CRANFIELD UNIVERSITY

R VAZ FERNANDES

AN ANALYSIS OF THE POTENTIAL BENEFITS TO AIRLINES OF FLIGHT DATA MONITORING PROGRAMMES

SCHOOL OF ENGINEERING
AIR TRANSPORT GROUP

MSc THESIS

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An analysis of the potential benefits to airlines of flight data monitoring programmes

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Abstract

A flight data monitoring (FDM) programme involves regularly downloading and analysing data recorded from an airline's operations. The primary purpose of this analysis is to improve the safety of the airline's operations by identifying and rectifying adverse trends in the flight operations.

It is not mandatory for an airline to run an FDM programme, with the exception of airlines in China and France. However, the number of carriers with such a programme is increasing as more airlines recognise the safety benefits that can arise from regularly monitoring flight data. It is likely that more countries will make FDM programmes mandatory in the coming years.

As well as the safety benefits, there are a range of other benefits which an airline with an FDM programme can enjoy. Some of these will reduce the costs incurred by the airline and these cost savings are likely to be more than sufficient to cover the costs of running the FDM programme.

This work describes the elements that make up an FDM programme, outlines what the costs are to run such a programme and describes the range of benefits available. These benefits are quantified with data taken from airlines that have established FDM programmes.

It is likely that as airlines become more mature in the use of their FDM programmes they will exploit more of these benefits and identify new ones, while at the same time improving the safety of their operations.

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Glossary

ACMS	Aircraft Condition Monitoring System
AIB	Accident Investigation Board
ASR	air safety report
ACARS	Aircraft Communications Addressing and Reporting System
AIDS	Aircraft Integrated Data Systems
AIMS	Aircraft Integrated Monitoring Systems
AOA	angle of attack
BAA	British Airports Authority
BASIS	British Airways Safety Information System
CG	centre of gravity
CAADRP	Civil Aircraft Airworthiness Data Recording Programme
CAAC	Civil Aviation Administration of China
CAA	Civil Aviation Authority
CAP	Civil Aviation Publication
CFIT	controlled flight into terrain
DAU	data acquisition unit
DMU	Data Management Unit
DAR	Digital AIDS Recorder
DFDAU	Digital FDAU
DFDMU	Digital FDMU
EGT	exhaust gas temperature
FAA	Federal Aviation Administration
FDAMS	Flight Data Acquisition & Management System
FDAU	Flight Data Acquisition Unit
FDIU	Flight Data Interface Unit
FDMU	Flight Data Management Unit
FDM	flight data monitoring
FDR	flight data recorders
FOQA	flight operational quality assurance
FSF	Flight Safety Foundation
FCOC	fuel-cooled oil cooler
GAO	General Accounting Office (United States)
GAIN	Global Aviation Information Network
GBP	Great Britain pounds
GPWS	ground proximity warning system
HF	high frequency
ILS	instrument landing system
IDG	integrated drive generator
ICAO	International Civil Aviation Organisation
ILSC	International Logistics Support Corporation
ISASI	International Society of Air Safety Investigators
LOMS	Line Operations Monitoring System

MO	magneto-optical
MCTOM	maximum certificated take-off mass
OFDM	operational flight data monitoring
OQAR	optical QAR
PCMCIA	Personal Computer Memory Card International Association
QAR	quick access recorders
SRG	Safety Regulation Group
SVT	single visit training
SSFDR	solid state FDR
STAR	standard arrival route
SOP	standard operating procedure
STC	supplemental type certificate
USD	United States dollars
UTRS	Universal Technical Resource Services, Inc.
VHF	very high frequency

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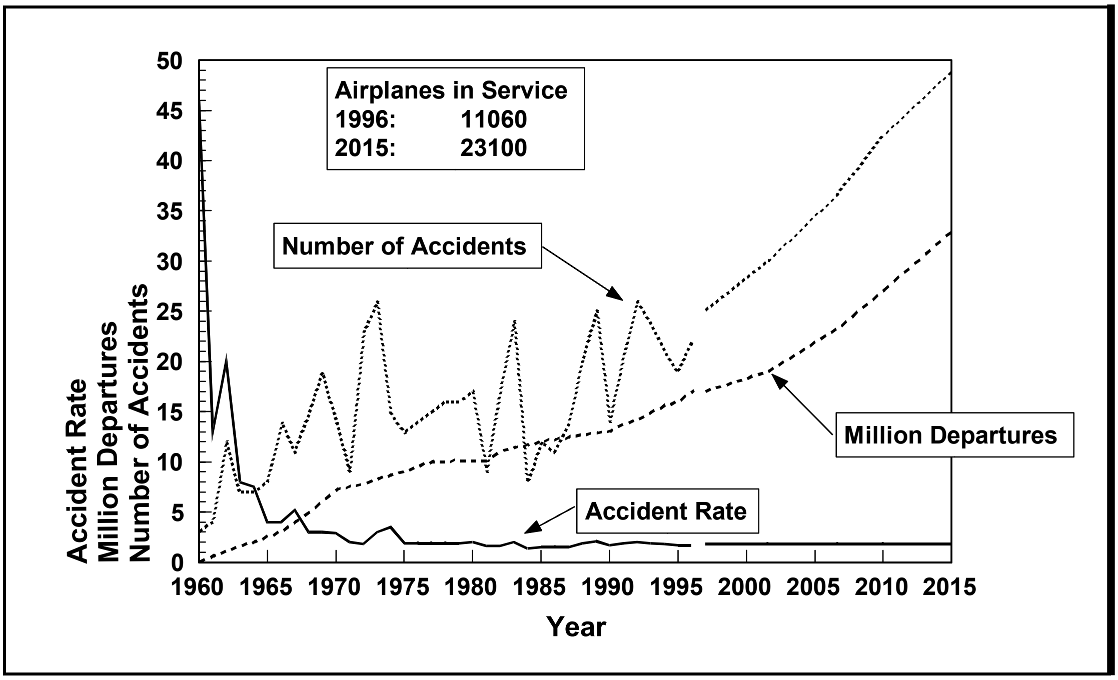
1 Introduction

Air transport is viewed as a very safe mode of transport, with the accident rate, as measured in terms of accidents per million departures, falling drastically in the last forty years. However, the accident rate has remained flat in recent years whilst air transport has continued to grow. As this traffic grows, the number of accidents will also increase, unless the accident rate is reduced further. This is shown in Figure 1.

Figure 1 - Historical and forecast levels of air transport departures, accident rate and total number of accidents.



Source: Schmidlin[1]

The aviation industry has realised that such an increase in the number of accidents is not acceptable which means the accident rate needs to be reduced. The industry is attempting to achieve this through pursuing several initiatives. One of these that has, until recently, received little recognition and has not enjoyed widespread use is the utilisation of flight data monitoring (FDM) programmes, also known as operational flight data monitoring (OFDM) or flight operational quality assurance (FOQA).

FDM programmes allow operators to gain a deeper understanding of their flight operations, through regularly analysing flight data from their aircraft. If such a programme is coupled together with other safety systems, such as confidential human factors reporting and incident reporting systems, it will help guide the aviation industry towards its goal of improved safety.

The obvious safety-related benefits of FDM programmes are becoming more widely recognised and more operators are starting to implement such programmes. However, there are also other potential benefits which are less widely appreciated, except by airlines which have had such programmes for many years. This thesis attempts to address the lack of knowledge of FDM programmes in general and, in particular, the scope of benefits that can arise from having such a programme.

1.1 Aims and objectives

1.1.1 Aim

The aim of the thesis is to describe FDM programmes and the range of potential benefits to an airline making use of such a programme.

1.1.2 Objectives

The objectives of the thesis are as follows:

- Provide an understanding of what is involved in an FDM programme.
- Determine the costs of an FDM programme
- Describe the range of benefits available from an FDM programme
- Quantify the benefits of an FDM programme

1.2 Thesis structure

- Chapter 1 is an introduction to the thesis.
- Chapter 2 describes some background information on FDM programmes. This includes a brief history of FDM, the position of the International Civil Aviation Organisation (ICAO) and regulatory authorities on FDM as well as a summary of how FDM programmes are typically run.

- Chapter 3 describes in detail how an FDM programme works as well as what the main requirements are in terms of hardware, software and manpower.
- Chapter 4 describes the costs associated with meeting the requirements outlined in the previous chapter.
- Chapter 5 highlights some major benefits to an airline which has an established FDM programme.
- Chapter 6 quantifies some of the benefits described in the previous chapter.
- Chapter 7 summarises the thesis and suggests areas for further study.

1.3 Previous studies into FDM programmes

In July 1995 the United States Federal Aviation Administration (FAA) initiated a two-year (later increased to three years) programme known as DEMOPROJ. The aim of this project was:

"…to facilitate the start-up of the FOQA initiative and to comprehensively assess the cost-benefits and safety enhancement effectiveness of an implemented FOQA program in which airlines voluntarily employ in-flight recorded data to routinely monitor their flight operations."[2]

DEMOPROJ was a USD 5.5 million project that involved four main United States airlines: Alaska Airlines, Continental, United Airlines and US Airways. Universal Technical Resource Services, Inc. (UTRS) was awarded the FAA contract to run DEMOPROJ.

In 1997 the United States General Accounting Office (GAO) produced a report about FDM programmes, primarily based on the work carried out under DEMOPROJ. This GAO report in turn formed the basis of the Flight Safety Foundation's (FSF) July-September 1998 Flight Safety Digest magazine on "Aviation Safety: US Efforts to Implement Flight Operational Quality Assurance Programs".

Since then there have been several international conferences dealing with flight safety issues, including a conference in Lisbon in 2001 focussed specifically on FDM within

Europe. The Global Aviation Information Network (GAIN), an international coalition of airlines, manufacturers, employee groups, governments and other aviation organisations, has arranged five conferences since 1996 to discuss safety issues, including FDM programmes. GAIN was formed to promote and facilitate the voluntary collection and sharing of safety information among users in the international aviation community in order to improve aviation safety.[3] To this end they have produced two documents which both include sections relating to FDM programmes. These documents are a Guide to Methods and Tools for Airline Flight Safety Analysis (Issue 1 December 2001) and a Flight Safety Operator's Handbook (Issue 2 December 2001).

The Safety Regulation Group (SRG) of the United Kingdom Civil Aviation Authority (CAA) has produced a Best Practice Guide for Operational Flight Data Monitoring (Draft Issue November 1999) and the CAA is currently working on a Civil Aviation Publication (CAP) on this subject.

The Flight Operations Support Department of Airbus, in partnership with Air France's Flight Safety Department, Cathay Pacific's Corporate Safety Department and the service supplier company Aeroconseil, have produced a Flight Operations Monitoring Handbook (Issue 3 February 2002). This is intended to serve as a guide to commercial airline operators to establish and manage their own FDM programmes.

The International Society of Air Safety Investigators (ISASI) has also discussed FDM programmes at some of its annual seminars and further articles have appeared in the ICAO Journal.

