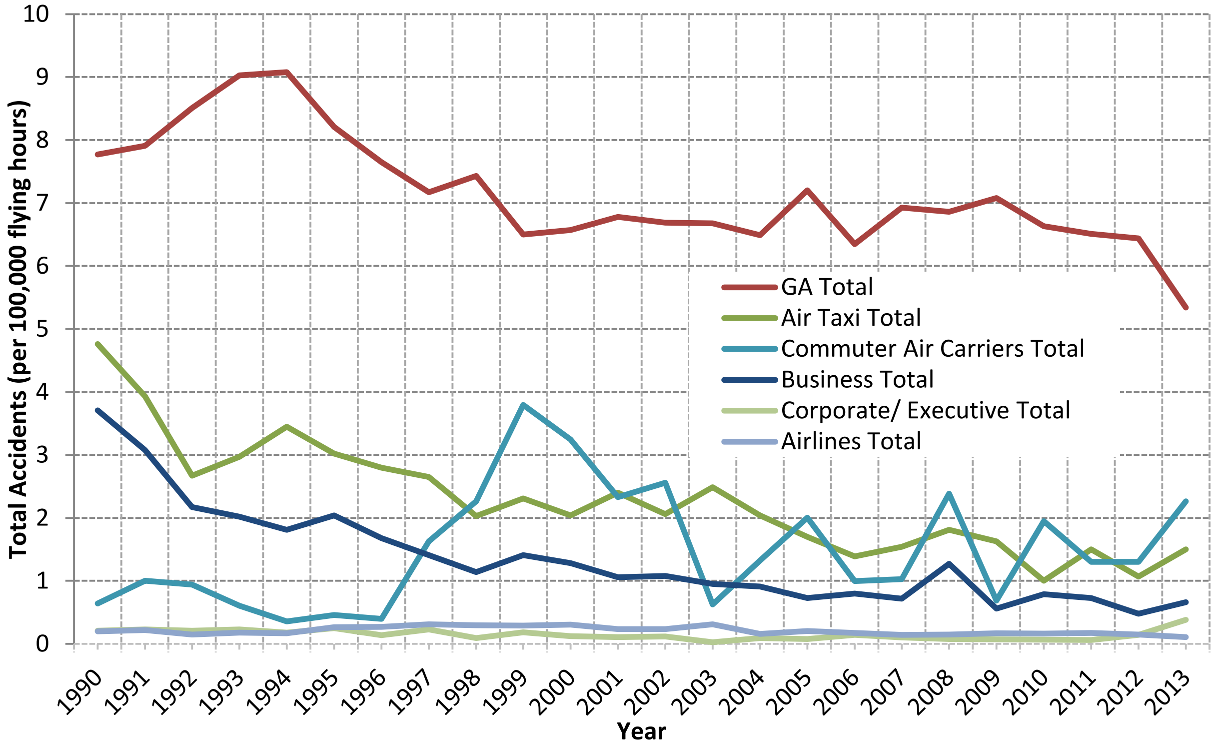


Figure 1, Accident Rates by Sector for USA, 1990 to 2013, adapted from (1)

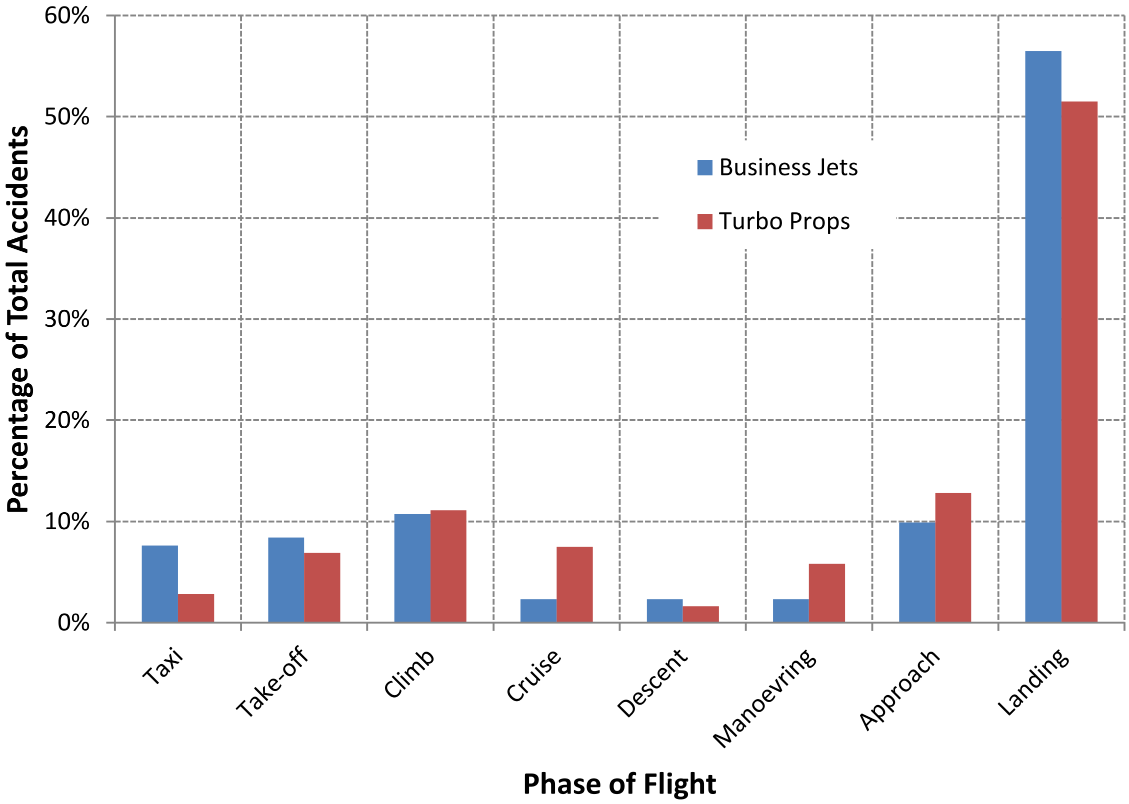


Figure 2, Business Aviation Accidents for USA from 2008 to 2013 by Phase of Flight, adapted from (2)

## 1.2 Flight Data Monitoring (FDM)

Flight data monitoring - the collection of real-time flight data for continuous safety improvement - has been routinely used by commercial airlines over the past 50 years. FDM facilitates the assurance of operational standards, traceable feedback into training & continuous improvement, supports safety management systems and a reporting culture to reduce risks (3). The adoption of FDM by the business aviation sector in the UK has been limited to date. Currently, only aircraft over 27 tonnes MTOW are legally required to operate an FDM programme. FDM is recommend but not mandatory for aircraft between 20 and 27 tonnes MTOW. The majority of business aviation operators operate a diverse range of aircraft makes/models and these may range from twin engine turbo-props to the wide body Airbus A300 (Figure 3).

The CAA actively encourages operators of smaller business aircraft to consider constructive and positive FDM based monitoring of compliance, flight crew performance will be improved and assured (3).

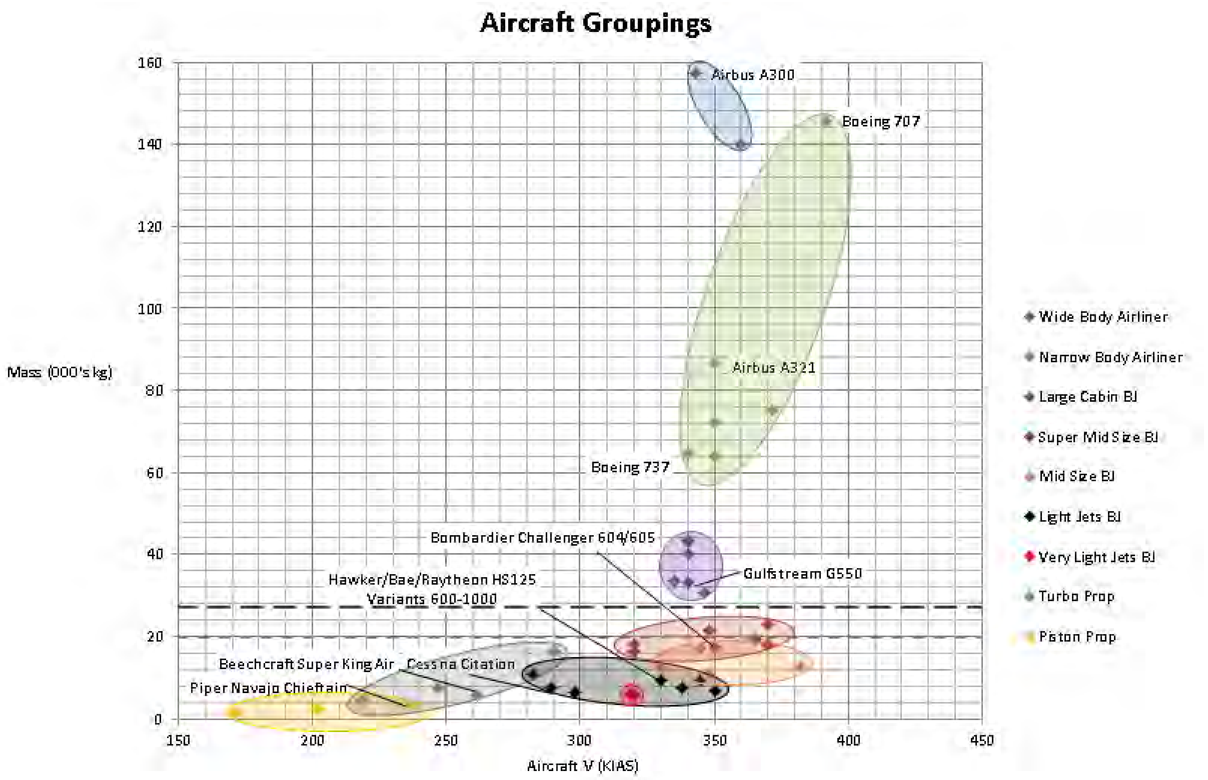


Figure 3, Diversity of Aircraft Used in Business Aviation

## 1.3 Business Drivers

The majority of FDM implementations have been through the individual programmes of CAT operators. However, if flight data can be recorded and analysed economically for Business Aviation operators with lower weight category or diverse aircraft sizes/models, then a more complete and balanced view of flight operations, risks and mitigating actions can be achieved (4). Aircraft in the Business Aviation sector are generally more diverse and of lower weight category than the CAT aircraft. In most cases, business aircraft fall below the mandatory weight limit for FDR or FDM programme and no flight data is therefore available to support an FDM programme. This project reviews potential COTS solutions in support of FDM for Business Aviation operators when installation of a mini/micro QAR may not be possible due to the absence of an FDR/SSFDR or digital data-bus.

## 1.4 Project Stakeholders

The key project stakeholders for this project are the UK CAA, Coventry University, DW Flight Data Monitoring and CASE.

### 1.4.1 The Corporate Aviation Safety Executive (CASE)

CASE (www.case-aviation.com) was established in 2008 by a group of like-minded safety managers whose aim was to collate and share data with the purpose of improving aviation safety. Since its inception, CASE has grown to become a vital group for a number of UK-based operators to share experiences with regards to flight safety.

As of May 2014, CASE's membership represents around two thirds of the UK's Business Aviation operators. CASE meets quarterly to share flight safety data and experiences, and it regularly sends out email reports highlighting the latest findings.

### 1.4.2 Coventry University

Coventry University (www.coventry.ac.uk) is a forward-looking University recognised as a provider of high quality education and multi-disciplinary research which has an established presence regionally, nationally and internationally with over 22,000 students and 2,000 staff. Voted 'Modern University of the Year' in 2014, 2015 and 2016 by the Times and Sunday Times in their league rankings, the University operates numerous large scale business support programmes for sectors such as aerospace, automotive, manufacturing, health technology, gaming and others. Coventry University provides research capacity for a number of EU funded projects including HELI-SAFE, Fly-Higher, FAST, MISSION, SYNERGY, ENSEMBLE, FITMAN, Flexinet, GREENet, CLEM, CASSANDRA, CAP4COM, CASES, SpinOff, CAPP-4-SMEs and SMARTER. In addition Coventry is also participating in Technology Strategy Board/ATI funded Future Flight Deck research programme. The research portfolio includes aircraft design, human factors, flight testing, mechanical engineering, manufacturing enterprise management, ICT communications and networking, and internet sensor technology. Coventry is a member of CASE, the UK Flight Safety Council (UKFSC), the General Aviation Safety Council (GASCo) and the European Operators Flight Data Monitoring forum (EOFDM).

## 1.5 Project objectives

The primary objectives of the COTS Business Aviation FDM project were:-

- To determine the device installation requirements and considerations including, but not limited to, power supply, manufacturer acceptance, avionics compatibility, insurance liabilities and STC requirements.
- To determine which flight parameters can be measured and at what frequency and precision.
- To determine whether these flight parameters can be related to Sig-7 events or pre-cursors.
- To determine whether the flight data received can be utilised to identify trends such that it can support an FDM programme.
- To compare the quality of the trend information against that received from a QAR (by comparing the data received from the QAR FDM Project), such that a Technical Paper can be produced which compares the effectiveness, value for money, benefits and limitations of each product.
- To publically disseminate the research findings as agreed by the participating stakeholders.

In addition, each of the project stakeholders has their own objectives/desired outcomes. Individual stakeholder objectives are detailed below:-

**Coventry University:** To meet the requirements of "REF-able work" as defined in terms of academic research.

**CASE Membership:** To evaluate alternative FDM solutions on behalf of the CASE members who operating diverse aircraft fleets, with legacy aircraft in lower weight categories.

**DfT/CAA:** To promote dissemination of Flight Data Monitoring programmes to aircraft having an MTWO < 27,000 kg.

## 1.6 Desired outcomes

The desired outcomes of the COTS FDM project were as follows:-

- The production of a Technical Paper (this report) which determines whether independent Flight Data Recorder (iFDR) systems can provide an appropriate low cost addition to QARs to support FDM programmes for the Business Aviation sector, for those aircraft that are not suitable for installation of QARs;
- The production of an evaluation methodology for COTS devices that has potential for extension to other aviation sectors (e.g. rotary wing and general aviation).

## 1.7 Report structure & content

In this section of the report, the background and key drivers to this research project have been described. The key stakeholders who have a vested interest and who have made significant contributions to the research have been described. The project aims, objectives and desired outcomes have also been described.

Section 2 reviews previous work in the field of Flight Data Monitoring and describes work conducted within Phase 1 of the related QAR FDM Project. Preliminary pre-cursor studies are described. The application and differences of FDM in the business environment are compared to the commercial airline environment. A brief survey of available independent Flight Data Recorders is described.

The results of a confidential survey of business operators in the UK environment is given in Section 3, with survey objectives, participants and results presented. In the context of this research, the meaning of these results is described.

Section 4 presents the objectives, methodology and results of desk-top study of FDM requirements in the business environment based upon use of FDM in the commercial sector. Linking to the CAA Sig-7 safety events and pre-cursors, a matrix of the capabilities of three types of device are presented (QAR, independent FDR and EFIS).

Within Section 5, the results of a technical assessment of one typical independent FDR are presented based upon bench tests in a laboratory environment. Installation requirements and integration with FDM analysis systems is described.

The results of an experimental study to simulate the use of three types of data collector devices (QAR, independent FDR and EFIS) are described in Section 6. Two methods were used to analyse the FDM results – 'pseudo' and real analysis using an FDM Analysis System. The number of possible Sig-7 safety events and pre-cursors that may be identified and recorded using these devices is compared.

Section 7 discusses the results of the bench study, simulation study and subsequent FDM analysis and implications for integration. Conclusions and recommendations drawn from the research and suggestions for follow-on work are stated in Section 8.

# 2 Previous Work in Field of Business Aviation FDM & Alternate Technologies

CASE aims to encourage members to adopt FDM and to assist in the consolidation of FDM insights from aircraft below the legal weight limit (27,000 tonnes) within the Business Aviation community. Both operators and the regulator will benefit from this oversight.

## 2.1 QAR FDM Project Phase 1

The objectives of the CASE QAR FDM Project Phase 1, funded by the CAA/DfT were:-

- Demonstrate the practical implications of MQAR installation and data acquisition
- Learn how to interpret and then use the data within the safety system
- Statistical analysis – v. small sample of flying – difficult to trend

The study provided insight into business operations and pre-cursor events. The following examples of events were identified [4]:-

- High airspeed below 10,000ft;
- High taxi speeds;
- High pitch rates at take-off;
- Crosswind landings;
- Glideslope ‘duck unders’;
- Flap overspeeds;
- Speedbrakes extended while significant thrust selected.

The project also provided insight into the technical challenges of adopting QARs in support of an FDM programme, namely:-

- Management of QAR installation process;
- Importance of training;
- Critical nature of company safety culture;
- The requirement for acquisition or estimation of aircraft weight to enable speed related FDM events;
- Differences between business aircraft handling and large airliners.

## 2.2 Flight Data Monitoring – Good Practice (CAP 739)

The UK CAA guide to 'good practice' in Flight Data Monitoring, CAP 739 (3) makes several recommendations to operators. In relation business aviation, the CAA suggests that guidance for smaller fleets applies and that complex, high performance aircraft are used for a diverse range of operations. It also recognises that some business aviation operators have aircraft over the 27 tonnes category. The challenges associated with these diverse operations are:-

- 'one-off' sectors/airfields including positioning flights;
- operations into non-ILS equipped, remote and secondary airfields;
- distributed small bases that may foster 'local practices';
- lack of standardisation of SOPs across types
- extended tours away from the normal base of operations.

All of these factors require attention, in defining related events in support of a suitable FDM analysis solution for the business aviation sector. In addition, it is desirable to link these events to significant safety outcomes, where practical.

## 2.3 Accident Pre-cursor Studies

In 2012, the UK CAA conducted a study to identify pre-cursor events in an attempt to prevent future accidents. The study in conjunction with a UK operator and an FDM provider focused on a single 'Sig-7' safety outcome: runway excursions. The feasibility of obtaining meaningful, reliable and practicable pre-cursor indicators of Landing Runway Overruns from a commercial Flight Data Monitoring analysis system was investigated. The aim of the study was to 'develop a set of targeted, reliable and consistent measures to contribute to direct Operator action to mitigate risks' (5). The study was based on a series of flights conducted by a short-haul CAT operator using a commercial FDM analysis package. The study found that user-defined inputs for conditions and constraints significantly affected results output. A recommendation was made to operators to utilise agreed, common criteria for determining an 'unstable approach', one example of a REX pre-cursor. At the time of the study, it was noted that the precision and accuracy of GPS data was not acceptable for practical use and that it was not possible to accurately determine the touchdown points of aircraft to estimate ‘length of runway remaining’.

# 3 In-flight Data Recording

The absence of legislation or digital data-bus to connect to a QAR means that alternate methods are needed to collect flight data for selected aircraft types below 27 tonnes MTOW to support an FDM programme. Advancements in Micro Electro Mechanical Systems & GPS technologies have resulted in the development of low-cost, stand-alone and portable FDRs, referred in this report as 'iFDRs', also known as Lightweight Aircraft Recording Systems in USA. These devices have seen increased use in the rotary wing sector with selected units recording audio and video data in addition to flight data. These data can be synchronised, re-played in 'real-time' and used for post-flight analysis. This increased usage in the rotary wing sector has been driven by high accident rates in the HEMS sector in recent years in the United States, resulting in an FAA directive Part 135.607 Flight Data Monitoring [6]. This requires that air ambulance operators will be required to fit 'an approved flight data monitoring system capable of recording flight performance data' from April 23rd, 2018. The directive highlights the focus on accident/incident investigation and there is no requirement for meaningful analysis in the interests of accident prevention using FDM or other means.

A preliminary review of the data requirement to support an FDM programme indicated that selected EFIS systems also have a data recording capability. These systems, where already installed, may therefore offer another alternative to the use of QARs or iFDRs. A comparison of functions & features of QARs ('baseline' device used in Phase 1 of the QAR FDM Project), common iFDRs and EFIS systems was conducted, the following device types are compared:-

- Type 1: QAR;
- Type 2: iFDR (with audio/visual recording);
- Type 3: EFIS;

The comparison of functions/features is presented in the following section.

## 3.1 Comparison of Typical Data Collection Devices

The comparison of three different device types is complicated by the wide range of different functions and features for each device (Table 1). Due to time and cost constraints, only one example of each device type, readily available to the research team was used for comparison. The device types emulated were:-

- Type1: Micro-Quick Access Recorder (μQAR)
- Type 2: Independent Flight Data Recorder (iFDR)
- Type 3: Electronic Flight Instrumentation System (EFIS)

The QAR device type emulated was compatible with devices used in Phase 1 of the QAR FDM Project (7). The iFDR device was capable of recording audio/video in addition to data and the EFIS device was compatible with those typically found in turbo-props, very light and light business jets. The study was intended to provide a broad understanding of the application of currently available COTS device types and not a detailed product review. There are many devices of similar capabilities in the open market and this mare is continually growing.

## Table 1, Comparison of devices from all categories

| | QAR (Type 1) | iFDR with Audio/Video (Type 2) | EFIS* (Type 3) |
|---|---|---|---|
| **No. of Data Parameters** | N/A | 16 | 49 |
| **Data Sampling Frequency (Hz)** | N/A | 64 | 1 |
| **Data Recording Frequency (Hz)** | N/A | 4 | 1 |
| **Time Period between samples (s)** | N/A | 0.25 | 1 |
| **Data bus Protocol** | ARINC 429/573/717/747 | N/A | ARINC 429 |
| **GPS Resolution (m)** | N/A | 2.5CEP<br>5.0SEP | 4.6 SEP |
| **Internal Data Storage Capacity (Gb)** | N/A | 8 | N/A |
| **Internal Data Storage Capacity (Hrs.)** | N/A | 2 Image/audio<br>200+ Inertial | N/A |
| **External Data Storage Capacity (Gb)** | 2 | 16 | 16 |
| **External Data Storage Capacity Time (Hrs.)** | 6000 | 4 Image/audio<br>200+ Inertial | 4000 |
| **Storage Medium** | Compact Flash | SD | SD |
| **Cost (US$)** | $5,678 | $7,500 | None |
| **Internal Battery Fitted?** | No | No | No |
| **External Power Source (Volts DC)** | 28 | 14-32 | 28 |
| **Modification Required?** | FAA/EASA Minor Mod | STC | N/a |

** Where already installed*

# 4 Business Aviation FDM Survey

To assess the diversity aircraft within the UK business aviation fleet of the CASE membership and the nature of existing FDM programmes, an online survey was prepared. The survey was designed to inform the research team of the current state of FDM implementation within the CASE membership and the most common type, makes/models of aircraft used to assist in confirming the scope of application of FDM.

The survey was conducted for members of the CASE group of business aviation operators using the BOS system, a secure web-based survey tool, compliant with Coventry University's ethical procedures. The survey consisted of 15 questions across 5 sections, with sections dedicated to contact information, company information and a section on FDM. The final two sections were questions on the type of aircraft operated by the respondent, both fixed-wing and rotary-wing where applicable.

## 4.1 Ethics & Confidentiality

Strict anonymity was maintained, as explained in the survey introduction and all data was handled in accordance with Coventry University's ethical procedures and according to the Data Protection Act 1998. Data was de-identified before presentation to CASE members and key stakeholders.

The questionnaire (Appendix A) was produced by the Coventry University research team and a link generated by the BOS system was provided to the CASE management team and this link was distributed via email and via ASC for operator representatives to complete.

## 4.2 Survey Participants

The survey was open to all operators in the CASE membership and 10 out of a possible 40 operational members responded (25%). Most of the responses were complete, however in a few cases, respondents chose not to answer all questions. Of the ten respondents, three operated only in Europe and seven globally.

## 4.3 Survey results

The survey, conducted in December 2015 showed that 5 out of 10 survey respondents (50%) have already implemented an FDM programme (Figure 4). Two operators intend to implement a programme within 12 months and 2 operators declared that they would not implement FDM unless it became a regulatory requirement for the weight class of the aircraft operated within their fleet.

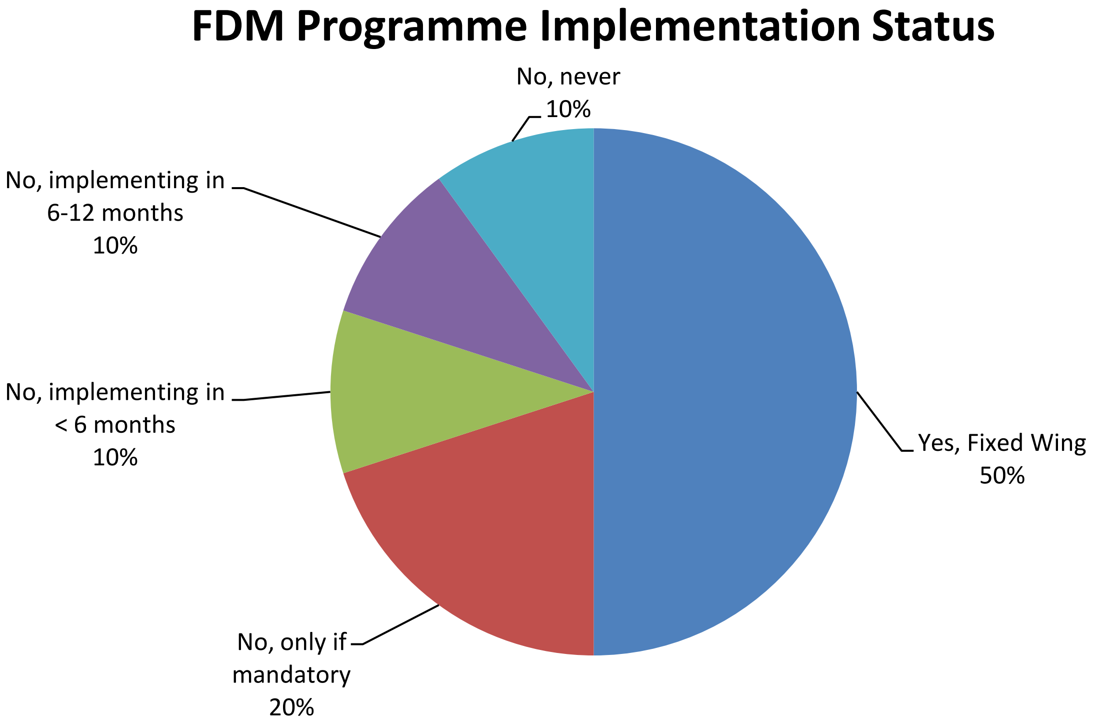


**Figure 4, FDM Programme Implementation Status (Dec 2014)**

The diversity of aircraft types, makes/models used by operators that responded to the survey (Figure 5) show that the Gulfstream G550 and Bombardier Challenger are the two most popular turbo-fan aircraft, with the Beechcraft King Air/Super King Air being the most popular turbo-prop aircraft used.