It is thus apparent that many organisations are interested in FDM programmes and are trying to issue guidelines on how to run them and share the information obtained from them. However, there does not as yet appear to be a single source of information on the subject or a detailed study of the potential benefits to be gained from such a programme. Furthermore, most of the studies to date have looked predominantly at the operational aspects of an FDM programme and few of them have highlighted the benefits available to other departments of the airline. This thesis aims to address this issue.

2 Background

2.1 Overview of FDM

Flight data monitoring is an activity carried out by an airline primarily as a means of monitoring and improving the safety of its flight operations.

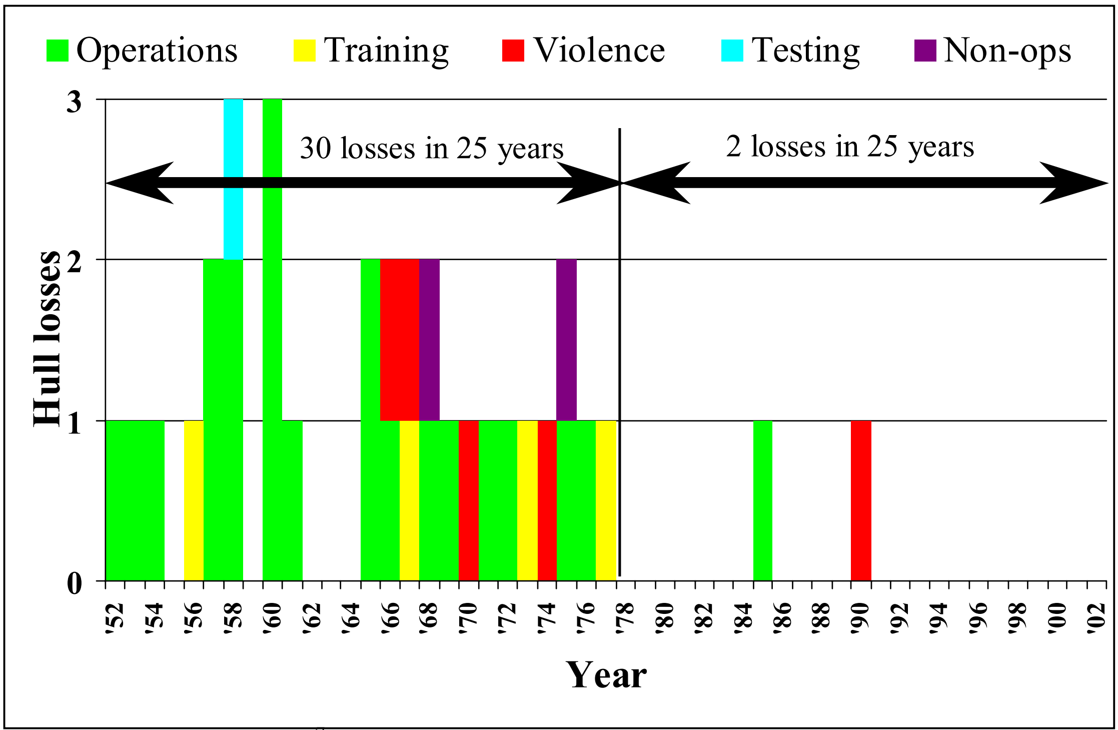
It involves regularly analysing flight data from every sector flown by every aircraft, discovering and examining any irregularities in the operations and keeping track of underlying trends in operational procedures and potentially dangerous events. If necessary, feedback on significant issues is provided, typically to the flight training department and sometimes to individual flight crew members.

In this way, FDM meets two key objectives. Firstly, it enables technical flaws, unsafe practices or conditions outside desired operating procedures to be detected at an early enough stage to prevent them leading to incidents or accidents.[4] Secondly, it provides an objective means of following-up on corrective actions, such as increased training or altered standard operating procedures, to determine if they have been successful.[5] Both of these ultimately contribute towards the safe operation of the airline.

2.2 History of FDM programmes

FDM programmes evolved from the use of flight data recorders (FDRs) which the United States Civil Aeronautics Administration made mandatory equipment in 1958. In the UK, the origins can be traced to the 1960s Civil Aircraft Airworthiness Data Recording Programme (CAADRP). British Airways was one of the first airlines to use data from FDRs in a monitoring programme, starting in 1962. In the late 1960s Trans World Airways began monitoring certain parameters relating to approaches and landings as their FDRs were removed from the aircraft for regular maintenance and All Nippon Airways started a flight data analysis programme in 1974. At least eight airlines have had voluntary FDM-type programmes in operation for more than 25 years[6] and most of them recognise the important safety benefits they have provided to the operation. This is demonstrated in Figure 2 which shows the number of hull losses, broken down by category, at British Airways over the last fifty years.

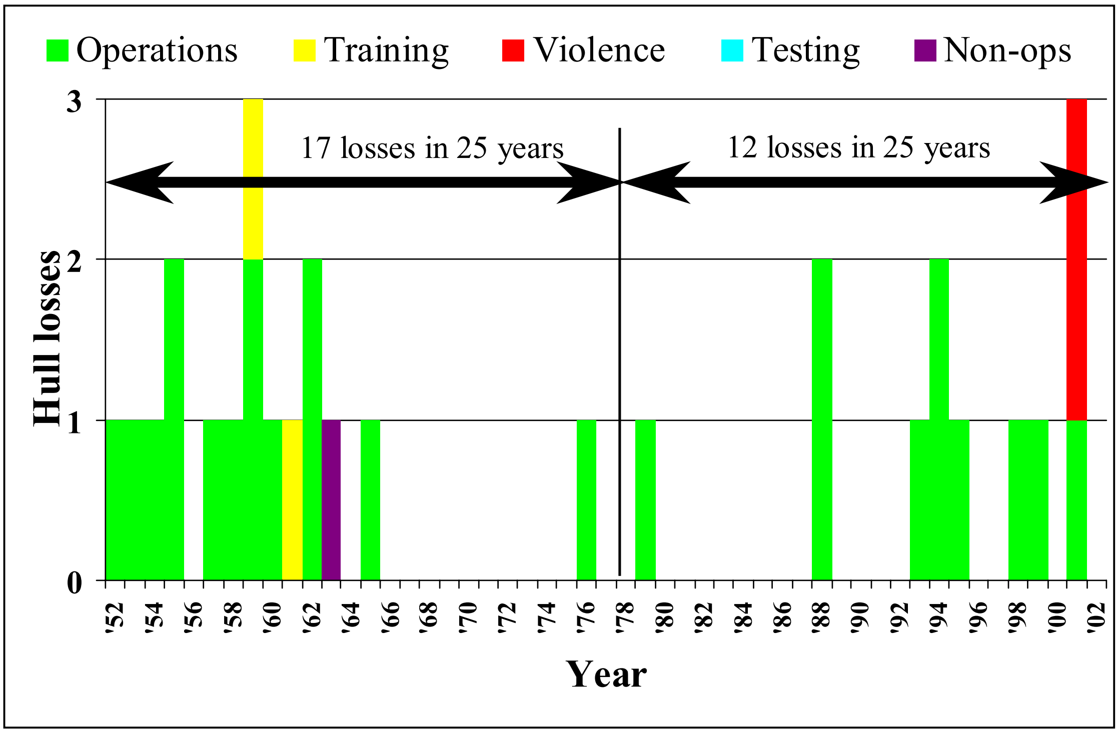
Figure 2 - British Airways hull losses by category between 1952 and 2002



Source: British Airways[7]

For comparison, Figure 3 shows the same information for American Airlines, which does not have an FDM programme.

Figure 3 - American Airlines hull losses by category between 1952 and 2002



Source: compiled by the author from various accident databases

Although some of the reduction in hull losses can be attributed to improvements in aircraft technology and pilot training, the improved operations resulting from British Airways' FDM programme have also played a part.

When comparing British Airways and American Airlines hull losses it is important to note that American Airlines has a fleet size more than twice that of British Airways and conducts twice as many air transport movements per year. It is significant, however, that in the last ten years, at least four of the hull losses have occurred during the approach or landing phases of flight. It is during these phases of flight that FDM programmes are acknowledged as being most beneficial in terms of improving operating procedures and hence safety.

The benefits of an FDM programme were highlighted by the Accident Investigation Board (AIB) which investigated the Gulf Air A320 accident to flight GF072 on 23 August 2000 near Bahrain International Airport. The final report stated that:

"Flight data analysis is a proven means to conduct regular safety analyses. Regular analysis of the flight parameters recorded by flight recorders, such as the digital AIDS[1] recorder (DAR), enables the study of trends in a wide spectrum of safety related areas of flight operations and maintenance practices. Such analysis provides valuable information indicating individual and general trends (such as: deviations from standard flight parameters, violations, etc.), that assists an airline in developing and updating its safety related policies.

In summary, at the time of the accident, the flight data analysis system was not functioning satisfactorily. Non-availability of flight data analysis deprived the airline of a valuable safety analysis tool."[8]

In its conclusions on the contributory factors to the accident the AIB noted the following factors:

"3.2 (1)(a) The captain did not adhere to a number of standard operating procedures

[1] Aircraft integrated data systems (AIDS)

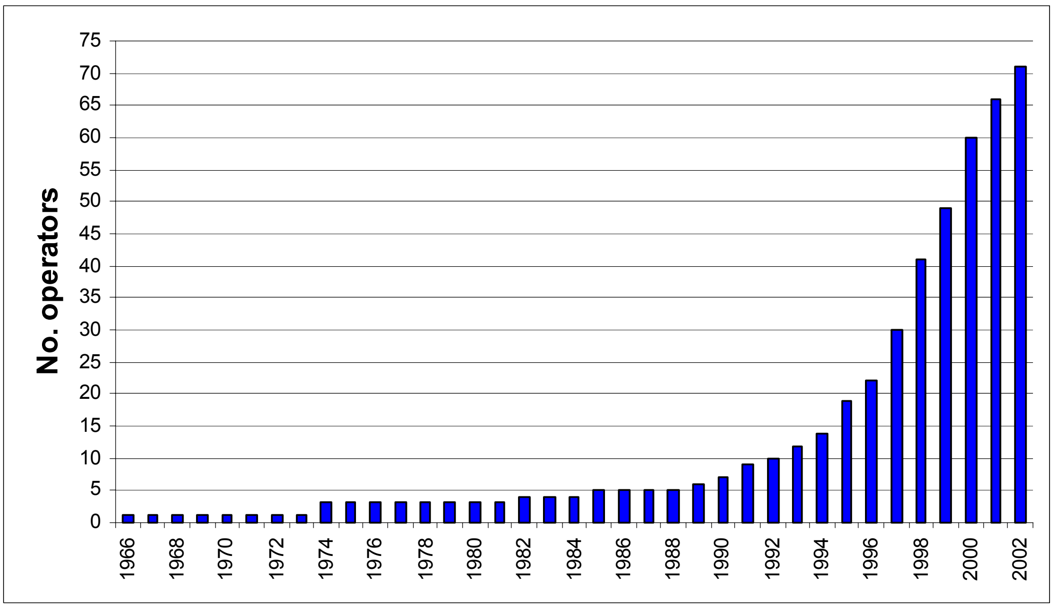
(SOPs); such as: significantly higher than standard aircraft speeds during the descent and the first approach; not stabilising the approach on the correct approach path; performing an orbit, a non-standard manoeuvre, close to the runway at low altitude; not performing the correct go-around procedure;

3.2 (2)(a)(iii) The airline's flight data analysis system was not functioning satisfactorily, and the flight safety department had a number of deficiencies."