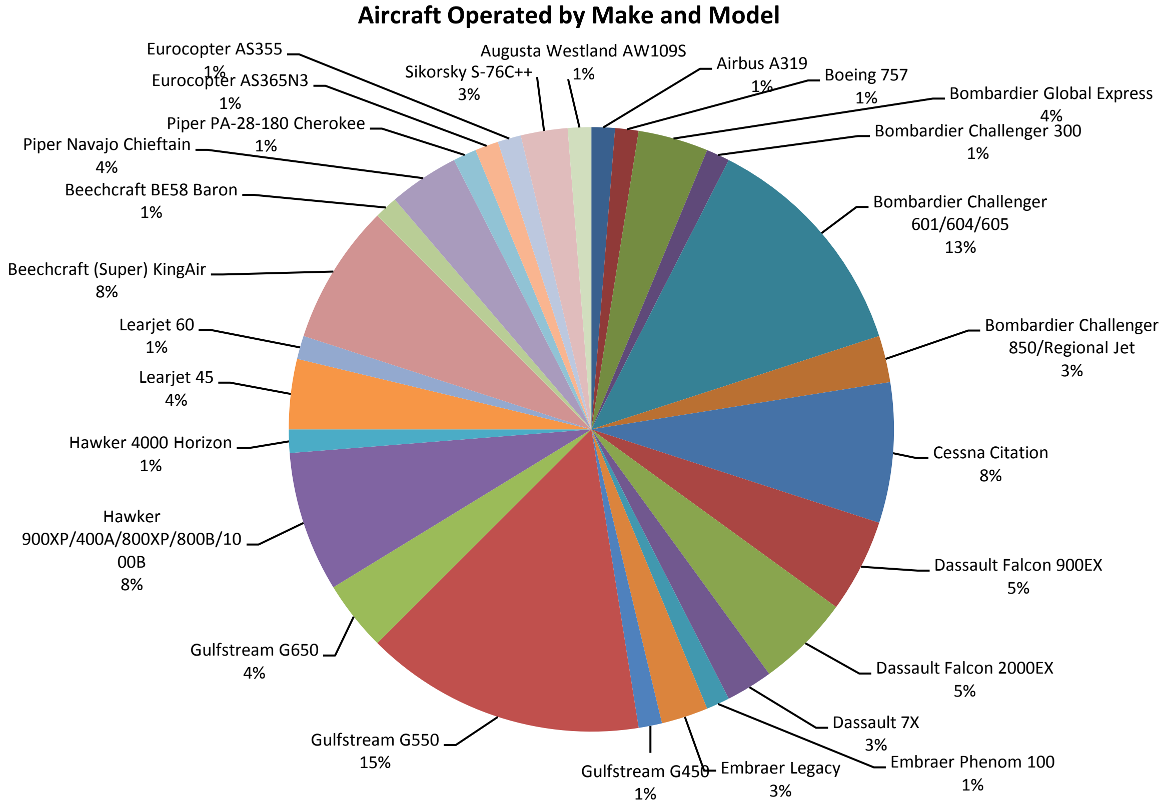


Figure 5, Aircraft Operated by Make and Model (Dec 2014)

The survey showed that although the ICAO mandatory lower weight limit for FDM is 27 tonnes, some aircraft in weight categories between 5 and 27 tonnes have QARs fitted (Figure 6). As weight category decreases the number of aircraft fitted with QARs also decrease. It should be noted that 3 out of 6 of the aircraft in the sub 27 tonne weight categories were fitted with QARs as part of the Phase 1 of the QAR FDM Project. The diversity of aircraft within different weight categories is evident (Figure 3) - several other aircraft models have been added to demonstrate the differences between categories/types.

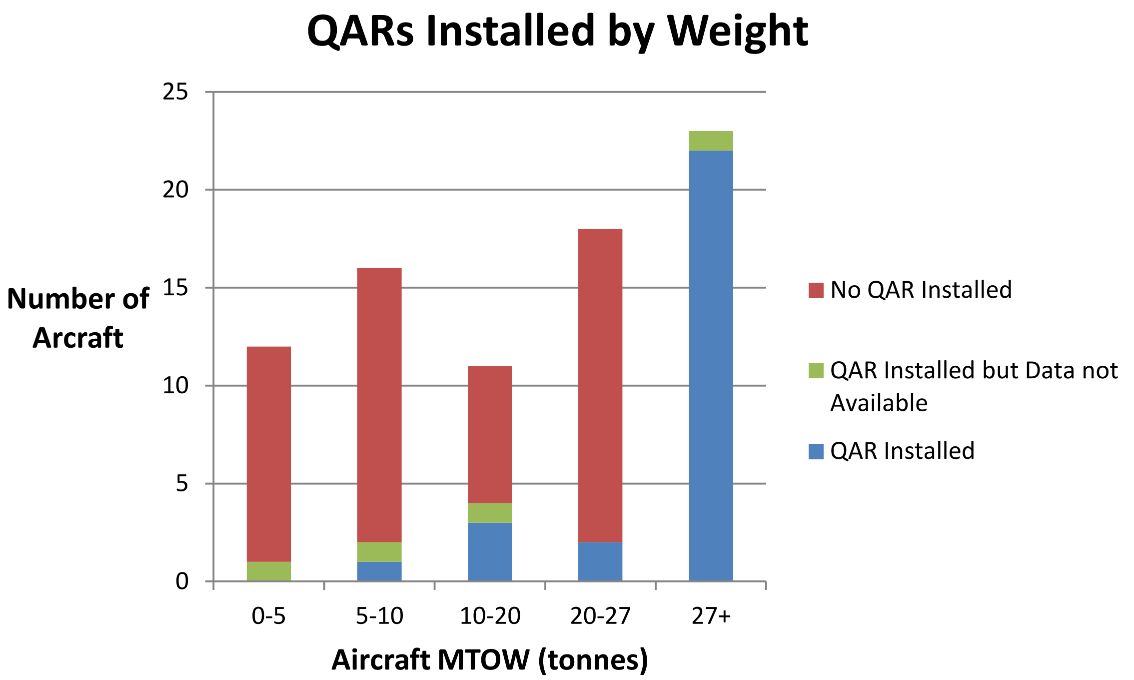


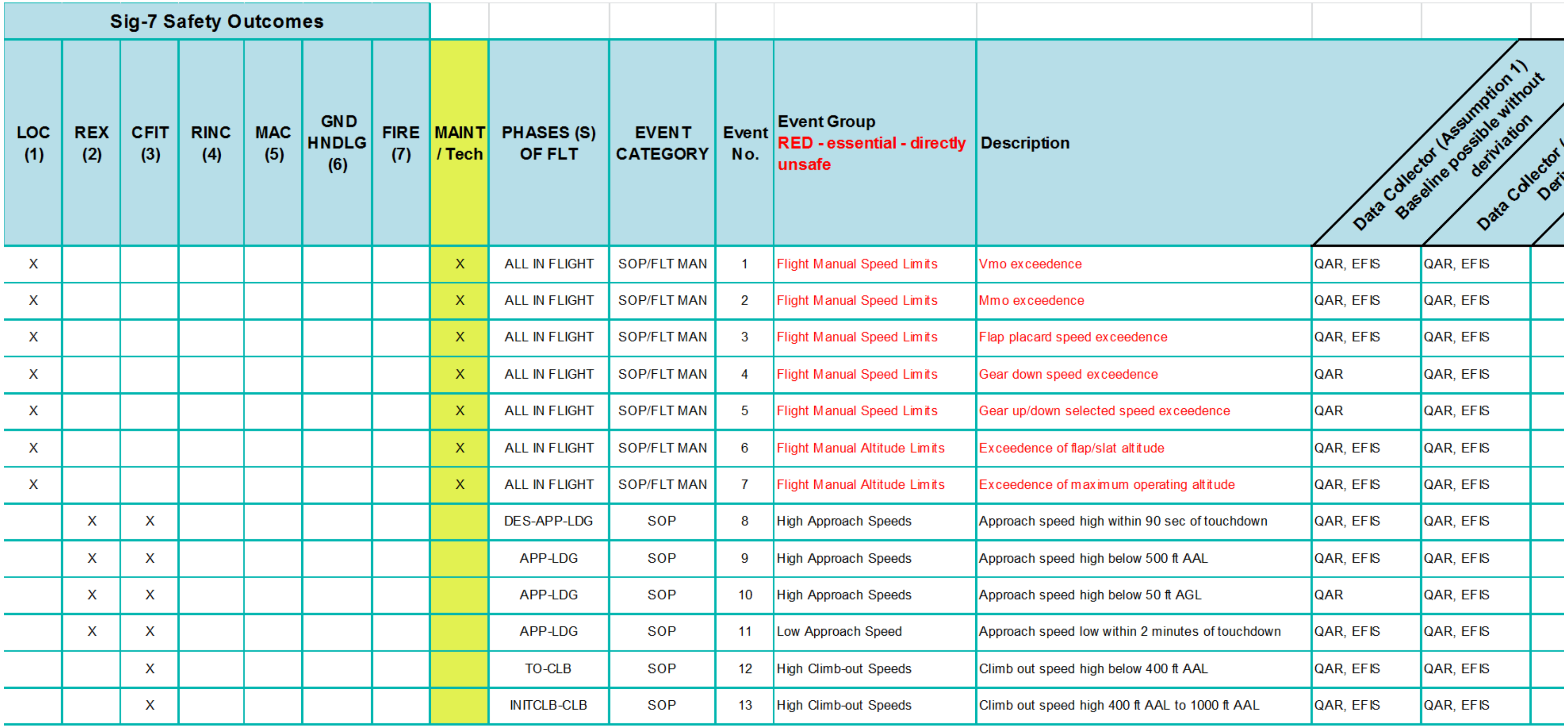
Figure 6, QARs installed by weight (Dec 2014)

# 5 FDM Requirements for Business Aviation & Device Capabilities

In order to assess the capabilities of different device types to support an FDM programme for business aviation, it was necessary to firstly, define requirements. To complete the requirements definition, a list of safety events was created based on previous FDM experience and available documented. In addition to listing the events, it was a requirement to align the events with CAA Sig-7 safety outcomes (8) where practical. The CAA Sig-7 safety outcomes were identified in 2009 following analyses of global fatal accidents and high-risk occurrences involving large UK CAT aircraft. The former involved the systematic analysis, by a multi-disciplinary team of experts, of more than 1,000 global fatal accidents dating back to 1980; identifying causal and contributory factors and accident consequences. Sig-7 safety outcomes are:-

1. Loss of Control in Flight
2. Runway Excursion
3. Controlled Flight into Terrain
4. Runway Incursion
5. Airborne Conflict
6. Ground Handling
7. Airborne and Post-Crash Fire

In addition, to these safety outcomes, pre-cursor events were identified and linked together with relevant safety outcomes. Pre-cursor events were determined from previous FDM experience and documented reports for selected events (5). This work examined the feasibility of obtaining meaningful, reliable and practicable precursor indicators for Sig-7 outcome number 2 - runway excursion (or Landing Runway Overruns) - from a commercial FDM system. These Sig-7 outcomes were linked to a series of pre-cursor events, which were in turn linked to a set of required flight data parameters needed to identify and configure events using an appropriate FDM solution. Each device collects a pre-defined set of data parameters at a particular rate and this can be used in turn to confirm the numbers and types of events that each device can usefully detect. The capabilities of each device can be summarised in matrix form (Figure 7).



| Sig-7 Safety Outcomes | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOC (1) | REX (2) | CFIT (3) | RINC (4) | MAC (5) | GND HNDLG (6) | FIRE (7) | MAINT / Tech | PHASES (S) OF FLT | EVENT CATEGORY | Event No. | Event Group<br>RED - essential - directly unsafe | Description | Data Collector (Assumption 1) Baseline possible without deriviation | Data Collector ( Deri |
| X | | | | | | | X | ALL IN FLIGHT | SOP/FLT MAN | 1 | Flight Manual Speed Limits | Vmo exceedence | QAR, EFIS | QAR, EFIS |
| X | | | | | | | X | ALL IN FLIGHT | SOP/FLT MAN | 2 | Flight Manual Speed Limits | Mmo exceedence | QAR, EFIS | QAR, EFIS |
| X | | | | | | | X | ALL IN FLIGHT | SOP/FLT MAN | 3 | Flight Manual Speed Limits | Flap placard speed exceedence | QAR, EFIS | QAR, EFIS |
| X | | | | | | | X | ALL IN FLIGHT | SOP/FLT MAN | 4 | Flight Manual Speed Limits | Gear down speed exceedence | QAR | QAR, EFIS |
| X | | | | | | | X | ALL IN FLIGHT | SOP/FLT MAN | 5 | Flight Manual Speed Limits | Gear up/down selected speed exceedence | QAR | QAR, EFIS |
| X | | | | | | | X | ALL IN FLIGHT | SOP/FLT MAN | 6 | Flight Manual Altitude Limits | Exceedence of flap/slat altitude | QAR, EFIS | QAR, EFIS |
| X | | | | | | | X | ALL IN FLIGHT | SOP/FLT MAN | 7 | Flight Manual Altitude Limits | Exceedence of maximum operating altitude | QAR, EFIS | QAR, EFIS |
| | X | X | | | | | | DES-APP-LDG | SOP | 8 | High Approach Speeds | Approach speed high within 90 sec of touchdown | QAR, EFIS | QAR, EFIS |
| | X | X | | | | | | APP-LDG | SOP | 9 | High Approach Speeds | Approach speed high below 500 ft AAL | QAR, EFIS | QAR, EFIS |
| | X | X | | | | | | APP-LDG | SOP | 10 | High Approach Speeds | Approach speed high below 50 ft AGL | QAR | QAR, EFIS |
| | X | X | | | | | | APP-LDG | SOP | 11 | Low Approach Speed | Approach speed low within 2 minutes of touchdown | QAR, EFIS | QAR, EFIS |
| | | X | | | | | | TO-CLB | SOP | 12 | High Climb-out Speeds | Climb out speed high below 400 ft AAL | QAR, EFIS | QAR, EFIS |
| | | X | | | | | | INITCLB-CLB | SOP | 13 | High Climb-out Speeds | Climb out speed high 400 ft AAL to 1000 ft AAL | QAR, EFIS | QAR, EFIS |

Figure 7, Sample of Pre-Cursor Matrix

The first seven columns of the matrix refer to Sig-7 safety outcomes. Using previously documented safety events and operator experience, each pre-cursor event was assigned to one or more Sig-7s safety outcomes. By applying filters to the columns, events could be categorised and viewed based on their association with any particular Sig-7 safety outcome, the parameters required, their frequency, precision, and accuracy. Two major classifications of events are presented:-

- Baseline events higher importance and time critical (e.g. speed, acceleration related)
- Extended events of lower importance and less time critical (e.g. low priority warnings & failures).

## 5.1 Pre-cursor & Sig-7 Events by Device type (Desktop Study Method)

Using a 'desktop' study method based on the CASE Pre-cursor Matrix, the theoretical number of detectable safety events for each device type was determined by considering the set of available parameter set (Table 2).

**Table 2, Comparison of Detectable Events (Pre-cursor Matrix) by Device Type**

| Events | Type 1 QAR | Type 2 iFDR | Type 3 EFIS |
|---|---|---|---|
| No. of Available Parameters | 86 | 16 | 49 |
| Baseline Events (59) | 59 | 9 | 30 |
| %age of QAR Baseline Events | 100% | 15.3% | 50.9% |
| Extended Events (22) | 22 | 11 | 17 |
| %age of QAR Extended Events | 100% | 50% | 77.2% |
| **ALL Events (81)** | **81** | **20** | **47** |
| **%age of ALL Events** | **100%** | **24.7%** | **58%** |
| Rank | 1 | 3 | 2 |

The results of the desktop study suggest that mini or micro-QARs (Type 1) devices (recording 86 parameters) are able to identify all defined baseline and extended safety events, 81 in total (100%). When considering the iFDRs (Type 2), limited to 16 flight parameters, the detectable safety event set reduces to 9 (15.3%) of the baseline events and 11 (50%) of the extended events, enabling 20 events in total (24.7% ) to be detected. A typical EFIS system (Type 3) with data export capability is capable of recording 49 parameters resulting in detection of 30 baseline events (50.9%) and 17 extended events (77.2%), enabling 47 events in total detected (58%). All FDM data must be capable of being uploaded to a compatible FDM analysis solution.

## 5.2 FDM Integration

In addition to the collection of data, any device type must be capable of uploading data to an FDM analysis solution to enable safety events to be detected, reports to be generated and visualisation of the flight (Figure 8). This project has considered only the FDM (or FOQA) integration for data analysis and not in support of training or maintenance analysis, which are out of scope.

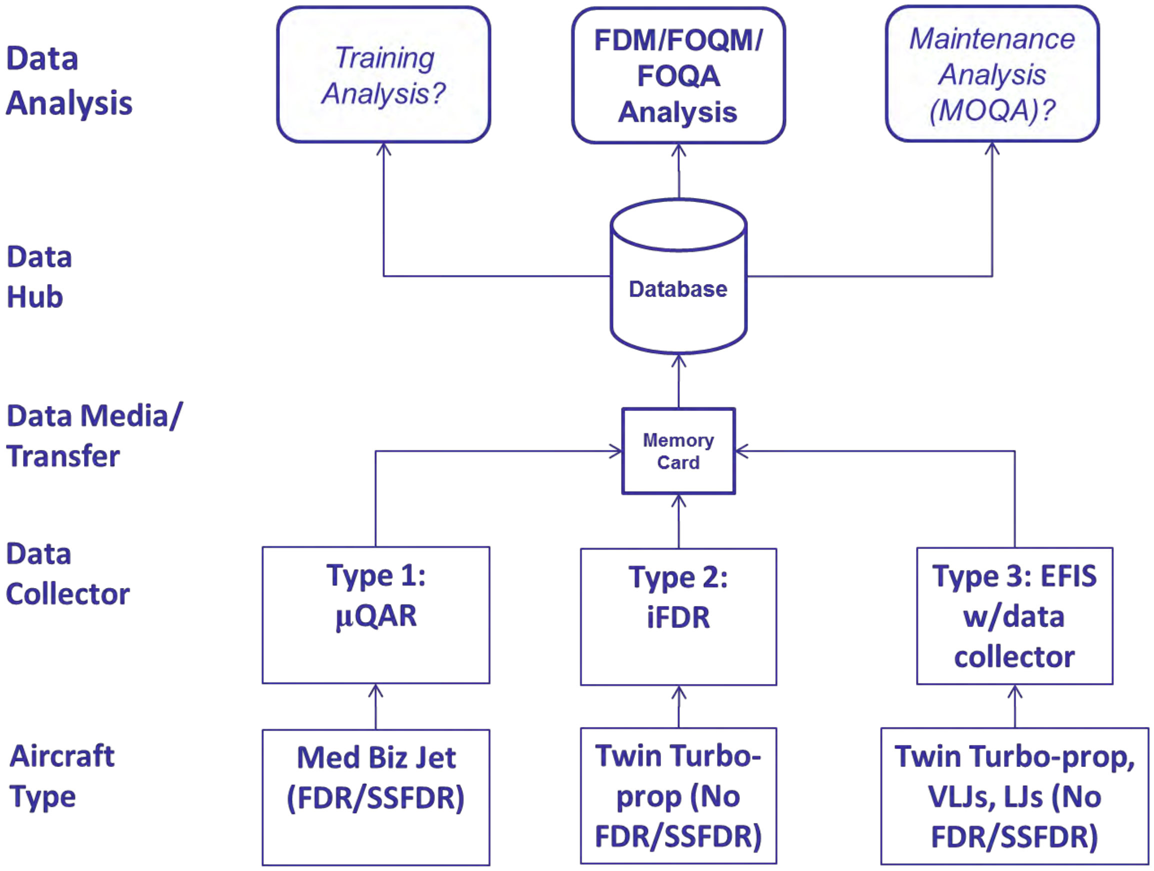


Figure 8, FDM Integration

# 6 Experimental Simulation of Devices using a Full Flight Simulator

The desktop study method used to determine the number of detectable safety events by device type, is similar to the approach used by some operators when a new aircraft is introduced to the fleet. The analysis of the QAR specification and development of the LFL can be a time consuming manual process. The desktop study method is also limited to the number of safety events as specified in the Pre-cursor Matrix (81).

Field trials to trigger a range of safety events exploiting the full sets of available parameters for each device type for the purposes of evaluation are impractical since it is likely that few only a few events will occur in the course of normal operations. A more robust method is required, one that is capable of generating a significant numbers of events in a controlled environment. To this end, a series of simulated flights was proposed to generate simulated flight data to emulate each device type in a controlled environment (e.g. known airports, fixed weather conditions etc.).

## 6.1 Objectives

The main objectives of the simulated flights were to:-

- Generate simulated flight data to emulate all three device types (QAR, iFDR and EFIS) taking into consideration required/available data parameters, frequency, precision and accuracy;
- Enable high level analysis of the data for each emulated device type using ‘pseudo FDM’ methods (manual);
- Enable detailed analysis using a commercial FDM analysis package (semi-automated) through FDM integration.

In order to accomplish these objectives, simulated flights were proposed using a commercial FFS, with a common business aircraft model.

## 6.2 Simulated flying tasks (LPC/OPC) & possible safety events

Initially, it was proposed to add a series of flying tasks (designed to trigger selected safety events) to existing LPC/OPC check rides content with a random selection of de-identified pilots undergoing recurrent training in a single aircraft make/model. However, due to high cost of FFS simulator time and the need for expediency, alternative methods were explored. A detailed (and confidential) review of the content of current LPC/OPCs for the Gulfstream G450/550 for an operator, suggested that given the nature of exercises and focus on abnormal/emergency procedures, a number of safety events were likely to be triggered during the flights negating the need for additional flying tasks simply to generate data.

The advantages of this approach were:-

- No additional simulator time was required,
- No additional cost to the project;
- A supply of pilots was readily available;
- Expected safety events could be anticipated;
- Data could be exported a saved to a log file for subsequent FDM analysis.

The simulator operator agreed to make de-identified data available for use in the study for planned simulator LPC/OPC sessions in a G450/550 FFS.

## 6.3 Equipment

The CAE G450/550 FFS used for the experimentation (Figure 9) was a Level-D flight simulator with FAA/CAA approvals and was fitted with Honeywell Primus Avionics/FMS (Figure 10).

Figure 9, G450/550 Full Flight Simulator Motion Platform Cockpit

Figure 10, G450/550 Full Flight Simulator with Honeywell Primus Avionics/FMS

## 6.4 Participants

The participants were commercial pilots with current medical certification undergoing LPC and/or OPC for the Gulfstream G450/550 business jet. Flight data was de-identified by CAE, analysis of individual pilot performance was not analysed or discussed and strict confidentiality was maintained.

## 6.5 Data recording and extraction

The recording and extraction of simulated fight data from the FFS was undertaken by CAE. A data extraction program was developed to extract select data parameters (global data variables within the simulator device) at a specified rate and precision. Five flights were conducted and these were based upon LPC/OPC exercises. The data extraction programme was manually initiated by the instructor prior to commencement of the simulator session. Data was recorded at a frequency of 7.33 Hz due to a limitation of the simulator data extraction program, this being the closed approximation to the required frequency of 8 Hz – the maximum frequency for FDR recorded data e.g. accelerations. In total 86 parameters were collected and the sampling frequency, accuracy and precision was based on the Pre-cursor Matrix. The data was exported in *.CSV format into 86 individual files (1 for each parameter) and these were merged into a single file for subsequent analysis using a custom-developed Matlab utility.

## 6.6 Simulator Sessions

Of the five simulator sessions recorded (Table 3), on detailed examination it appeared that Session 1 did not follow the anticipated LPC/OPC script, therefore it was excluded from the analysis. However, Sessions 2 to 5 were usable and generally followed the script (allowing flexibility and variations for instructors to focus on assessment of pilot proficiency). The analysis commenced with manual or 'Pseudo-FDM' analysis to validate data and associated events ('sensibility check').

**Table 3, Summary of FFS Sessions**

| Simulator Session No. | Aircraft | Pilot | LPC/OPC | Duration (hrs) | No. Files | File Size (Mb) | Usable? |
|---|---|---|---|---|---|---|---|
| ~~1~~ | ~~G550~~ | ~~1~~ | ~~??~~ | ~~1~~ | ~~88~~ | ~~9.23~~ | ~~No~~ |
| 2 | G550 | 2 | Yes | 2 | 88 | 18.25 | Yes |
| 3 | G550 | 3 | Yes | 4 | 88 | 34.60 | Yes |
| 4 | G550 | 4 | Yes | 4 | 88 | 34.00 | Yes |
| 5 | G550 | 5 | Yes | 4 | 88 | 37.00 | Yes |
| **Total** | | **4** | | **14** | **352** | **123.85** | |

## 6.7 ‘Pseudo-FDM’ Results Analysis (Manual)

‘Pseudo FDM’ analysis was conducted for each device type (QAR, iFDR and EFIS) using Datplot (9) and/or Excel and Matlab scripting. Datplot tool is a free data plotting utility normally used for the presentation of flight test data. It allows tabulation of data, presentation and annotation for use in flight test report preparation. Using the Pre-Cursor Matrix, flight data was reviewed in DatPlot and safety events were manually identified (Figure 11, Figure 12 & Figure 13):-

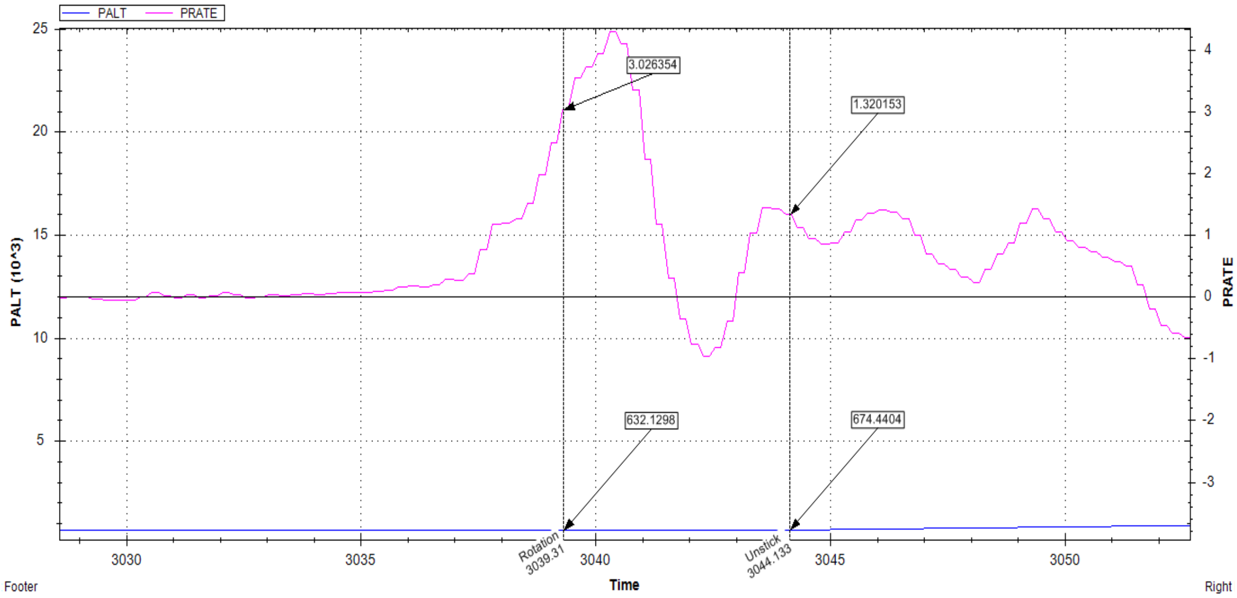


Figure 11, Pseudo Analysis for QAR (@2 Hz), Event 16: Pitch Rate High on Take-off (> 3 deg/s)