Among the recommendations to the regulatory authority of Oman were that they ensure that Gulf Air reviews and improves the functioning and utilisation of the A320 flight data analysis system, in accordance with the regulatory requirements (recommendation B-01-6).

More airlines now recognise the benefits of an FDM programme and many operators now have such a programme in place. Appendix A lists the airlines which are known to have an FDM programme, together with the date when they first had software to run the FDM programme. Figure 4 below shows this information graphically and it can be seen that there has been a large increase in airlines implementing FDM programmes in the last five years. This is partly due to the ICAO recommendation (see section 2.3).

Figure 4 - Graph showing the growth in airlines with FDM programmes.



Source: compiled by the author

2.3 ICAO position on FDM programmes

Historically, FDM programs have been entirely voluntary. However, this is changing, as the safety benefits of FDM programmes become more widely recognised. Amendment 26 to Annex 6 – Operation of Aircraft, Part 1 of the ICAO Convention on Civil Aircraft states the following:[9]

3.6.2 From 1 January 2002, an operator of an aeroplane of a maximum certificated take-off mass (MCTOM) in excess of 20 000kg should establish and maintain a flight data analysis programme as part of its accident prevention and flight safety programme.

3.6.3 From 1 January 2005, an operator of an aeroplane of a MCTOM in excess of 27 000kg shall establish and maintain a flight data analysis programme as part of its accident prevention and flight safety programme.

3.6.4 A flight data analysis programme shall be non-punitive and contain adequate safeguards to protect the source(s) of the data.

The use of an FDM programme will thus become mandatory in many countries over the next few years. ICAO emphasises that the data should be used for flight safety purposes only and that the data analysis should be non-punitive. However, due to the wide variety of legal systems around the world each state should determine the most appropriate method of protecting an FDM programme in their own country and individual operators should establish internal safeguards to prevent abuse of their FDM programmes.

2.4 Regulatory position on FDM programmes

An FDM programme provides obvious safety benefits and it also fits in well with a pro-active safety management system, to provide assurance that safety levels are being met or improved. Furthermore, now that it is a recommended practice, any operator without a fully functional programme in place could be seen as not making "best endeavours" and hence culpable in the event of an incident or accident.[10]

The civil aviation authority in China was the first authority to mandate a flight quality monitoring programme, in response to a number of accidents to Chinese carriers in the early 1990s. Documents were issued in 1997 defining the technical requirements for the programme and giving an outline of how the monitoring programme should be run.[11]

The French civil aviation authority also issued an FDM requirement, which became mandatory in 2000. This applies to aircraft with a MCTOM over 10 000kg or with more than 19 seats and it is linked to JAR-OPS-1.037 which deals with accident prevention and flight safety programmes.[12]

The UK CAA supports the ICAO recommendations and extends them to include operators of aircraft under 27 000kg and helicopters. Data from British Airways' FDM programme is made available to the CAA under a research contract and the CAA uses this data in the following ways:[13]

- to continue improving FDM techniques.
- to give informed advice and guidance to operators.
- to give support for the UK's Mandatory Occurrence Reporting Scheme.
- to assist the formulation of airworthiness and operational requirements.

The US FAA supports FDM programmes but does not plan to make them mandatory. In its final rule on FDM programmes (known as FOQA programs in the United States) the FAA stated:[5]

"This final rule does not require any operator to implement a FOQA program, nor does it require any operator who desires to voluntarily implement such a program to obtain FAA approval to do so, or to submit FOQA information from such an internal program to the FAA."

The rule explains the protection that is available to airlines with FAA-approved FDM programmes and how they can qualify for this protection:

"This rule codifies enforcement protection for FOQA programs. It states that except for criminal or deliberate acts, the Administrator will not use an operator's FOQA data or aggregate FOQA data in an enforcement action against that operator or its employees when such FOQA data or aggregate FOQA data is obtained from a FOQA program that is approved by the Administrator."

"However, in order to qualify for the enforcement protection afforded by this rule, the rule provides that FAA initial and continuing approval of the proposed program would be required, as well as the submission of aggregate FOQA information to the FAA."

The FAA sees benefits from an FDM programme because it provides information on the national aviation system to allow the assessment of the safety and efficacy of the operational use of the national airspace, it generates empirical data that can be used to evaluate new programmes and it serves as a catalyst for voluntary information exchanges.[14]

Airlines are not generally required to submit findings from their FDM programmes to their relevant regulatory authority. The exception to this rule is in China where the airlines are required to submit their monitoring results to the relevant government department.[11] However, other airlines such as British Airways, KLM and TAP Air Portugal produce summary documents for their management and these documents are also sent to their regulators. Lufthansa and Air France, on the other hand, do not provide any FDM information to their respective regulators.[15]

From a regulatory point of view, only the Chinese CAA currently requires the submission of FDM bulletins produced by airlines for communication of FDM issues. However, the Swiss CAA requests a copy of FDM-related safety bulletins as part of their auditing system and the French, Irish and UK CAA would like to receive information regarding lessons learnt, rather than detailed data, from the FDM programme, in order to disseminate this to other operators. As noted above, the FAA requires data submission from carriers with FAA-approved FDM programmes.

2.5 Implementing and running an FDM programme

Implementing and running an FDM programme requires an airline to have a system and documented procedures in place to achieve the following:

- Continuously record up to several hundred flight parameters from aircraft systems and sensors. This may entail equipping aircraft with specialised recording devices known as quick access recorders (QARs).
- Physically transfer the QAR recording media to a suitable location for replay and analysis.
- Transcribe the data recorded on the QAR media into a format which is suitable for further analysis.
- Analyse the transcribed data to identify individual flights, establish phases of flight (such as taxi, take-off, cruise, descent, approach, landing) and identify abnormal events or departures from defined limits (known as exceedances).
- Generate reports and graphs to assist personnel in interpreting the results of the analysis.
- Keep a record of previous events so that trends over time can be determined.

The details of an FDM programme will be described in depth in Chapter 3.

3 Explanation of FDM

3.1 Capturing flight data on aircraft

Aircraft have several systems in them, such as propulsion, navigation, autopilot, communication and flight control systems. These systems contain a vast amount of information relating to the aircraft and its flight, for example throttle position, fuel flow, engine temperature, compass heading, altitude, pitch angle, roll angle, airspeed, elevator position and hundreds of others. These items of information are known as parameters and most are presented to the flight crew in the cockpit.

The parameters all pass through the aircraft's data acquisition unit (DAU) for processing and formatting. This unit has a variety of proprietary names, depending on the manufacturer, for instance Flight Data Interface Unit (FDIU), Data Management Unit (DMU), Flight Data Management Unit (FDMU), Flight Data Acquisition Unit (FDAU), Flight Data Acquisition & Management System (FDAMS), Digital FDMU (DFDMU) and Digital FDAU (DFDAU).

Software in the DAU determines what parameters are captured, how many times per second they are recorded and how all the parameters are put together into a data frame. A single data frame consists of four seconds of encoded flight data. The data frame is made up of four subframes, each one second long, and each subframe is made up of a number of data words. A data word contains the binary value of the aircraft parameter in question and there can be 64, 128, 256 or 512 words per subframe.

The first data word in each subframe is a synchronisation word and it is a unique code for each of the four subframes. Thus, each data frame begins with a specific combination of four subframe synchronisation words. This specific combination is repeated for every single data frame and it is used to identify where a new data frame begins. In theory, all the data words in a particular subframe could record different parameters, that is up to 512 different parameters per subframe. In practice, if a parameter is sampled more than once a second it will appear more than once in each subframe. Similarly, each of the four subframes can, in theory, record a completely different set of data words to each other. In practice, many parameters are sampled once a second so they will appear in each subframe. Others, such as certain engine parameters, are only sampled once every two seconds or even once every four seconds. They will not, therefore, appear in every single data frame.

The layout of a data frame is shown diagrammatically in Figure 5 below.

Figure 5 - Representation of a single data frame output from a DAU

	DATA FRAME			
	Subframe 1	**Subframe 2**	**Subframe 3**	**Subframe 4**
Data Word	**1st second**	**2nd second**	**3rd second**	**4th second**
1	Sync Word 1	Sync Word 2	Sync Word 3	Sync Word 4
2	Heading	Heading	Heading	Heading
3	Pitch Att	Roll Att	Pitch Att	Roll Att
4	Vertical G	Vertical G	Vertical G	Vertical G
	⋮	⋮	⋮	⋮
12	Vertical G	Vertical G	Vertical G	Vertical G
	⋮	⋮	⋮	⋮
256	Fuel Flow Engine #1	Fuel Flow Engine #2	Fuel Flow Engine #3	Fuel Flow Engine #4

Source: Spirent Systems

This example shows that the following information:

- The first data word in each subframe contains a unique synchronisation word
- The second data word in each subframe contains the aircraft's heading which is sampled every second
- The third data word in the first and third subframes records the aircraft's pitch attitude whilst in the second and fourth subframes it records the aircraft's roll attitude. This indicates that pitch and roll attitude are sampled every two seconds.
- The fourth and twelfth data words in each subframe record the aircraft's vertical acceleration. This indicates that vertical acceleration is sampled twice every second.

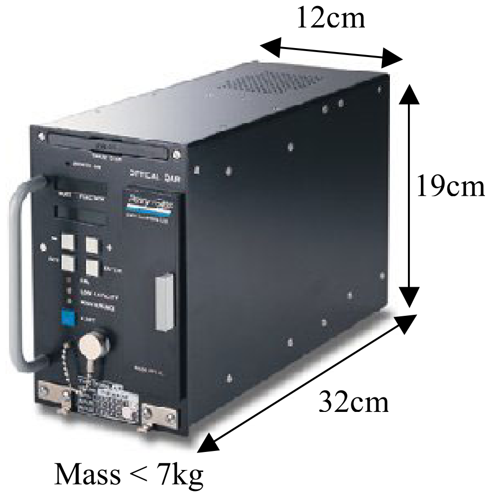
- The last data word, number 256 in this example, records the fuel flow to each engine in turn. Thus, for this four-engined aircraft, the fuel flow to a particular engine is sampled once every four seconds.