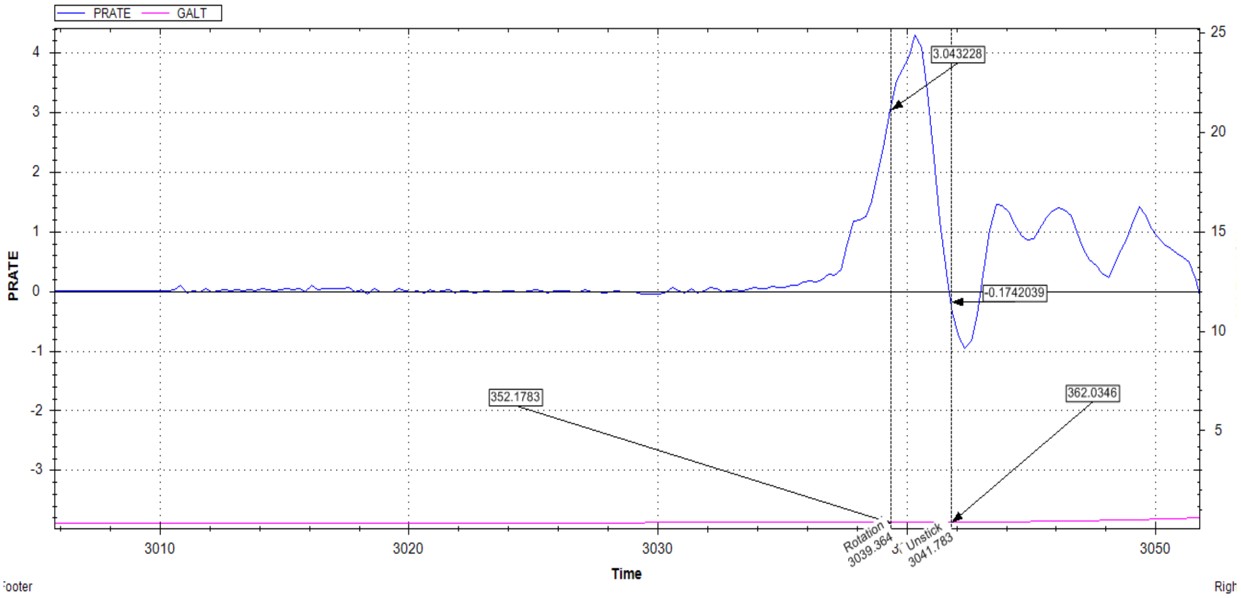


Figure 12, Pseudo Analysis for iFDR (@4 Hz), Event 16: Pitch Rate High on Take-off (> 3 deg/s)

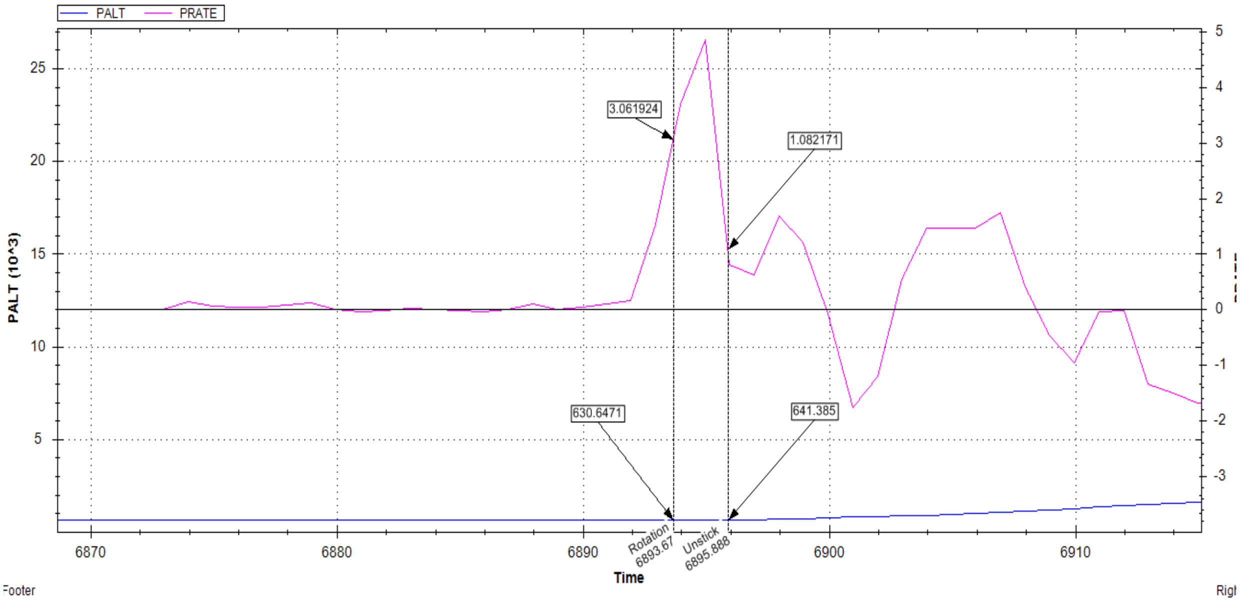


**Figure 13, Pseudo Analysis for EFIS (@1 Hz), Event 16: Pitch Rate High on Take-off (> 3 deg/s)**

A comparison of the plotted results for one event - Pitch Rate High on Take-off - highlights the effects on presentation and analysis of the data due to differences in sampling rates for each device. QAR data sampled at 2 Hz (Figure 11), iFDR at 4 Hz (Figure 12) and EFIS sampled at the lowest rate of 1 Hz (Figure 13).

Comparing all three devices for all manually identified safety events in the Pre-Cursor Matrix using Pseudo-FDM (Table 4), shows that the QAR detected all 6 events, the iFDR only 2 events and the EFIS system 5 events. Considering all 6 events, the limitations of the iFDR are due to the lack of available data for calibrated airspeed, pressure altitude, flap and gear position. The EFIS failed to identify one event due to the lack of available data for flap and gear position.

## Table 4, Comparison of Different Device Types Using 'Pseudo-FDM' (Manual) for Selected Events

| | | | DEVICE TYPE | | | |
|---|---|---|---|---|---|---|
| **Event No.** | **Event Name** | **Event Triggers** | **QAR (LFL_1)** | **iFDR (LFL_2)** | **EFIS (LFL_ 3)** | **Notes** |
| 11 | Approach speed low within 2 minutes of touchdown | ΔPALT<500, CAS<129 | X | | X | **Not detectable by iFDR -requires calibrated airspeed & pressure altitude** |
| 10 | Approach speed high below 50 ft AGL | ΔPALT<50, CAS>120 | X | | X | **Not detectable by iFDR -requires calibrated airspeed & pressure altitude** |
| 16 | Pitch rate high on take-off | PRATE>3 | X | X | X | 2 occurrences |
| 18 | Unstick Speed Low | CAS<140 | X | | X | 2 occurrences**, Not detectable by iFDR -requires calibrated airspeed** |
| 35 | Go-around below 1000 ft AAL | ΔPALT=+ve, ΔFLAP=-ve or ΔGEAR=-ve | X | | | **Not detectable by iFDR or EFIS - requires flap & gear position** |
| 37 | High Speed Rejected take-off | ΔGSPD=Δ±ve | X | X | X | |
| | | ***No. of Events*** | ***6*** | ***2*** | ***5*** | |

## 6.8 'Real-FDM' Results Analysis (Semi-automated)

'Real-FDM' analysis of simulator Sessions 2 to 5 was conducted using a commercial FDM analysis system and a CSV 'plug-in' jointly developed in conjunction with Coventry University. This enabled text-based simulator data output to be uploaded directly to the commercial FDM analysis system (Figure 14) using pre-defined Logical Frame Layouts (or file structures) for each device type (Appendix B1). The commercial FDM analysis system contains approximately 200 pre-defined safety events and was configured for a Gulfstream IV series aircraft for this analysis. Simulator session data was loaded and scanned for events and the results produced in tabulated form for all flights. The data was verified using flight visualisation of the simulated flight data (Figure 15) and manual review of report output files. In order to load the simulated data into the commercial FDM analysis system (normally designed for real flight data extracted using QAR device types) it was necessary to hard code 'missing' parameters using default values (e.g. flap setting, ILS, air/ground switch). A manual analysis of all events was conducted to filter out 'false positives' (false events triggered by pre-setting of the selected parameters) in order to determine genuine safety events (Appendix B2).

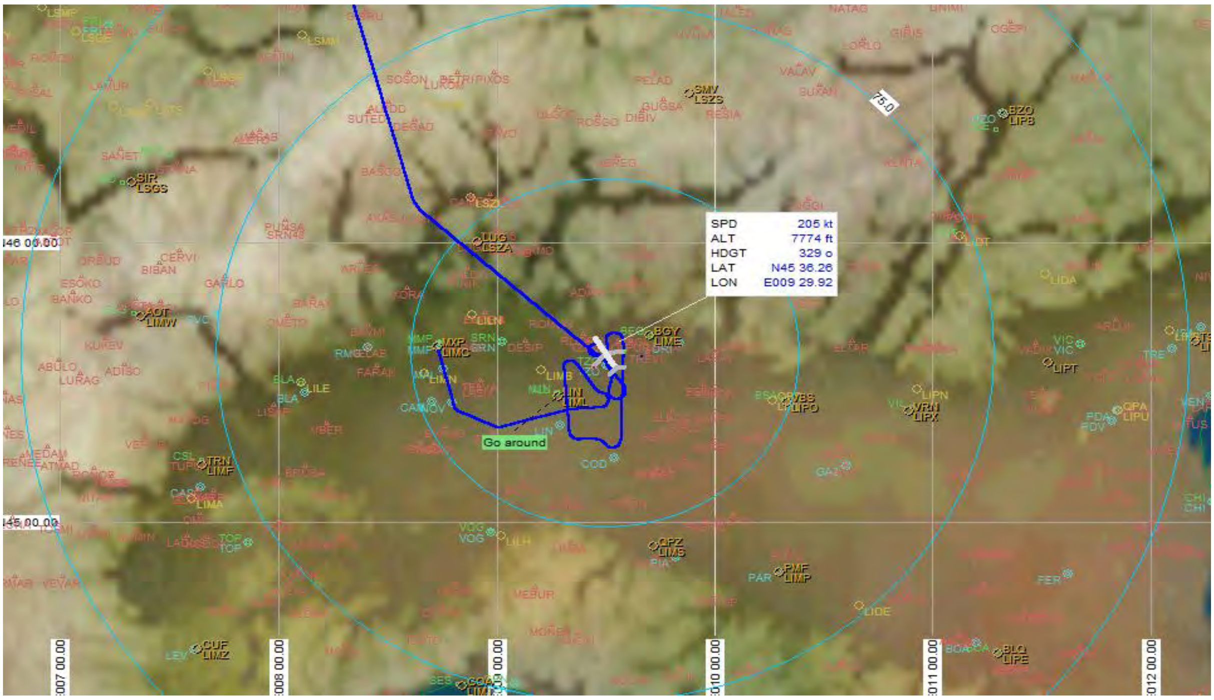


Figure 14, Simulated Flight using a Commercial FDM Analysis System

**Figure 15, Visualisation of Simulated Flight using a Commercial FDM Analysis System**

A summary of the number of safety events detected by the commercial FDM analysis system for each defined device type (see Table 5) suggests that when considering all simulator sessions the QAR device (Type '1') detected 101 events (75.4% of total events) using 65 parameters sampled between 0.25 and 8 Hz. The iFDR device (Type '2') detected 59 events (44%) sampling 16 parameters at 4 Hz and the EFIS device (Type '3 ') detected 94 events (70%), sampling 49 parameters at 1 Hz.