Once the DAU has processed and packaged the data into a frame, the frame is output to the FDR. The data acquired by the DAU can also be output to a QAR. The QAR can be configured to record far more parameters than the legal minimum required for the FDR. Typically, the QAR is located in the cockpit or electronics bay of the aircraft and the data frames are recorded on to a magneto-optical (MO) disk or Personal Computer Memory Card International Association (PCMCIA) cards, commonly known as PC cards. Early QARs recorded data on to tape cartridges and although these are still in widespread use in the industry, new aircraft generally use MO disks or PC cards as the recording medium. The recording media used by QARs and the location of the QARs in the aircraft make it easier to access and remove the flight data from the unit, hence the name quick access recorder.

However, it is not mandatory to have a QAR fitted to an aircraft. Early generation jet aircraft such as Boeing 727, McDonnell-Douglas DC-9, Airbus A300 and aircraft built through the 1990s are unlikely to be equipped with QARs, unless this was specifically requested by the airline and supplied as part of the buyer-furnished equipment. New aircraft delivered to airlines will typically be fitted with some kind of QAR as part of the standard equipment.

Figure 6 shows an optical QAR (OQAR), so-called because it records data on to MO disks.

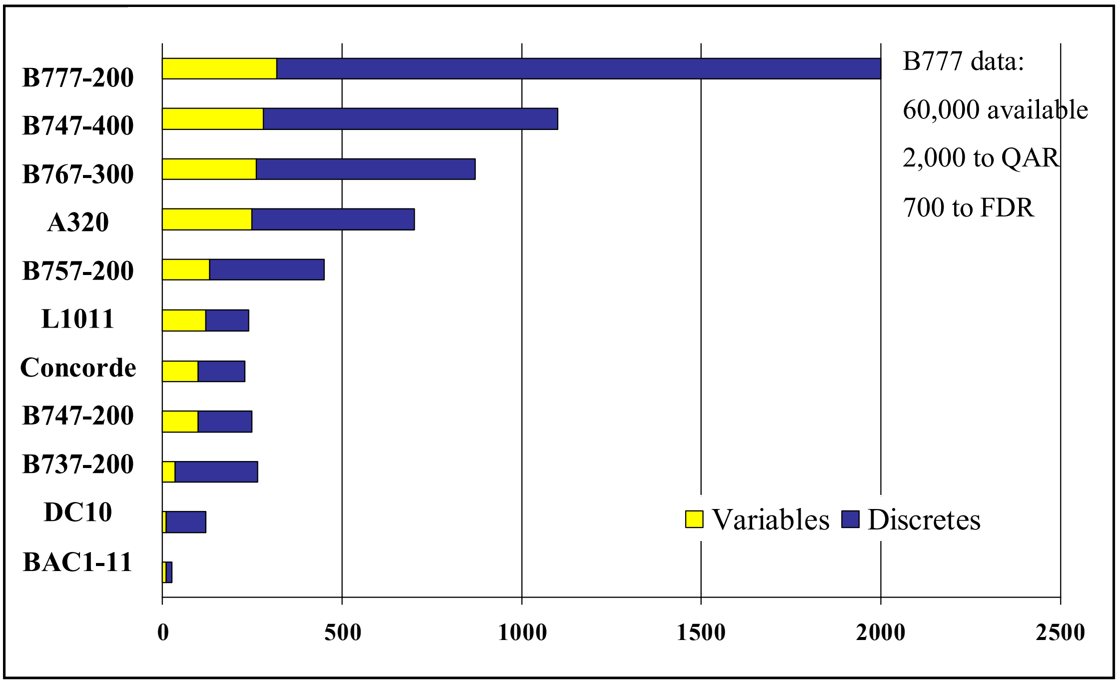
Figure 6 - Picture of an OQAR



Source: Penny and Giles[16]

Airlines can choose what parameters they want to be recorded on the QAR and this can range from a few hundred parameters for early generation aircraft like the Boeing 757 to over a thousand parameters on new generation aircraft like the Boeing 777. Figure 7 below gives an indication of the number of parameters that are recorded by the QAR on different aircraft in British Airways' fleet.

Figure 7 - Number of QAR parameters recorded by fleet type at British Airways



Source: British Airways[7]

The data for an FDM programme can thus be captured either by an FDR or a QAR. The principle advantage of using data captured on the FDR is that the recording system is already required on all transport aircraft so there are no additional costs in acquiring new hardware for this element of the FDM programme.

However, FDRs are not designed or located for frequent access and downloads of the data. This would make it time-consuming to download the data regularly and could also cause additional wear on the FDR requiring increased maintenance. (If it was a solid state FDR (SSFDR) the data would be recorded on to integrated circuits rather than tapes, making it easier to download, although access would still be difficult.)

Another factor is that FDRs are not currently required to record a large number of parameters. The 1997 FAA flight recorder rule states that aircraft, seating 20 or more passengers, which are manufactured after August 18 2002, must have FDRs which record a minimum of 88 parameters, out of the thousands which are now available on modern aircraft. Aircraft manufactured before this date have even lower minimum limits.[17]

Finally, the most advanced FDRs can currently store only 25 hours of flight data compared with up to 960 hours of data which can be stored on a QAR. Thus, using the FDR for an FDM programme would necessitate far more frequent data downloads with an associated increase in manpower costs.

For the reasons outlined above FDM programmes are usually run with QARs. However, airlines may choose to use a combination of capturing data with FDRs or QARs depending on the mix of aircraft they operate, the planned life of the aircraft with the airline and the ownership of the aircraft.

The next stage in an FDM programme involves downloading the flight data recorded on the aircraft so that it can be taken to a ground facility for analysis. This is discussed in section 3.2.

3.2 Downloading flight data from aircraft

In the majority of FDM programmes the flight data is downloaded from either the FDR or the QAR.

If a QAR is used, downloading the data involves physically removing the recording medium (tape, MO disk or PC card) from the QAR and replacing it with another one. This can be done during a normal turnaround and takes around half a man-hour, including collecting the new tape, disk or card from stores, replacing it on the aircraft and completing the associated entry in the aircraft's technical log.

If the data is downloaded from the FDR this will most probably be done while the FDR is still on the aircraft. Alternatively, the FDR can be removed from the aircraft and sent to a workshop where the data can be downloaded. However, due to the limited data capacity on the FDR, data downloading will have to be carried out very regularly. If the FDR is removed every time the data is to be downloaded, this will necessitate frequent removals of the FDR which is undesirable from a reliability and logistics point of view. Thus, it is better to download data directly from the FDR whilst it is still on the aircraft. Whether the procedure is carried out on the aircraft or in a workshop, it will require an interface unit which can be connected to that particular type of FDR. This unit will typically download the data on to a PC card, although with some download units it is possible to send the data electronically to the analysis facility, without the need for PC cards.

One vendor supplies a unit to download FDR data directly on the aircraft. The unit can only be used with one aircraft at a time so it may be necessary to have more than one unit, depending on the size of the airline's fleet and the frequency of downloads. Alternatively, the vendor can supply a desktop interface for replaying FDRs in a workshop environment. Once again, the total number needed would depend on the total fleet size, the number of spare FDRs and the time that the FDR is available in the workshop.

An alternative to downloading data from either the QAR or FDR is available on aircraft with a newer type of DAU. This newer DAU has the facility to record flight data directly on to a PC card housed within the DAU, in addition to outputting data to the FDR and a QAR if necessary. Thus data can be downloaded from the aircraft simply by removing the PC card from the DAU, in a similar manner to the QAR.

The data downloads typically take place every three to twenty days.

3.3 Transferring flight data to an analysis centre

Most airlines will have a single facility where they replay the flight data from their aircraft and perform further analyses on the data. The media that the data is recorded on thus need to be sent from the aircraft's location to the analysis centre. This is usually achieved via secure internal company mail, due to the sensitive nature of the data. In order to aid this process, data downloads are usually only performed when the aircraft is at the airport closest to the analysis centre.

At Virgin Atlantic, staff from the airline's headquarters have to visit every aircraft at least once every week to update the documentation on the aircraft. Part of the duties of these staff include collecting any MO disks which have been removed from the aircraft and returning them to the analysis facility at the airline's headquarters.

It is also possible to transfer data electronically from remote sites, for example line stations or main hangars, to the analysis centre. In order to do this, though, the data must be encrypted to protect it and the transmission line must be secure.

3.4 Replaying flight data

Once the raw data is at the analysis facility, usually on a QAR tape, MO disk or PC card, it must be replayed to convert it from binary data into engineering units, for example to change the binary number 000011101011 into the decimal number 235, which might represent the aircraft's indicated airspeed in knots. To perform this conversion, it is necessary to know where each data frame begins on the recording (this is identified by the combination of the four unique subframe synchronisation codes, as described in section 3.1), how many words each frame contains, what parameters are recorded, what their sampling rate is and what conversions or equations were used in recording the parameters.

This replay and conversion is carried out by software which must be purchased from a vendor. The software is customised for each airline and has specific modules to deal with each fleet in the airline, since different aircraft will have different data frame layouts.

As part of this replaying process, the data is checked for errors or anomalies and bad or inconsistent data is noted and filtered out. Once the raw data has been converted into engineering units it is further analysed by the software as described in the next section.

There are several companies which provide the replay software and the cost of the software will depend largely on how much analysis the airline wishes to perform. The airline may also have to invest in new computer hardware to run the software efficiently, as well as storage facilities to archive the flight data.

Any new aircraft types introduced by the airline will have to be included in the FDM programme which will mean buying in additional software modules to analyse the data from their recorders. For these purposes, aircraft which are stretched or shortened models of a basic airframe would be considered a different fleet type. Thus, the Airbus A321 would require a different software module to the Airbus A320. Other software modules can be purchased to perform analyses of engine data and aircraft performance data.

When the analysis software is first bought, the FDM users will need to be trained in its use. The level of training required depends on the sophistication of the software being purchased but typical training courses run from three to ten days.

On top of this, there is usually an ongoing maintenance support contract in order to rectify specific problems encountered by the airline, provide software upgrades to the airline as they are issued and assist with any queries the customer may have.

Typically, the annual maintenance and support fee is between 10% and 20% of the price of the replay software.

3.5 Analysing flight data

Once the data is in engineering units it can be further analysed to determine if certain parameters have exceeded pre-determined limits. Such exceedances are known as events and examples include:

- high descent rate below an altitude of 400ft
- approach speed low below an altitude of 50ft
- unstick speed high
- maximum operating altitude exceedance
- late selection of flaps to landing configuration
- high normal acceleration on the ground (hard landing)
- engine over-temperature
- excessive bank angles
- deviation from glidepath

There can be over 100 such events defined by an airline and these must be checked for every flight of every aircraft. Thus the only way to do this practically is through using computer software which searches through specified parameters in the flight data and checks if the limits have been exceeded. These limits can be specified by the airline and changed when required.