**Table 5, Summary of the ALL Events by Device Type & Simulator Session**

| Simulator Session | LFL_1 (QAR) | LFL_2 (iFDR) | LFL_3 (EFIS) |
|---|---|---|---|
| **2** | 19 | 9 | 13 |
| **3** | 37 | 27 | 40 |
| **4** | 27 | 13 | 23 |
| **5** | 18 | 10 | 18 |
| **Grand Total** | **101** | **59** | **94** |
| **Using QAR as a 'baseline'** | **(100%)** | **(58.4%)** | **(93.1%)** |

Table 6, Summary of ALL Events by Device Type & Simulator Session Excluding 'False +VEs'

| Simulator Sessions | LFL_1 (QAR) | LFL_2 (iFDR) | LFL_3 (EFIS) |
|---|---|---|---|
| **2** | 16 | 1 | 6 |
| **3** | 35 | 14 | 27 |
| **4** | 27 | 5 | 14 |
| **5** | 18 | 2 | 9 |
| **Grand Total** | **96** | **22** | **56** |
| **Using QAR as a 'baseline'** | **(100%)** | **(22.9%)** | **(58.3%)** |

Detailed analysis of task events by device type (Appendix B2) showed that valid events were detected by the devices but some events were missed by the QAR and 'false positive' events were 'detected' for both the iFDR and EFIS. By manually reviewing the output and removing 'false positive' events, the total number of triggered safety events reduced from 254 to 174 (-31.5%). However, the analysis of numbers of events alone does not reflect the weighting or importance of events. To this end, a detailed analysis of events by phase of flight was conducted (Figure 16 & Table 7).

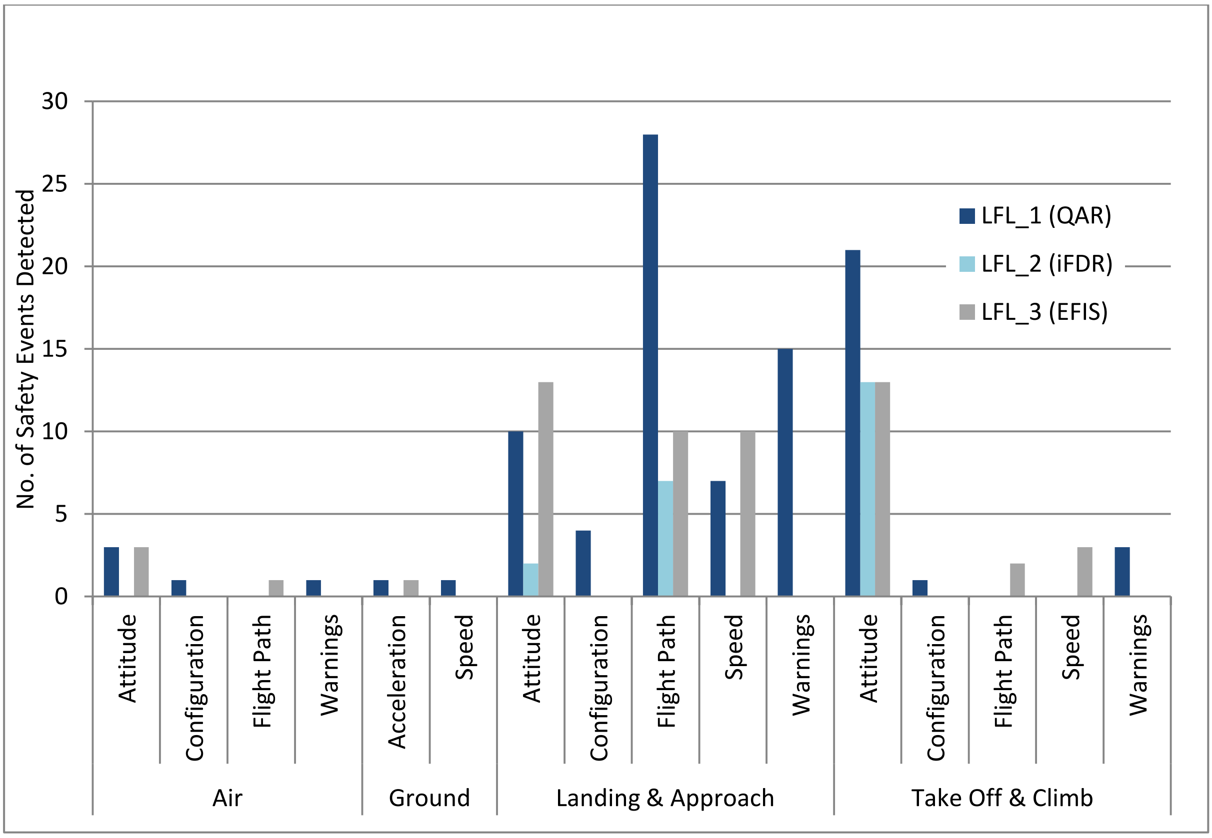


Figure 16, No. Events/Types by Phase of Flight & Device Type

A summary of the number of events/types by phase of flight & device with 'false positive removed (Figure 16 & Table 7), shows that the QAR device type detected all event types across all phase of flight. The simulated iFDR device type detected only attitude and flight path events in the take-off & climb and landing & approach phases of flight. The simulated EFIS (LFL_3) device type detected all event types (except configurations & warnings) in all phases of flight. A further detailed breakdown of individual safety events detected by event type/phase of flight and device is given in Appendix B3 and Appendix B4.

**Table 7, Summary of Number of Events/Types by Phase of Flight & Device**

| Event Type/Phase | LFL_1 (QAR) | LFL_2 (iFDR) | LFL_3 (EFIS) |
|---|---|---|---|
| **Acceleration** | **1** | | **1** |
| Ground | 1 | | 1 |
| **Attitude** | **34** | **15** | **29** |
| Air | 3 | | 3 |
| Landing & Approach | 10 | 2 | 13 |
| Take Off & Climb | 21 | 13 | 13 |
| **Configuration** | **6** | | |
| Air | 1 | | |
| Landing & Approach | 4 | | |
| Take Off & Climb | 1 | | |
| **Flight Path** | **28** | **7** | **13** |
| Air | | | 1 |
| Landing & Approach | 28 | 7 | 10 |
| Take Off & Climb | | | 2 |
| **Speed** | **8** | | **13** |
| Ground | 1 | | |
| Landing & Approach | 7 | | 10 |
| Take Off & Climb | | | 3 |
| **Warnings** | **19** | | |
| Air | 1 | | |
| Landing & Approach | 15 | | |
| Take Off & Climb | 3 | | |
| **Grand Total** | **96** | **22** | **56** |
| **Using QAR as a 'baseline'** | **(100%)** | **(22.9%)** | **(58.3%)** |

**Table 8, Summary of Number of Events by Phase of Flight & Device**

| Phase of Flight | LFL_1 (QAR) | LFL_2 (iFDR) | LFL_3 (EFIS) |
|---|---|---|---|
| **Air** | 5 | | 4 |
| | (100%) | (0%) | (80%) |
| **Ground** | 2 | | 1 |
| | (100%) | (0%) | (50%) |
| **Landing & Approach** | 64 | 9 | 33 |
| | (100%) | (14%) | (52%) |
| **Take Off & Climb** | 25 | 13 | 18 |
| | (100%) | (52%) | (72%) |
| **Grand Total** | **96** | **22** | **56** |
| **Using QAR as a 'baseline'** | **(100%)** | **(23%)** | **(58%)** |

The analysis of the number of safety events alone does not provide a comprehensive assessment of the capabilities of the devices. Using phases of flight (Table 8) it is possible however, to imply 'weighting' to events since it is known that higher accident/incident rates are apparent in the take-off, climb, approach & landing (2), therefore detection of pre-cursor events in these phases is of higher importance. The results show that in comparison with the QAR, the iFDR was only capable of detecting more than 50% of events in the take-off and climb phases of flight only. The EFIS device type was capable of detecting more than 50% of events in all phases of flight, including the take-off & climb and approach & landing.

The results have important implications for the practical use of these device types in relation to FDM for business aviation.

# 7 Discussion of Results

The results of the 'Real FDM' analysis using a commercial FDM analysis system were largely in agreement with the limited desktop analysis using the Pre-cursor Matrix, although only six safety events were compared in detail. The 'pseudo-FDM' proved manually intensive but as a sensibility check provided a useful overview and context to each of the simulated flights, enabling phases of flight to be easily identified before loading the data into the commercial FDM analysis system.

Using the QAR as a 'baseline' the 'Real-FDM' analysis shows that when false positive events were excluded, the QAR identified the highest number of safety events (100%), followed by EFIS (58.3%) and iFDR (22.9%). It has been proven in the analysis that decreasing the number and type of available parameters has a significant effect on the number of events detected.

The results also show that in a few selected cases, low sampling frequencies (<2 Hz) may result in some safety events being missed or reported at lower levels of severity due to 'clipping' of the data and missing maximum/minimum values. For high performance business jets, with increased pitch/roll rate and acceleration, higher sampling frequencies are desirable.

The analysis of the number of safety events alone does not provide a comprehensive assessment of the capabilities of the devices. Using phases of flight, it is possible however, to imply 'weighting' to events since it is known that higher accident/incident rates are apparent in the take-off, climb, approach & landing (ref), therefore detection of pre-cursor events in these phases is of higher importance.

In respect of the increased 'weighting' of detected events, particularly in the take-off & climb and approach & landing phases of flight, when compared to the QAR, the EFIS device type detected more than half of all safety events in these phases of flight whereas the iFDR proved adequate only in the take-off & climb phases of flight.

## 7.1 Realism of the Simulated Data

The simulated data was adjusted for the effects of temporary signal loss (e.g. GPS) and/or signal noise. All simulator data output was recorded and stored at a frequency of 7.33 Hz in scientific notation format with coefficients specified to 6 places of decimal precision (e.g. coefficient x $10^{\text{exponent}}$) and commonly accepted sensor tolerance. Linear interpolation was used by the FDM analysis system during the data load process to replicate a sampling rate of 8 Hz for all recorded data. For selected parameters such as degrees latitude and longitude, the use of scientific notation resulted in reduced precision when plotting flightpath and ground track for the range of data values present in the dataset.

## 7.2 False Negative Events (Missed Events) in the 'Real-FDM' Analysis

Analysis of the data showed that some event types that were expected to be detected by the QAR (LFL_1) were missed. Upon investigation it was found that the key parameters pitch, rate of climb/descent, wind speed/direction and stick pusher activated were inadvertently omitted from the emulated QAR (LFL_1) definition (Appendix B1). These parameters would normally be included in the definition of the QAR LFL that is required to feed an FDM system. Pitch is always present, climb or descent rates are either recorded or derived, wind speed/direction are usually recorded but not essential to FDM and stick shaker/pusher are always recorded. The inclusion of these missing parameters where applicable, would increase the number of detected safety events for the devices emulated, therefore the results for emulated QAR devices are likely to have been understated. In addition, the slow sampling rate used for roll angle (2 Hz) compared to pitch angle (4 Hz), may also account for the missing event 'excessive bank on take-off'. Further detailed analysis of the data is desirable.

## 7.3 False Positive Events in the 'Real-FDM' Analysis

The 'false positive' events detected were related to airspeed and configuration event types and were mainly related to the iFDR (LFL_2) and EFIS (LFL_3). They were probably triggered by the use of fixed/dummy values of selected parameters such as flap setting and air/ground switch as these data are not recorded by these device types but are required (and expected) by the commercial FDM analysis system to identify and confirm normal phases of flight. In addition, the lack of CAS for iFDR (LFL_2) resulted in the substitution of CAS with GSPD. False positive events were also generated for the simulator device (LFL_0) and QAR device (LFL_1) and these were due to discontinuities in the (simulated) flight data. Examiners frequently re-position the aircraft to perform and/or repeat tasks as part of the LPC/OPC checks and as such flights do not follow the normal sequence of flight phases (e.g. taxi, take-off, climb, cruise, descent etc.).

## 7.4 FDM Integration

The use of simulated flight data has enabled FDM integration to be tested and proven with an example of commercial FDM analysis system. Integration required the custom development of a plug-in to import CSV data directly into the commercial FDM analysis system. CSV file type data plug-ins may be necessary to enable EFIS and iFDR data to be input to commercial FDM analysis systems and these may require further custom development.

# 8 Conclusions

The high-level technical installation requirements examples of three different device types have been established. Under EASA regulations, QARs require minor modifications, iFDRs require STCs and EFIS systems with a data recording capability require no additional installation or modification. However, it should be noted that not all EFIS systems are capable of recording data on a removable media.

Three typical examples of data collection devices (QAR, iFDR and EFIS) have been reviewed and the number, frequency, precision and accuracy of recorded flight data parameters has been established. Each device type has been successfully emulated using a desktop study and simulated flights.

It has been demonstrated that it is possible to relate flight data parameters and associated safety events to Sig-7 events through the development of the Pre-Cursors Matrix.

For the given scope of tests and simulated devices used in conjunction with a commercial FDM analysis solution it has been shown that iFDRs are capable of detecting up to 50% of safety events in the take-off & climb phases of flight. The extension of the basic parameter set (16 parameters) by the use of data derived from the basic set and use of supplementary data (wind speed/direction, terrain etc.), may enhance device capabilities, further investigation is required.

In contrast, EFIS systems where installed offer broader capability, detecting at least 50% of safety events in ALL phases of flight due to the availability of additional parameters (e.g. air data and real-time weather information). The addition of configuration and warning information to EFIS systems could further enhance capabilities in support of FDM programmes for Business Aviation.

In summary, where fitted EFIS systems used for data collection in support of an FDM programme for Business Aviation aircraft less than 20 tonnes MTOW may offer several advantages over the iFDR solutions, these being lower cost and ability to detect > 50 % of safety events in ALL phases of flight. That said, iFDRs enable basic FDM capability for data collection for legacy aircraft where EFIS systems are not installed.

With regard to methodology, it has been shown that flight simulation using LPC/OPC data can be used as an effective means in the evaluation of COTS technologies in support of an FDM programme. This method has potential to reduce the time required to complete a manual desktop evaluation of a new aircraft introduced to the fleet and a practical means by which to evaluate the newly defined LFLs using simulated flight data representative of that which will be present in normal and abnormal flight operations.