Following this analysis, any events which have been identified by the software are highlighted and stored for further analysis. The remaining data can be archived if the airline needs it or else it is simply deleted from the QAR recording medium which can then be used again on the aircraft. At some airlines the policy is to retain flight data from the FDM programme, including that relating to individual events, for thirty days.[18]

The events detected by the software are presented to the FDM analyst who then has to confirm that the events are genuine and not due to bad data or circumstances particular to that flight. For instance, on certain approaches into New York, the aircraft is deliberately flown with a certain deviation from the instrument landing system (ILS) approach. This deviation is detected as an abnormal event because it can be a precursor to a landing accident. However, if the analyst sees that such an event has been detected on this particular New York approach then the event can be discarded as invalid.

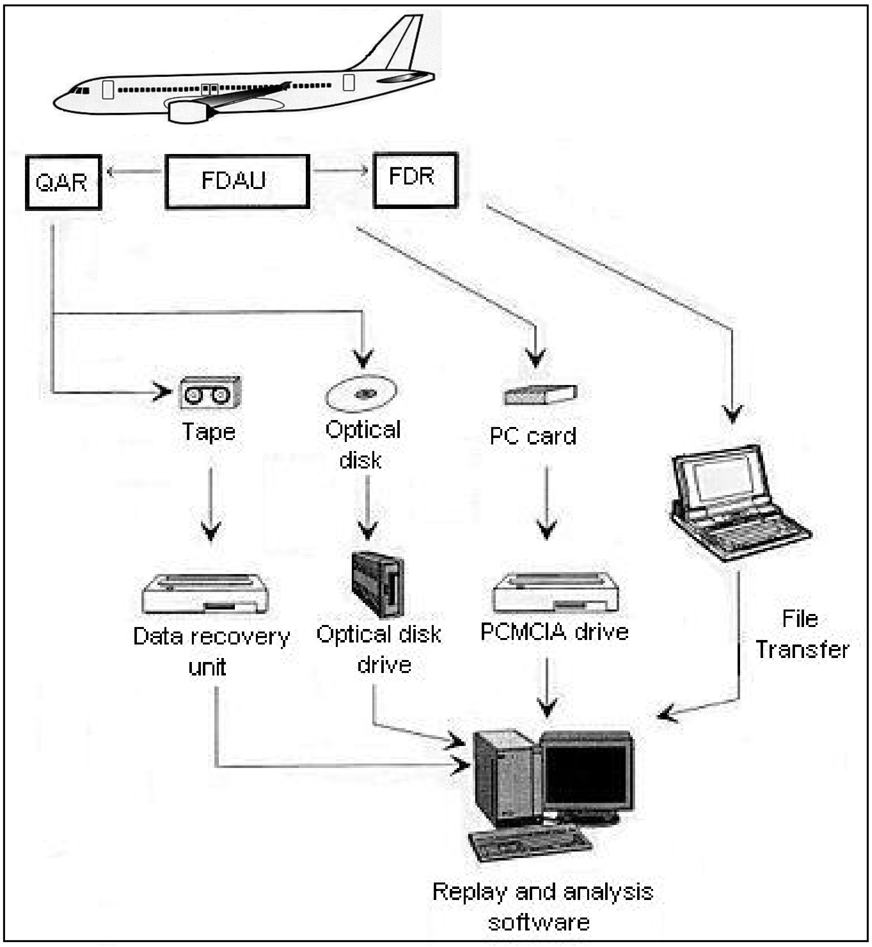
Any events which have been detected and validated by the FDM analyst are stored in a database. If the event is serious, data from the analysis may be used to support an internal investigation, possibly in conjunction with an air safety report (ASR) which has already been raised for the event. The database of events can be used to monitor trends, for instance, if a certain fleet of aircraft is experiencing a particular event, such as a hard landing, more frequently than other fleets.

FDM analysts may also be required to produce periodical bulletins or reports for various departments as well as investigating other ways to use the data in order to maximise the benefit from the FDM programme. This manpower requirement is usually the most significant on-going cost item in an FDM programme.

Finally, flight data can be used to recreate a flight on a computer, providing visualisation of the cockpit instruments and three dimensional external views of the aircraft's flight. This is useful for training purposes and also in investigating serious events or incidents.

The FDM process is summarised in Figure 8 below.

Figure 8 - Overview of FDM programme



Source: Sagem[19]

3.6 Practical considerations of FDM programmes

In practice, an airline will typically have a small group of employees in its safety or quality departments whose duties include running the FDM programme. The FDM programme should be part of a broader safety management system within the airline. The flight data, and particularly records of any abnormal events, are normally considered sensitive in nature so the data is often de-identified. This means masking any information which could lead to identification of the flight or its cockpit crew, such as flight number, date, commander’s name, airport code and aircraft registration.

The flight data is considered confidential and access to it is limited. In case further action needs to be taken against a pilot, such as extra training measures, there is usually a pilot union representative involved with the FDM programme. The airline’s pilot union will usually have a documented policy regarding the use of data obtained from an FDM programme.

Different personnel involved with the FDM programme will have different levels of access to the flight data. The FDM programme manager will normally have full access to all the data, including the identity of particular flights, and this person will also be able to set privilege levels for other users. Other members may be allowed to edit certain data or they may be restricted to only viewing de-identified data.

3.7 Hardware and software requirements of FDM programmes

The following are the main hardware and software requirements for an FDM programme:

- a data recorder on every aircraft in the fleet (either an FDR or QAR).
- sufficient QAR media to replace the ones being analysed or an interface unit to download data directly from the FDR.
- a replaying device capable of replaying all the different types of QAR media. This may be a separate device or a special drive on a standard computer.
- software to replay the QAR media or download the data from the FDR
- software to analyse the flight data and identify exceedances.
- computer storage space to archive data and maintain a database of events.

3.8 Manpower requirements of FDM programmes

The main requirements for manpower occur in:

- the removal of the recording media from the QAR and replacing them again; or the downloading of data directly from the FDR on board the aircraft
- transporting the QAR media or stored FDR data to the analysis facility
- loading the QAR media for analysis or transferring the FDR data to the analysis system
- analysing the final output from the software package to determine if events are genuine and understanding the causes behind them. This analysis can be very detailed, especially if further reports have to be written.

3.9 Suppliers and customers of FDM programs

There are several companies that provide hardware, software or services relating to FDM programmes and these are summarised in Table 1 and Table 2.

Table 1 - Comparison of main FDM hardware suppliers

Company	DAU	FDR	FDR download device	QAR
Austin Digital	✗	✗	✓	✗
Avionica	✗	✗	✓	✓
BAE Systems	✓	✓	✗	✓
Honeywell	✓	✓	✓	✗
ILSC[2]	✓	✓	✓	✗
L3 Communications	✗	✓	✓	✗
Penny & Giles	✗	✓	✓	✓
Sagem	✓	✓	✗	✓
Smiths Aerospace	✓	✓	✓	✗
Spirent Systems	✗	✗	✓	✗
Teledyne	✓	✗	✗	✓

Table 2 - Comparison of main FDM software suppliers

Company	Replay data	Analyse data	Event database	Data visualisation
Airbus (LOMS)[3]	✓	✓	✓	✓
Austin Digital	✓	✓	✓	✗
Avionica	✓	✓[4]	✗	✗
BASIS[5] (British Airways)	✓	✓	✓	✓
Flight Data Services	✓	✓	✓	✗
Flightscape	✓	✓	✗	✓
Honeywell	✓[6]	✓	✗	✗
L3 Communications	✓	✓	✗	✗
Sagem	✓	✓	✓	✗
SimAuthor	✗	✗	✗	✓
Smiths Aerospace	✓	✗	✗	✗
Spirent Systems	✓	✓	✓	✓
SystemWare	✓	✓	✗	✓
Teledyne Controls	✓	✓	✓	✗

[2] International Logistics Support Corporation (ILSC) bought the flight data recorder line of business from Lockheed Martin Aeronautics Company in February 2002.

[3] Line Operations Monitoring System (LOMS)

[4] Avionica had a product which could perform trend analyses but this has now been withdrawn from the market and they promote and sell Sagem software instead.

[5] British Airways Safety Information System

[6] Honeywell is no longer offering its analysis software on the market.

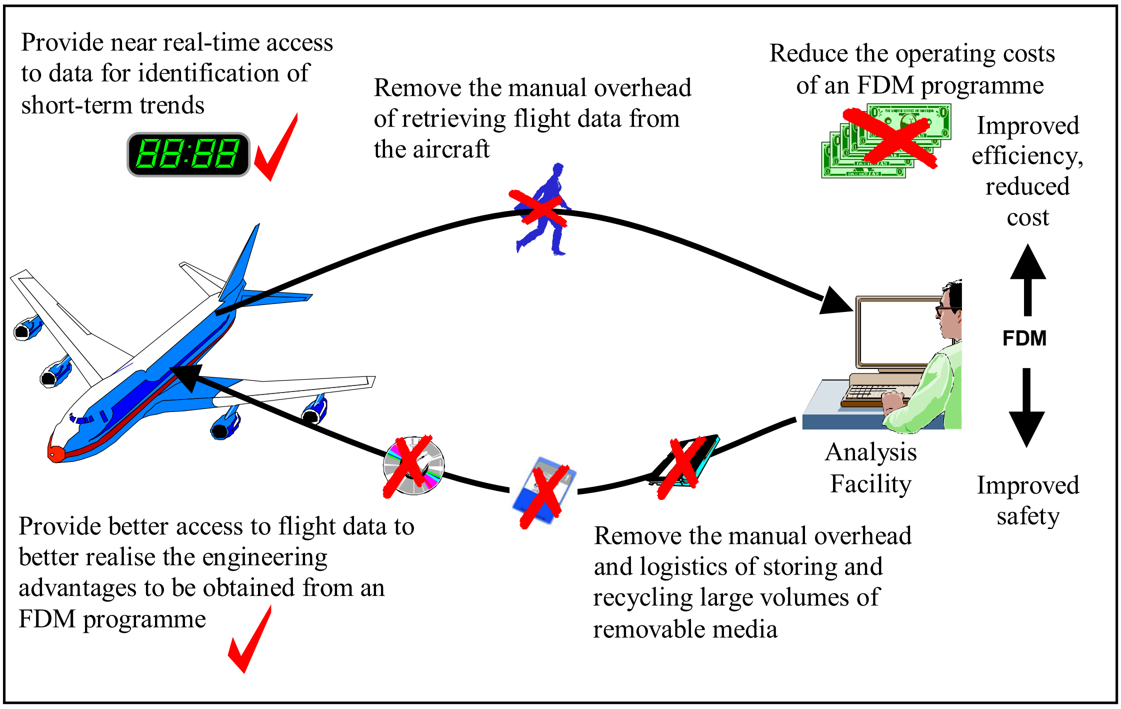
3.10 Future improvements to FDM programmes

One of the difficulties in running an FDM programme efficiently is that large volumes of data have to be recorded and transported from the aircraft to the analysis facility on a regular basis. The use of QARs and tapes, MO disks or PC cards to achieve this is costly and results in a logistics overhead to manage the process.

One FDM hardware manufacturer has developed a system which removes this overhead. The system replaces the QAR with a more advanced version which is capable of transmitting recorded flight data wirelessly. It uses existing cellular networks for mobile telephones and transmits the data through an antenna built into the QAR. This means that no modifications are required to the aircraft and no receivers or fibre optic links need to be installed at airports. The data is then transferred securely over the internet to the airline's analysis facility.

The advantages of this system are that it eliminates the manpower, logistics and cost overheads of manually removing recording media from QARs and transporting them between the aircraft and the analysis centre. Data can be downloaded immediately after every flight, rather than several days later, thus improving the effectiveness of the FDM programme. Also, the risk of losing data due to faulty QARs or damaged recording media is reduced. This is summarised in Figure 9 below.

Figure 9 - Summary of the benefits of using wireless data transfer in an FDM programme



Source: Penny and Giles Aerospace[20]

4 Costs

4.1 Overview of main cost items

The main components of cost in an FDM programme are the cost of the physical equipment, such as QARs, recording media and computers for analysis, the cost of the replay and analysis software, the cost of training and the cost of the manpower. The implementation costs can be substantial, particularly for major international airlines with large fleets.

Once the programme has been established, however, a major carrier is likely to find that the manpower cost proves to be the most significant long-term item, as they will typically need one full-time FDM analyst for every fifteen to twenty aircraft in the fleet. Smaller regional airlines, on the other hand, may find that the ongoing manpower costs are of similar magnitude to the cost of consumables, staff training and software support.

An international European airline has estimated the breakdown of their on-going FDM costs as follows:

a) Personnel - 80%
b) Software - 10%
c) Hardware - 5%
d) Administrative overhead - 5%

The costs of an FDM programme can broadly be considered in two categories:

1. the cost of the technology to capture and automatically analyse the flight data
2. the cost of the manpower needed to run the FDM programme

Clearly, the total cost of an FDM programme will also be affected by the number of aircraft the airline operates and the mix of fleet types. The two components of cost identified above are examined in detail in the following sections.

4.2 Capturing flight data on aircraft

In the majority of FDM programmes, data is captured with a QAR. If the aircraft in an airline's fleet are not already equipped with QARs then the installation of them will entail the following costs:

- cost of purchasing the QARs
- aircraft downtime to install the QARs. This may be incorporated into existing maintenance downtime but there will still be the additional man-hours required to install the system.
- cost of spares and extra recording media (tapes, MO disks, PC cards).

A typical QAR would cost from USD 10 000 to USD 20 000, depending on the total quantity being purchased and the configuration required. One QAR unit would be required for each aircraft plus sufficient spares to cover unserviceability of the QARs.

The time and cost to install a QAR will vary depending on the generation of the aircraft. Modern aircraft are manufactured with a slot in which a QAR can be fitted and on these aircraft installation is simply a matter of slotting the QAR into the rack. On older generation aircraft, however, it will be necessary to alter the wiring in the aircraft and build in a rack for the QAR. Apart from the time for the physical installation there is also the time required to design and certify the modifications. This represents a significant cost, estimated at between USD 25 000 and 50 000.[39]

The approximate costs of the recording media used in QARs are as follows:

- MO disk - USD 5
- QAR tape - USD 20
- PC card - USD 350.

A large airline will require several hundred tapes, MO disks or PC cards to support its fleet. Between five and ten tapes or disks per aircraft is usual, as this provides a buffer in the system and allows for delays in the running of the FDM programme.

Typical costs for this part of an FDM programme are summarised in Table 3 below. These are calculated for an airline which has twenty aircraft which have not been delivered with QARs but which have been manufactured with the ability to fit them. Two hundred MO disks are used to support the programme.

Table 3 - Typical costs of an FDM programme: part 1

Section	Element of FDM	Cost (USD)
4.2	Purchasing QARs	300 000
	Installation of QARs	2 500
	Purchasing MO disks	1 000
	Total	**303 500**

4.3 Downloading flight data from aircraft

Assuming the flight data is captured on a QAR, downloading the data is simply a matter of removing the recording media from the QAR and replacing it. This typically takes half a man-hour. At one international British airline maintenance costs are calculated at USD 65 per hour. Therefore, a typical cost for this part of an FDM programme would be around USD 40 000, assuming the recording media are removed every five to seven days and a fleet size of twenty aircraft. This is shown in Table 4.

Table 4 - Typical costs of an FDM programme: part 2

Section	Element of FDM	Cost (USD)
4.2	Purchasing QARs	300 000
	Installation of QARs	2 500
	Purchasing MO disks	1 000
4.3	Downloading data	40 000
	Total	**343 500**

4.4 Transferring flight data to an analysis centre

It is assumed that this will be achieved as part of the normal maintenance or operational activities that are in existence at the airline. Thus there will be no extra cost incurred during this phase of the FDM programme.

4.5 Replaying flight data

The main elements of cost involved with the replaying of data are as follows:

- computer hardware
- replay software
- staff training
- support contract

Most FDM programmes can be run on standard computer hardware. A suitable system can be purchased for under USD 3 000. The cost of the replay software can range from USD 65 000 to 200 000 per licence, depending on the number of fleet types, the level of analysis and the vendor. Training costs range between USD 500 and 1 200 per day, depending on the length of the overall training period. The support contract is an annual fee and is typically 15% of the cost of the software. These costs are summarised in Table 5 below.

Table 5 - Typical costs of an FDM programme: part 3

Section	Element of FDM	Cost (USD)
4.2	Purchasing QARs	300 000
	Installation of QARs	2 500
	Purchasing MO disks	1 000
4.3	Downloading data	40 000
4.5	Computer hardware	3 000
	Replay software	150 000
	Staff training	5 000
	Support contract	22 500
	Total	**524 000**

4.6 Analysing flight data

As an example of the manpower required during the analysis, at one British carrier approximately 1 000 flights are analysed each month. On average, one event is detected per flight (although in practice many flights will have no events and a few flights will have several events.) The analyst must briefly validate each event to determine if it is legitimate. An analyst can validate around three events a minute on average, so the validation of all these events takes around 5.5 hours per month.

Once the events have been validated some of them will require more detailed investigation. Approximately one in ten events will need to be studied in more detail and such analysis would typically take around twenty minutes per event. This gives rise to about 33 hours of analysis per month. Thus the event validation and detailed analysis take 38.5 hours per month which is equivalent to one working week.

The replay of each MO disk takes about twenty minutes and this operator receives at least one disk from each aircraft every week. Thus, there are around one hundred disks to replay each month which takes around 33 hours, equivalent to approximately another working week in terms of man-hours. In practice, other work can be carried out whilst the disk is being replayed so there is some overlap.

Apart from this basic replay work, an analyst will also have to prepare news bulletins on the findings from the FDM programme, arrange regular meetings with interested parties and liaise with a number of other departments to obtain and share information. That is why an airline with a fleet of over twenty aircraft will need at least one full-time FDM analyst to run the programme. Such an analyst could expect to earn a salary of at least USD 45 000. The total costs for setting up and running an FDM programme for one year are summarised in Table 6.

Table 6 - Typical costs of an FDM programme: part 4

Section	Element of FDM	Cost (USD)
4.2	Purchasing QARs	300 000
	Installation of QARs	2 500
	Purchasing MO disks	1 000
4.3	Downloading data	40 000
4.5	Computer hardware	3 000
	Replay software	150 000
	Staff training	5 000
	Support contract	22 500
4.6	FDM analyst salary	45 000
	Total	**569 000**

4.7 Start-up and recurring costs

The estimated cost of USD 569 000 quoted above is made up of costs which are incurred at the start of an FDM programme as well as costs that occur regularly throughout the programme. It is therefore useful to consider the costs in the following two categories: start-up cost and recurring costs.[21]

4.7.1 Start-up costs

These relate to one-time costs for initially setting up an FDM programme or introducing new aircraft types into the programme. Such costs would include:

- cost of hardware to be installed on aircraft, such as QARs and any necessary cables or mountings.
- cost of modifications to the aircraft. This will be incurred if an older generation aircraft type is being fitted with a QAR and the airline is required to seek a supplemental type certificate (STC) for the aircraft as a result of the modification work required to fit a QAR.
- labour costs during installation of the equipment on the aircraft.
- loss of revenue due to the aircraft downtime during installation of the equipment.
- cost of other hardware required for the FDM programme, such as a unit to download data directly from FDRs, computer hardware to run the software for replaying and analysing flight data.
- cost of the replay and analysis software, including specific software modules for each aircraft type.
- initial training of FDM staff.

4.7.2 Recurring costs

These relate mainly to the manpower costs in running an FDM programme and include:

- salaries for full time and part time FDM staff.
- additional training either for new FDM staff or for new software in the FDM programme.

- engineering and maintenance costs associated with the FDM equipment, such as inspections and overhauls of QARs and man-hours for downloading data or removing FDRs or QAR recording media.
- logistics costs for transporting recording media, such as MO disks or PC cards, securely to and from the analysis centre.
- cost of consumables such as the QAR recording media and office supplies in the FDM department.

Table 7 is derived from Table 6 and shows a comparison between the start-up costs and the significant recurring costs. The start-up costs include the one-off installation and set-up costs as well as the recurring costs in the first year, and are called the first year costs.

Table 7 – Comparison of first year costs versus recurring costs of an FDM programme

Section	Element of FDM	First year costs (USD)	Annual Cost (USD)
4.2	Purchasing QARs	300 000	-
	Installation of QARs	2 500	-
	Purchasing MO disks	1 000	-
4.3	Downloading data	40 000	40 000
4.5	Computer hardware	3 000	-
	Replay software	150 000	-
	Staff training	5 000	-
	Support contract	22 500	22 500
4.6	FDM analyst salary	45 000	45 000
	Total	**569 000**	**107 500**

4.8 FAA estimate of FDM costs

As part of their FDM demonstration project DEMOPROJ the FAA estimated the costs to airlines in setting up an FDM programme. The estimate covered the cost of equipping 15, 50 and 100 aircraft with QARs, the cost of purchasing a software analysis system and the cost of salaries for FDM staff. The equipment costs were based on the prices paid to vendors in the actual project and they were amortised over five years in order to obtain annual estimates. The staff costs were based on costs from one of the airlines which participated in DEMOPROJ.[22] The results are summarised in Table 8 below.

Table 8 – FAA estimated total annual costs by fleet size for an airline setting up an FDM programme.

Fleet size (no. aircraft)	**15**	**50**	**100**
Equipment costs (USD)	98 500	259 000	492 000
Personnel costs (USD)	385 000	500 000	775 000
Total annual costs (USD)	**483 500**	**759 000**	**1 267 000**

The figures are from 1997 so they are somewhat lower than the calculation above. However, they are of the same magnitude, although the cost breakdown is different. This difference arises from spreading the initial set-up costs over five years and, it is believed, from using higher staff salaries.