## 8.1 Future work

As a result of this study, follow-on work is recommended to include flight trials to evaluate practical installation and usage of iFDRs and EFIS devices in a real-world environment as this is not possible by using desk-top and simulation studies alone. In addition, the feasibility of using extended parameters sets by use of derived data is also proposed.

First generation Flight Data Recorders used only 4 raw data parameters sampling at 1 Hz (Normal Acceleration 5 Hz) and this led to the use of additional data parameters derived from the basic parameter set to enable flight path and ground track to be plotted. The usability of iFDRs with a limited set of 16 parameters may be enhanced by the use of derived parameters such as high precision GPS data and external databases.

# 9 More Information

If you require any further information regarding this project please contact Mike Bromfield (Principal Investigator):-

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# APPENDIX A

## CASE Member Survey

## Survey Questions

1. First Name?
2. Last Name?
3. Email Address?
4. Contact Number?
5. Company Name?
6. Company Address?
7. Scope of Operations? (UK, EU, Global)
8. Do you have an established FDM programme for aircraft in your fleet?
9. If No, When do you envisage implementing FDM?
10. What is your principal flight data analysis solution?
11. What is your principal Flight Animation Software?
12. How is your data analysed? (In House/Hosted Service)
13. How many full time analysts are involved in your FDM programme?

14. Fixed Wing Fleet

| Aircraft Registration Mark | Make, Model and Variant | What type of QAR is fitted? |
|---|---|---|
| | | |

15. Rotary Wing Fleet

| Aircraft Registration Mark | Make, Model and Variant | What type of QAR is fitted? |
|---|---|---|
| | | |

## APPENDIX B1

## LFLs by Device Type

| PARAMETER/SAMPLING FREQ. (Hz) | LFL_0 SIM | LFL_1 QAR | LFL_2 iFDR | LFL_3 EFIS | UOM | Notes |
|---|---|---|---|---|---|---|
| Timestamp | 8 | 8 | 4 | 1 | sec | |
| Calibrated_Airspeed | 8 | 1 | | 1 | knot | |
| Groundspeed | 8 | 1 | 4 | 1 | knot | |
| Pressure_Altitude | 8 | 1 | 4* | 1 | foot | iFDR = GPS Altitude |
| AAL | 8 | 1 | | | foot | |
| Runway_Length | 8 | | | | foot | |
| Radio_Altitude | 8 | 2 | | | foot | |
| Magnetic_Heading | 8 | 1 | 4 | 1 | deg | |
| Indicated_Mach_Number | 8 | 1 | | | Mach | |
| Pitch_Angle | 8 | 4 | 4 | 1 | deg | |
| Roll_Angle | 8 | 2 | 4 | 1 | deg | |
| Yaw_Angle | 8 | 1 | 4 | | deg | |
| Outside_Air_Temperature | 8 | 1 | | 1 | degC | |
| Gear | 8 | 1 | | | % | |
| Flap_Lever | 8 | 1 | | | % | |
| Flap | 8 | 1 | | | % | |
| Spoiler_Lever | 8 | 1 | | | % | |
| Spoiler | 8 | 1 | | | % | |
| Spoiler_2 | 8 | 1 | | | % | |
| Spoiler_3 | 8 | 1 | | | % | |
| Spoiler_4 | 8 | 1 | | | % | |
| Spoiler_5 | 8 | 1 | | | % | |
| Spoiler_6 | 8 | 1 | | | % | |
| Spoiler_7 | 8 | 1 | | | % | |
| Spoiler_8 | 8 | 1 | | | % | |
| Angle_of_Attack | 8 | 1 | | | deg | |
| Pitch_Rate | 8 | 4 | 4 | | deg/s | |
| Roll_Rate | 8 | 2 | 4 | | deg/s | |
| Yaw_Rate | 8 | 1 | 4 | | deg/s | |
| Weight | 8 | 1 | | | lb | |
| Normal_Acceleration | 8 | 8 | 4 | 1 | ft/s^2 | |
| Longitudinal_Acceleration | 8 | 2 | 4 | | ft/s^2 | |
| Lateral_Acceleration | 8 | 2 | 4 | 1 | ft/s^2 | |
| Engine_#1_Pressure_Ratio | 8 | 0.25 | | 1 | % | |
| Engine_#2_Pressure_Ratio | 8 | 0.25 | | 1 | % | |
| Reference_Speed | 8 | 1 | | | knot | |
| Reference_Speed_With_Current_Flap | 8 | 1 | | | knot | |
| Air_Ground | 8 | 2 | | | | |
| EGPWS | 8 | 1 | | | | |
| Stick_Shaker | 8 | 1 | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Stick_Pusher | 8 | | | | | Missing from QAR LFL |
| Master_Warning | 8 | 1 | | | | |
| TCAS_Warning_Vertical_Speed | 8 | 1 | | 1 | | |
| TCAS_Warning_Climb_Climb | 8 | 1 | | 1 | | |
| TCAS_Warning_Climb_Climb_Now | 8 | 1 | | 1 | | |
| TCAS_Warning_Climb_Crossing_Climb | 8 | 1 | | 1 | | |
| TCAS_Warning_Clear_Conflict | 8 | 1 | | 1 | | |
| TCAS_Warning_Descend_Crossing_Descend | 8 | 1 | | 1 | | |
| TCAS_Warning_Descend_Descend | 8 | 1 | | 1 | | |
| TCAS_Warning_Descend_Descend_Now | 8 | 1 | | 1 | | |
| TCAS_Warning_Increase_Climb | 8 | 1 | | 1 | | |
| TCAS_Warning_Increase_Descent | 8 | 1 | | 1 | | |
| TCAS_Warning_Monitor_Vertical_Speed | 8 | 1 | | 1 | | |
| TCAS_Warning_Maintain_Vertical_Speed_Cros | 8 | 1 | | 1 | | |
| TCAS_Warning_Maintain_Vertical_Speed_Main | 8 | 1 | | 1 | | |
| TCAS_Warning_System_Test_Fail | 8 | 1 | | 1 | | |
| TCAS_Warning_System_Test_OK | 8 | 1 | | 1 | | |
| TCAS_Warning_Test | 8 | 1 | | 1 | | |
| TCAS_Warning_Traffic_Traffic | 8 | 1 | | 1 | | |
| TCAS_Warning_Test_Complete | 8 | 1 | | 1 | | |
| TCAS_Warning_Test_Track | 8 | 1 | | 1 | | |
| TCAS_Warning_Test_Lost | 8 | 1 | | 1 | | |
| TCAS_Warning_Test_Dropped | 8 | 1 | | 1 | | |
| Latitude | 8 | 1 | 4 | 1 | deg | |
| Longitude | 8 | 1 | 4 | 1 | deg | |
| Glideslope | 8 | 1 | | | dot | |
| Localiser | 8 | 1 | | | dot | |
| GPS_Altitude | 8 | | 4 | | foot | Missing from EFIS LFL |
| Vertical_Speed | 8 | | 4 | 1 | ft/min | |
| Altitude_Above_Mean_Sea_Level | 8 | | 4* | 1 | foot | iFDR = GPS Altitude |
| Track | 8 | | | 1 | deg | |
| Track_for_Test_Output | 8 | | | 1 | deg | |
| Engine_#1_Fuel_Flow | 8 | | | 1 | | Missing from QAR LFL |
| Engine_#2_Fuel_Flow | 8 | | | 1 | | Missing from QAR LFL |
| Engine_#1_Oil_Temperature | 8 | | | 1 | degC | |
| Engine_#2_Oil_Temperature | 8 | | | 1 | degC | |
| Engine_#1_Oil_Pressure | 8 | | | 1 | psi | |
| Engine_#2_Oil_Pressure | 8 | | | 1 | psi | |
| True Airspeed | 8 | | | 1 | knot | |
| Course | 8 | | | 1 | deg | |
| Windspeed | 8 | | | 1 | knot | Missing from QAR LFL |
| Wind_Direction | 8 | | | 1 | deg | Missing from QAR LFL |

| | | | | | |
|---|---|---|---|---|---|
| Elevator_Position | 8 | | | | deg |
| Port_Aileron | 8 | | | | deg |
| Starboard_Aileron | 8 | | | | deg |
| Rudder_Deflection | 8 | | | | deg |
| **Total Number of Parameters** | **86** | **65** | **16** | **49** | |

## APPENDIX B2

## Safety Events by Type by Device(Excluding ‘False +VEs’)

| Event Type/Name | LFL_0 (SIM) | LFL_1 (QAR) | LFL_2 (iFDR) | LFL_3 (EFIS) | Grand Total |
|---|---|---|---|---|---|
| **Acceleration** | **2** | **1** | | **2** | **5** |
| Abnormal vertical acceleration (ground) | 1 | 1 | | 1 | 3 |
| High normal acceleration (landing) | 1 | | | 1 | 2 |
| **Attitude** | **46** | **34** | **16** | **29** | **125** |
| Abnormal Pitch (High) | 1 | | | 1 | 2 |
| Excessive bank | 3 | 3 | | 2 | 8 |
| Excessive bank after takeoff (<1000ft) | 1 | 1 | | 2 | 4 |
| Excessive bank after takeoff (<50ft) | 2 | 1 | | | 3 |
| Excessive bank on approach (<250ft) | 2 | 2 | | 1 | 5 |
| Excessive bank on approach (<500ft) | 6 | 5 | | 5 | 16 |
| Excessive bank on approach (<50ft) | 1 | 1 | | 2 | 4 |
| Excessive Bank on landing (at touchdown) | 1 | 1 | 1 | 1 | 4 |
| Excessive Bank on landing (below Flare Ht) | 1 | 1 | 1 | 1 | 4 |
| Excessive Bank on takeoff (below Flare Ht) | 6 | 5 | 7 | 6 | 24 |
| Pitch attitude high during initial climb | 2 | 2 | | | 4 |
| Pitch High post Go Around | 2 | 2 | | | 4 |
| Pitch Low (approach) | 2 | | | 2 | 4 |
| Pitch Low post Go Around | 8 | 8 | | | 16 |
| Pitch rate high (initial climb) | | | | 1 | 1 |
| Pitch rate high on take-off | 8 | 2 | 6 | 4 | 20 |
| Pitch rate low on take-off | | | 1 | | 1 |
| Unstable approach (roll) | | | | 1 | 1 |
| **Configuration** | **7** | **6** | | | **13** |
| Early config change after take-off (height) | 1 | 1 | | | 2 |
| Flap Placard Speed Exceeded | 2 | 1 | | | 3 |
| Late land flap (duration) | 1 | 1 | | | 2 |
| Reduced flap landing | 3 | 3 | | | 6 |
| **Flight Path** | **37** | **27** | **7** | **13** | **84** |
| Abnormal Sink Rate | 1 | | | 1 | 2 |
| Above Vertical Profile (500ft AAL) | | 1 | | 1 | 2 |
| Below Vertical Profile (1000ft AAL) | 1 | 1 | 1 | 1 | 4 |
| Deep Landing (distance from 50ft RALT) | 3 | 1 | 4 | 3 | 11 |
| Deep Landing (distance from GS Aerial) | 4 | 3 | | | 7 |
| Deviation above glideslope | 4 | 4 | | | 8 |
| Deviation below glideslope | 1 | 1 | | | 2 |
| High rate of descent (<1000ft) | 2 | | | 1 | 3 |
| High rate of descent (<500ft) | 1 | | | 1 | 2 |
| Initial climb height loss | 3 | | | 2 | 5 |
| Late Acquisition (ILS) | 8 | 7 | | | 15 |
| Late Initial Stabilisation (Ht AAL) | 2 | 2 | | | 4 |

| | | | | | |
|---|---|---|---|---|---|
| Long Flare (distance from flare height) | | | 1 | 1 | 2 |
| Long Flare (duration from flare height) | | | 1 | 1 | 2 |
| Un-stabilised at Low Altitude (Ht AAL) | 5 | 5 | | 1 | 11 |
| Unstable approach (G/S variation) | 2 | 2 | | | 4 |
| **Speed** | **20** | **8** | | **13** | **41** |
| Approach Speed High (<1000ft) | 3 | 2 | | | 5 |
| Approach Speed High (<500ft) | 1 | | | | 1 |
| High crosswind component (landing) | 6 | | | 5 | 11 |
| High crosswind component (take-off) | 3 | | | 3 | 6 |
| High Tailwind Component (landing) | 1 | | | | 1 |
| High Taxi Speed (after landing) | 1 | 1 | | 1 | 3 |
| High Taxi Speed (before take-off) | 4 | 4 | | 4 | 12 |
| Rough taxiing | 1 | 1 | | | 2 |
| **Warnings** | **18** | **20** | | | **38** |
| Go around | 15 | 15 | | | 30 |
| Rejected take-off | 3 | 5 | | | 8 |
| **Grand Total** | **130** | **96** | **23** | **57** | **306** |