4.9 Effect of aircraft size and fleet size on FDM costs

From the above analysis it is apparent that the costs of setting up and running an FDM programme are independent of the size of the aircraft. Thus, a regional airline operating a fleet of twenty Fokker 50s will incur virtually the same costs as an international airline with a fleet of twenty Boeing 747s. This is a disadvantage to the regional airline as the costs become a more significant element of their revenue. For the international airline, the costs are minimal, especially when compared to expenditure in other areas such as in-flight entertainment.

As an airline grows, more flight data will be generated and it will be necessary to add staff to the FDM programme in order to run it effectively. This could entail extra training costs, possibly another licence for the replay and analysis software as well as the salary of the new FDM analyst. In terms of hardware, more QARs and recording media would need to be purchased, and possibly additional computer hardware.

5 Benefits

5.1 Overview

The principal benefit of an FDM programme has traditionally been perceived as improved safety in flight operations. However, other benefits arise from the additional data available on aircraft and engine systems. This additional data allows the airlines to optimise the operating characteristics of its aircraft, such as fuel consumption, while avoiding unplanned costs such as unnecessary engine maintenance.

Transport Canada's Transportation Development Centre identified some further savings in the areas of maintenance, warranty claims, reduced insurance premiums and increased aircraft availability as well as improved pilot training programmes and operating procedures. [23]

5.2 Main benefits

The benefits can be classified into two areas: safety benefits and cost benefits.

5.2.1 Safety benefits

Safety benefits arise from the increased level of knowledge an airline has of how its aircraft are being operated. The detailed data available from an FDM programme allows the airline to determine what its risks are in certain areas and to monitor these risks over time. Once it knows where its main risks lie, it can train its pilots to handle and minimise these risks, thereby improving its operations. The safety benefits can be summarised as follows:

1. improved pilot training programmes
2. improved operating procedures.
3. improved safety in flight operations
4. more detailed investigation of ASRs

These improvements should result in the airline being less likely to have a potentially fatal accident or incident. It should be noted that an FDM programme is particularly suited to avoiding certain types of accidents and incidents. These are ones which occur during the take-off, approach and landing phases of a flight. Other types of accidents or incidents, such as runway incursions, are unlikely to be influenced by an FDM programme.

5.2.2 Cost benefits

Cost benefits arise when the data from an FDM programme is used to reduce a particular cost incurred by the airline. Traditionally, the vast quantity of data available on aircraft systems has lent itself to reducing costs in the engineering and maintenance departments. However, as the use of FDM programmes has become more sophisticated, cost benefits have been identified in other areas as well. The main areas where cost benefits can be realised are listed below:

1. increased aircraft availability
2. optimum fuel consumption
3. avoiding unnecessary engine maintenance
4. other maintenance activity
5. warranty and liability claims
6. reduced insurance premiums
7. reduced Aircraft Communications Addressing and Reporting System (ACARS) messages
8. avoiding noise fines
9. reduced number of FDR downloads

It is evident that some of these cost benefits are linked directly to the safety benefits. For instance, if an airline's pilots fly their aircraft closer to the standard operating procedures (SOPs) they are less likely to have an accident or incident. The airline will thus be safer and make fewer claims on its insurance company. This should then be reflected in reduced insurance premiums.

There are some other, more general benefits that can arise from having an FDM programme. These are as follows:

1. improvements to infrastructure

2. monitoring of franchisees
3. research
4. consultancy

These areas of benefits will be discussed in more detail individually, giving examples wherever appropriate.

5.3 Safety benefits

5.3.1 Improved pilot training programmes

Analysis of operational flight data may indicate that a particular event is occurring regularly and appears to be related to how pilots have been trained to fly the aircraft. In such cases, altering the training programme could reduce the number of events, and this can be verified later by FDM data. Sometimes, only very minor changes are necessary to the training programme.

As an example, a British operator found from its FDM programme that there was an increase in flap placard speed (the maximum speed allowable with flaps extended) exceedances by pilots converting from the Airbus A320 to the heavier Airbus A321. This information was fed back to the newly converted pilots and immediately resulted in a reduced number of incidents.[26]

By analysing the data from the entire airline's operations, rather than just looking at specific events, it may be possible to show that pilot performance is consistently good. For instance, in looking at a particular parameter, such as rate of descent during the approach, there may be a small standard deviation and the mean may remain constant over time. As a result of this information it may be possible to justify reducing the amount of recurrent training pilots receive each month. If this saves five hours of training per pilot per month it is possible to calculate the annual savings based on the average pilot's salary and cost of simulator time.

In the United States, the FAA runs an Advanced Qualification Program (AQP) for pilot training and checking. Within this there is a single visit training (SVT) concept which allows for better training of pilots in a single visit to a training facility every twelve months. However, if an airline can show that its pilots' performance on a certain fleet type is very good the FAA may accept a proposal to extend the SVT cycle from a twelve month cycle to a thirteen month cycle. This would result in a one month reduction in training costs.[34]

5.3.2 Improved operating procedures

The benefit of FDM programmes in improving operating procedures is best illustrated by a case study.[24]

The example relates to the standard take-off procedure for commercial aircraft. When an aircraft is taking off it must reach a certain speed before the wings will be able to generate enough lift to allow the aircraft to fly. At this rotation speed, called V_R, the nose of the aircraft is raised to a pitch attitude of around 12 to 15 degrees. The aircraft then leaves the ground and gains altitude, whilst continuing to accelerate. During this initial climb, there is a minimum safe climb-out speed, called V_2. This is the speed that the aircraft must maintain in order to achieve a sufficient climb rate should an engine fail during take-off. A normal climb-out speed is between V_2 + 15kt and V_2 + 25kt. If the aircraft climbs-out at a speed below V_2 and one of its engines fails the aircraft is in danger of stalling or losing directional control, both of which can lead to an accident.

In early 1992, a Boeing 767 belonging to an international airline took off from San Francisco International Airport. During the initial climb, the speed decreased close to V_2 with the aircraft pitch attitude increasing to 24 degrees at an altitude of 2600ft. The pitch attitude was then reduced by the pilot but the speed continued to decrease until it reached a minimum of V_2 – 25kt.

This was the most serious of a series of take-off speed regression events that were regularly detected by the FDM programme since that airline introduced the Boeing 767 into service. To address this, pilots were alerted to the incidents and instructed to limit the pitch attitude of the aircraft to 20 degrees. Over the next three years the frequency of the incidents reduced but in early 1995, another Boeing 767 took off from San Francisco and experienced a similar speed regression, indicating the problem had not been solved.

The airline's Flight Analysis department subsequently studied all 80 Boeing 767 take-offs over a nine day period in March 1995 from which they made the following discoveries:

- 36 take-offs (45%) showed a speed regression greater than 10kt
- 8 take-offs (10%) showed a speed regression down to V_2 (equivalent to an approximately 20kt speed regression)
- all the regressions occurred with an aircraft pitch attitude of 17 to 19 degrees

These findings were discussed with pilots, who gave their observations from the flights. From this discussion it was determined that the automatic flight director, which showed pilots what pitch attitude to adopt during the climb-out, was placing undue emphasis on aircraft pitch attitude at the expense of airspeed. Thus, pilots were given new instructions to stop the rotation at 15 degrees, adjust the aircraft pitch to maintain a suitable airspeed and to ignore the flight director until reaching an altitude of 1500 ft.

At the end of June 1995, a new study of 100 take-offs was carried out. This revealed that only one take-off (1%) had a significant speed regression to V_2 + 3kt, with the aircraft pitch maintained at 17 degrees.

By early 1996 the problem seemed to have been entirely eliminated. Of 1500 take-offs analysed, only two (0.1%) experienced a climb-out speed less than V_2 +10kt. Thus the operating procedure during take-offs on the Boeing 767 fleet had improved significantly since 1992.

5.3.3 Improved safety in flight operations

Better pilot training encourages pilots to follow the improved SOPs more closely. The direct result of this is that the airline's operations become safer. Many airlines with FDM programmes have reported improvements in the operation of their aircraft, particularly in the landing and approach phases of flight. These are the phases of flight during which most accidents occur and by improving operational performance in this area the likelihood of an accident or incident is reduced. Examples of improvements in these areas could include more stabilised approaches, better control of sink rates and aircraft attitude on touchdown.

An example of improved safety in flight operations comes from British Airways.[25] In 1991, they were experiencing many false ground proximity warning system (GPWS) warnings. Analysis of 300 warnings revealed that only 13% were genuine. As a result, the flight crew's perception of the warning system was poor which meant that only 40% of all the warnings received the correct response.

However, seven of the 39 genuine warnings received no response at all. This lack of action could have resulted in a controlled flight into terrain (CFIT) type of accident. Such a situation was a serious risk and therefore not acceptable. It was dealt with by changing the policy regarding GPWS warnings, introducing GPWS simulator training and helping the manufacturer to improve the warning system. Subsequent analysis of 120 warnings confirmed that they all received the correct response, thus proving that the safety of the flight operations had been improved.

5.3.4 More detailed investigation of ASRs

An ASR is raised by a pilot whenever the pilot feels that the safety of a flight has been compromised in some way. The ASR will give a brief explanation of the event but if the airline wishes to examine the ASR in more detail it must gather extra data from other sources. For ASRs of a technical nature, flight data can be used as part of the investigation and, in such instances, an FDM programme will be also be helpful. Not only will it allow data to be analysed from the flight in question but it will also allow comparisons to be made with similar flights.

An example of this was an ASR that was raised by the pilot of an Airbus A340 at a European airline. On the Airbus A340, fuel is stored in a trim tank in the tailplane at the rear of the aircraft. As the fuel in the main wing tanks is burnt during cruise the centre of gravity (CG) of the aircraft shifts backwards and fuel must occasionally be transferred from the trim tank to the wing tanks, in order to keep the CG within limits. This fuel transfer is carried out automatically by the flight management computer.

During the incident reported, the pilot received a warning that the CG had exceeded the rear limit and he had to manually transfer all the fuel out of the trim tank.

CG position is not a parameter that must be recorded by the FDR so during the investigation of the ASR data had to be obtained from the QAR. Through the FDM programme it was possible to analyse the particular flight and compare the profile of the CG position on that flight with that of a normal flight. This information helped to locate the source of the problem and it would have been much more difficult to do this without the data from the FDM programme. As well as the safety benefit obtained from investigating this ASR there was also a cost benefit because an improperly balanced aircraft will burn more fuel.

5.4 Cost benefits

5.4.1 Increased aircraft availability

The increased aircraft availability can arise from the FDM programme reducing the number of incidents which would render the aircraft unserviceable, such as a heavy landing or tailstrike. It can also arise from the FDM programme preventing unnecessary maintenance from being carried out by showing that an event was within limits. Alternatively, it could detect a situation which requires maintenance but which has not been picked up by the engineering department, such as an inspection of the flaps if the flap placard speed has been exceeded. If this maintenance is not carried out at a planned time it may result in the aircraft becoming unserviceable later on, requiring unscheduled maintenance and disrupting the operating plan.