# APPENDIX B3

## Simulator Task Events by Device Type with Analysis

## (Examples: Simulator Session 3)

| Flight No. | LPC/OPC Task No. | Event No. | Event(s) Generated | Event(s) Detected | | | | Notes 2 |
|---|---|---|---|---|---|---|---|---|
| | | | SIMULATOR SESSION | 3 | | | | |
| | | | | Sim | QAR | iFDR | EFIS | |
| | 1 | | | | | | | |
| | 2 | | | | | | | |
| | 3 | | | | | | | |
| | 4 | | | | | | | |
| | 5 | | | | | | | |
| | 6 | | | | | | | |
| | 7 | | | | | | | |
| | 8 | | | | | | | |
| | 9 | | | | | | | |
| | 10 | | | | | | | |
| | 11 | | | | | | | |
| | 12 | | | | | | | |
| | 13 | | | | | | | |
| 1 | 14 | | Reduced Flap Landing | | | F | F | |
| | | 1 | Deep Landing | ✓ | M | ✓ | ✓ | |
| | | | ILS Procedure Not Flown | | | F | F | |
| | 15 | | | | | | | |
| | 16 | | | | | | | |
| | 24 | 2 | High Taxi Speed (after landing) | ✓ | ✓ | | ✓ | |
| 2 | 17 | 3 | Pitch High on Take-off | ✓ | M | ✓ | ✓ | Missed Event: Lack of QAR Pitch Parameter |
| | | 4 | Initial Climb Height Loss | ✓ | M | | | Missed Event: Lack of QAR RoD/RoC Parameter |
| | 18 | | | | | | | |
| | 19 | | | | | | | |
| | 20 | 5 | Go Around | ✓ | ✓ | | | |
| | | 6 | Pitch Low Post Go Around | ✓ | ✓ | | | |
| | 21 | | Unstable Approach (roll) | | | | F | False Event: EFIS further analysis req'd |
| | | 7 | High Rate of Descent (<1000ft) | ✓ | M | | ✓ | Missed Event: Lack of QAR RoC/RoD Parameter |
| | | 8 | High Rate of Descent (<500ft) | ✓ | M | | ✓ | Missed Event: Lack of QAR RoC/RoD Parameter |
| | | 9 | Excessive Bank on Approach | ✓ | ✓ | | ✓ | |
| | | | ILS Procedure not flown | | | F | F | False Event: iFDR/EFIS ILS flag constant |
| | 22 | 10 | Reduced Flap Landing | ✓ | ✓ | F | F | False Event: iFDR/EFIS flap constant |
| 3 | 16 | 11 | High Taxi Speed Before Take-off | ✓ | ✓ | | ✓ | |
| | 17 | 12 | Pitch Rate High on Take-off | ✓ | M | ✓ | ✓ | Missed Event: QAR further analysis req'd |
| | | 13 | Excessive Bank on Take-off | ✓ | M | ✓ | M | Missed Event: QAR/EFIS Roll sampling rate low QAR 2 Hz/EFIS 1 Hz (SIM 8 Hz/iFDR 4Hz) |
| | 19 | 14 | High Rate of Descent (<1000ft) | ✓ | M | | | Missed Event: Lack of QAR RoC/RoD Parameter |
| | 20 | 15 | Go Around | ✓ | ✓ | | | |
| | | 16 | Pitch Low Post Go Around | ✓ | ✓ | | | |
| | | - | Late Acquisition ILS | ✓ | M | | | Missed Event: QAR further analysis req'd |
| | 19 | 17 | Approach Speed High (<500ft) | ✓ | M | | | Missed Event: QAR further analysis req'd |
| | | 18 | Excessive Bank on Approach (<500ft) | ✓ | ✓ | | ✓ | |
| | | 19 | Late Acquisition (ILS) – Localiser | ✓ | ✓ | | | |
| | | 20 | Unstabilised at Low Altitude | ✓ | ✓ | | | |
| | | 21 | Deviation Below Glideslope (Below 500ft) | ✓ | ✓ | | | |
| | | 22 | Excessive bank on approach (<250ft) | ✓ | ✓ | | ✓ | |
| | | | ILS Procedure not flown | | | F | F | False Event: iFDR/EFIS ILS flag constant |
| | | 23 | High Crosswind component landing | ✓ | M | | ✓ | Missed Event: QAR Lack of Windspeed/Direction |
| | | 24 | Reduced Flap Landing | ✓ | ✓ | F | F | False Event: iFDR/EFIS flap constant |
| 4 | 22 | | | | | | | |
| | 23 | | | | | | | |
| | | | | | | | | |
| | 24 | 25 | High Taxi Speed (Before Take-off) | ✓ | M | | M | Missed Event: QAR/EFIS further analysis req'd |
| | | | Rejected Take-off | | F | | | False Event: QAR further analysis req'd |
| | 25 | 26 | Pitch Rate High on Take-off | ✓ | ✓ | ✓ | ✓ | |
| | | 27 | Pitch Rate High on Take-off | ✓ | M | ✓ | M | Missed Event: QAR/EFIS further analysis req'd |
| | | 28 | Excessive Bank on Take-off (below 20ft) | ✓ | ✓ | ✓ | ✓ | |
| | | 29 | High Crosswind component (take-off) | ✓ | M | | ✓ | Missed Event: QAR Lack of Windspeed/Direction |
| | 26 | 30 | Pitch Attitude High during initial climb | ✓ | ✓ | | | |
| | | | Pitch rate high (initial climb) | | | | F | False Event: EFIS further analysis req'd |
| | 27 | | | | | | | |
| | 28 | | | | | | | |
| | 29 | | | | | | | |
| | 30 | | | | | | | |
| | 31 | | | | | | | |
| | 32 | | | | | | | |
| | 33 | 31 | Go Around | ✓ | ✓ | | | |
| | 14 | 32 | Excessive Bank on Approach (<500ft) | ✓ | ✓ | | | |
| | | 33 | High Crosswind Component (Landing) | ✓ | M | | ✓ | Missed Event: QAR Lack of Windspeed/Direction |
| | | | Reduced flap landing | | | F | F | False Event: iFDR/EFIS flap constant |
| | | 34 | Excessive Bank on Landing (at touchdown) | ✓ | M | ✓ | ✓ | Missed Event: QAR Roll sampling rate? (2 Hz) |
| | | | ILS Procedure not flown | | | | F | False Event: iFDR/EFIS ILS flag constant |
| 5 | 24 | | Rejected Take-off | | F | | | False Event: QAR further analysis req'd |
| | 25 | 35 | Pitch Rate High on Take-off | ✓ | ✓ | ✓ | | |
| | | 36 | Pitch Rate High on Take-off | ✓ | M | ✓ | | Missed Event: QAR further analysis req'd |
| | | 37 | Excessive Bank on Take-off (below 20ft) | ✓ | ✓ | ✓ | ✓ | |
| | | 38 | High Crosswind Component at 100ft | ✓ | M | | ✓ | Missed Event: QAR Lack of Windspeed/Direction |
| | 26 | | | | | | | |
| | 33 | 39 | Go Around | ✓ | ✓ | | | |
| | | 40 | Pitch Low Post Go Around | ✓ | ✓ | | | |
| | 34 | 41 | Late Acquisition ILS – Localiser | ✓ | ✓ | | | |
| | | | ILS Procedure not flown | | | F | F | False Event: iFDR/EFIS ILS flag constant |
| | | 42 | High Crosswind Component (Landing) | ✓ | M | | ✓ | Missed Event: QAR Lack of Windspeed/Direction |
| | | 43 | Reduced Flap Landing | ✓ | ✓ | F | F | False Event: iFDR/EFIS flap constant |
| | 35 | 44 | Deep Landing | ✓ | ✓ | M | | |
| 6 | | | Excessive bank | ✓ | ✓ | M | ✓ | Missed Event: iFDR further analysis req'd |
| | | | Stall Warning | ✓ | ✓ | | | |
| | | | Stall Warning | ✓ | M | | | Missed Event: QAR further analysis req'd |
| | | | High crosswind component (take-off) | ✓ | M | | ✓ | Missed Event: QAR Lack of Windspeed/Direction |
| | | | Initial climb height loss | ✓ | M | | | Missed Event: QAR Lack of RoC/RoD Parameter |
| | | | Early config change after take-off (height) | ✓ | ✓ | | | |
| | | | Excessive bank after takeoff (<50ft) | ✓ | ✓ | | | |
| | | | Late Initial Stabilisation (Ht AAL) | ✓ | ✓ | | ✓ | |
| | | | Un-stabilised at Low Altitude (Ht AAL) | ✓ | ✓ | | | |
| | | | High crosswind component (landing) | ✓ | M | | | Missed Event: Lack of QAR RoC/RoD Parameter |
| | | | High Tailwind Component (landing) | ✓ | M | | | Missed Event: Lack of QAR RoC/RoD Parameter |
| | | | Late land flap (duration) | ✓ | ✓ | F | F | False Event: iFDR/EFIS flap constant |
| | | | Deep Landing (distance from 50ft RALT) | | | F | F | False Event: iFDR/EFIS flap constant |
| | | | Long Flare (distance from flare height) | | | F | F | False Event: iFDR/EFIS flap constant |
| | | | Long Flare (duration from flare height) | | | F | F | False Event: iFDR/EFIS flap constant |
| | | | Abnormal vertical acceleration (ground) | ✓ | ✓ | | ✓ | Missed Event: iFDR further analysis req'd |
| | | | Total Events Detected | 58 | 34 | 27 | 38 | |
| KEY: | | | Sim Baseline | 100% | 59% | 47% | 66% | |
| ✓ | Valid Event Detected | | QAR Baseline | 171% | 100% | 79% | 112% | |
| M | Expected Event Missed | | | | | | | |
| F | False +Ve Event Detected: | | Total Events Detected exc False | 58 | 32 | 14 | 22 | |
| | | | Sim Baseline | 100% | 55% | 24% | 38% | |
| | | | QAR Baseline | 171% | 94% | 41% | 65% | |

## APPENDIXB4

## Detailed Event Type by Phase of Flight & Device Type

| Event Type | LFL_1 (QAR) | LFL_2 (iFDR) | LFL_3 (EFIS) |
|---|---|---|---|
| **Acceleration** | **1** | | **1** |
| **Ground** | **1** | | **1** |
| Abnormal vertical acceleration (ground) | *1* | | *1* |
| **Attitude** | **34** | **15** | **29** |
| **Air** | **3** | | **3** |
| Abnormal Pitch (High) | | | *1* |
| Excessive bank | *3* | | *2* |
| **Landing & Approach** | **10** | **2** | **13** |
| Excessive bank on approach (<250ft) | *2* | | *1* |
| Excessive bank on approach (<500ft) | *5* | | *5* |
| Excessive bank on approach (<50ft) | *1* | | *2* |
| Excessive Bank on landing (at touchdown) | *1* | *1* | *1* |
| Excessive Bank on landing (below Flare Ht) | *1* | *1* | *1* |
| Pitch Low (approach) | | | *2* |
| Unstable approach (roll) | | | *1* |
| **Take Off & Climb** | **21** | **13** | **13** |
| Excessive bank after takeoff (<1000ft) | *1* | | *2* |
| Excessive bank after takeoff (<50ft) | *1* | | |
| Excessive Bank on takeoff (below Flare Ht) | *5* | *7* | *6* |
| Pitch attitude high during initial climb | *2* | | |
| Pitch High post Go Around | *2* | | |
| Pitch Low post Go Around | *8* | | |
| Pitch rate high (initial climb) | | | *1* |
| Pitch rate high on take-off | *2* | *6* | *4* |
| **Configuration** | **6** | | |
| **Air** | **1** | | |
| Flap Placard Speed Exceeded | *1* | | |
| **Landing & Approach** | **4** | | |
| Late land flap (duration) | *1* | | |
| Reduced flap landing | *3* | | |
| **Take Off & Climb** | **1** | | |
| Early config change after take-off (height) | *1* | | |
| **Flight Path** | **28** | **7** | **13** |
| **Air** | | | **1** |
| Abnormal Sink Rate | | | *1* |
| **Landing & Approach** | **28** | **7** | **10** |
| Above Vertical Profile (500ft AAL) | *1* | | *1* |
| Below Vertical Profile (1000ft AAL) | *1* | *1* | *1* |
| Deep Landing (distance from 50ft RALT) | *1* | *4* | *3* |
| Deep Landing (distance from GS Aerial) | *4* | | |
| Deviation above glideslope | *4* | | |

| | | | |
|---|---|---|---|
| Deviation below glideslope | *1* | | |
| High rate of descent (<1000ft) | | | *1* |
| High rate of descent (<500ft) | | | *1* |
| Late Acquisition (ILS) | *7* | | |
| Late Initial Stabilisation (Ht AAL) | *2* | | |
| Long Flare (distance from flare height) | | *1* | *1* |
| Long Flare (duration from flare height) | | *1* | *1* |
| Un-stabilised at Low Altitude (Ht AAL) | *5* | | *1* |
| Unstable approach (G/S variation) | *2* | | |
| **Take Off & Climb** | | | **2** |
| Initial climb height loss | | | *2* |
| **Speed** | **8** | | **13** |
| **Ground** | **1** | | |
| Rough taxiing | *1* | | |
| **Landing & Approach** | **7** | | **10** |
| Approach Speed High (<1000ft) | *2* | | |
| High crosswind component (landing) | | | *5* |
| High Taxi Speed (after landing) | *1* | | *1* |
| High Taxi Speed (before take-off) | *4* | | *4* |
| **Take Off & Climb** | | | **3** |
| High crosswind component (take-off) | | | *3* |
| **Warnings** | **19** | | |
| **Air** | **1** | | |
| Stall Warning | *1* | | |
| **Landing & Approach** | **15** | | |
| Go around | *15* | | |
| **Take Off & Climb** | **3** | | |
| Rejected take-off | *3* | | |
| **Grand Total** | **96** | **22** | **56** |
| **Using QAR as a ‘baseline’ (%)** | **(100%)** | **(22.9%)** | **(58.3%)** |