An example of an FDM programme preventing unnecessary maintenance is provided by a British airline. On take-off from Gibraltar, the crew of a Boeing 737 saw an engine over-temperature and decided to return. However, on the ground, analysis of the flight data revealed that it was an extremely marginal excursion which was within limits for the engine so the flight was able to continue. This avoided the total cancellation of the flight and grounding of the aircraft until a spare engine could be sourced.[26]

Another example comes from a European flag carrier.[26] The crew of a Boeing 747-400 refused to fly an aircraft with a reported fuel imbalance on the last flight. However, analysis of the FDM data showed that the fuel balance was within the specified limits and the crew then accepted the aircraft. Had they not accepted it, there would have been a delay while fuel was transferred between the fuel tanks with the possibility of the flight being postponed or even cancelled.

5.4.2 Optimum fuel consumption

FDM programmes can be used to monitor fuel consumption of specific aircraft and compare them with the rest of the fleet. From this is may be possible to identify aircraft which are burning more fuel than others, possibly due to misalignment of components which causes extra drag, and this can be corrected on future maintenance inputs.

Another source of savings comes from optimising flying routes. For example, one international carrier had a new standard arrival route (STAR) for Hong Kong. This STAR was 225 nautical miles long and pilots felt this could be shortened. Data from the FDM programme proved that the STAR could be shortened by 75 nautical miles without risk. This meant less fuel needed to be uplifted and hence there was a reduced overall fuel burn.[26]

This airline is continuing routing investigations in order to achieve more STAR reductions at other airports. Studies have resulted in shortened flying routes, with particular success on routes over Russia, and this has resulted in dramatic fuel reductions. Regular analysis of flight routes can also discourage ‘sight-seeing’ excursions by pilots, with the associated reduction in fuel consumption.

5.4.3 Avoiding unnecessary engine maintenance

According to engine maintenance manuals, after ten over-temperature events of unknown cause an engine must be removed and inspected. However, if data from an FDM programme shows why an over temperature event occurred, or that it did not actually occur, then the time until the engine has to be removed and inspected is extended. If the cost of an engine removal and inspection is divided among the ten over-temperature events then the savings achieved from not counting one event can be calculated.

As an example, a United States Boeing 737 operator experienced an engine over temperature event. Data from the aircraft was sent to the engine manufacturer and the detailed temperature profile was discussed. From this it was agreed that the engine could be left on the wing, thus avoiding an early engine removal and overhaul.[26]

Another example is a British carrier which had a Boeing 747 with an intermittent indication of very high engine vibrations in one of its engines. At first it was thought to be an indication fault but on changing the indicator the problem persisted and an unscheduled engine removal was planned to determine if the problem was in the engine. However, the aircraft was due for heavy maintenance within a month and if it could be shown that the problem was not serious, the engine could be left on the wing until then. Data from the FDM programme was used to show that the magnitude of the indicated engine vibrations was so large that the engine could not have physically continued operating had the indications been correct. Thus, it was accepted that there was no fault with the engine and an unscheduled removal was not necessary. During the subsequent heavy maintenance work it was found that the wiring between the engine and the vibration indicator was faulty and this was causing the erratic readings.

5.4.4 Other maintenance activity

There are many different areas where FDM programmes can be of benefit to aircraft maintenance activities. Some examples will serve to highlight this.

In analysing the flight data from a particular Boeing 757, a British airline noticed a rising oil quantity and dropping oil pressure in one of the engines. Line maintenance personnel were sent to inspect the engine at the next turnaround. They noticed a smell of fuel in the oil which led to them finding a split in the fuel-cooled oil cooler (FCOC). Finding this split allowed it to be repaired before the engine was damaged, which would have been a potentially expensive incident.[26]

If an airline monitors brake usage more closely through an FDM programme this can lead to an increase in the number of cycles between brake removals and overhauls which results in reduced maintenance costs. An example of this was a United States operator monitoring Boeing 737 brake wear at Charlotte Airport. Runway 31 at the airport has a non-precision approach and it was noted that there were several aircraft landing with high touchdown speeds, which therefore required more braking by the pilots. In order to address this a procedure change was agreed with the air traffic control which resulted in the pilots being able to better control their landing speed, allowing them to land at slower speeds. As a result of this brake wear was reduced significantly.[26]

In another example, a European flag carrier noticed that they were experiencing a high number of failures of their Boeing 747-400 integrated drive generators (IDGs), resulting in a high consumption of spares. The airline suspected a design error was causing high oil temperatures and Boeing suspected this was due to a problem with the cooler valves. FDM data was then used to isolate a design fault in the cooling system which was subsequently rectified.[26]

Finally, it should be noted that, due to its nature, a maintenance benefit is also likely to result in the benefit of increased aircraft availability as well as improving safety, as shown by the following example. Data from one United States airline's FDM programme highlighted a slowing flap deployment time on a particular aircraft.[26] Line maintenance personnel were sent to inspect the flaps at the next turnaround and they found early signs of a hydraulic leak which was then rectified. If the hydraulic leak had not been fixed it is likely that the flap mechanism would not have been able to function. Had this happened as the flaps were being set for take-off the aircraft would not have been able to proceed and this could have led to a potentially expensive delay or cancellation of a service. However, if the flap mechanism had malfunctioned during a flight, when the flaps were being extended for landing, this could have resulted in an asymmetric flap situation during flight or a landing being made at a higher speed with the increased risk of a runway overrun. Both of these represent significant hazards to the safe operation of the aircraft.

5.4.5 Warranty and liability claims

The data from an FDM programme can be used to set a datum for measurement of performance guarantees from equipment manufacturers. If it can be shown that the actual performance is outside the specified levels then the airline is in a position to claim compensation under the terms of the warranty.

Another example of how an airline can benefit from a warranty claim is given by a European operator. They took delivery of a new Boeing 767 and it was noticed that there was a consistent difference in the minimum manoeuvring speed indications on the captain's and first officer's flight instruments. A large number of man-hours was spent on troubleshooting this problem. FDM data pointed to something unusual with the angle of attack (AOA) readings from the two sides of the aircraft and a physical inspection revealed a wrongly shimmed AOA sensor. Boeing accepted a warranty claim for the man-hours spent resolving this problem.[26]

It is also possible that an airline can save making payments to its customers who are making warranty claims from the airline. For example, the cargo department of the airline quoted in the previous paragraph receives many claims for losses of perishable goods due to the aircraft's hold temperature being too high or low. FDM data records the hold temperature and has been used to show that the variations are within the specifications, thus saving the claim pay-out.

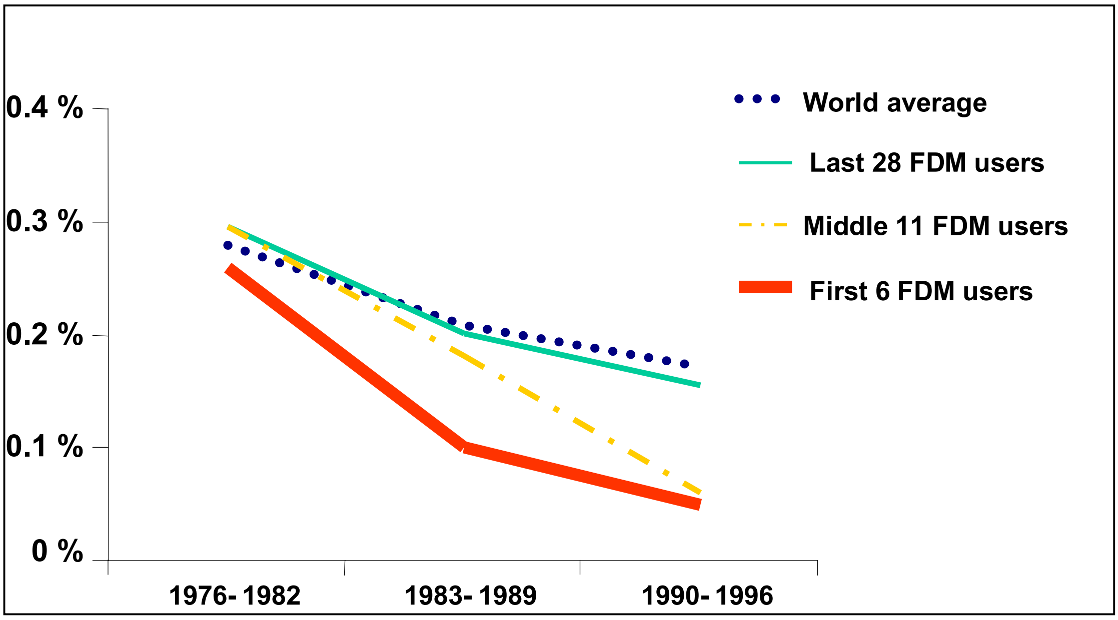
An example where an airline can avoid a liability claim comes from an Asian operator. They use the QAR to record whether the 'Fasten Seat Belts' sign is on or off. This information can be useful if a passenger is making a claim for injuries sustained during turbulence, because it can be proved whether the passenger should have had his or her seat belt fastened at the time.

5.4.6 Reduced insurance premiums

Insurance companies may reduce premiums for airlines which have established FDM programmes. This is due to the long-term benefits of having such programs, as highlighted by British Airways who established a data analysis programme in the 1960s (see Chapter 2).

Skandia Insurance has recently overlaid FAA data with that of non-US airlines. This shows that airlines which have been using FDM programmes for seven to fourteen years now have a lower accident rate than US airlines, the majority of which have had no FDM programmes or else have not had a programme for more than five years. Those airlines which have used FDM for more than 14 years have an accident rate under half that experienced by the US carriers.[25] This is shown in Figure 10 below.

Figure 10 - Comparison of hull loss rates (shown as hull losses as % of total hulls flying) between airlines with FDM programmes



Source: Spirent Systems[26]

It may also be possible to prove statistically that the probability of an accident or incident occurring has been reduced. This could be done through analysis of the operational data for a whole fleet to show trends in the mean and standard deviation of a particular parameter over time. The following quote shows that airline insurers will consider the measures taken by an airline to reduce its risk:

"Underwriters are risk takers and the less risk they see, the readier they become to accept an individual airline's exposure at a competitive price. The more attractive the airline's insurance business the lower the price can be, as more and more underwriters would like to accept this risk. By showing that the airline is proactive in safety matters and works with the latest techniques to reduce claims on its policy, the airline will gain in whatever market conditions that prevail during the renewal negotiations.[27]

5.4.7 Reduced ACARS messages

ACARS is a very high frequency (VHF) air-to-ground data link that uses nearly 600 high frequency (HF) and VHF stations throughout the United States and overseas to provide operational radio communications for the aircraft industry[28] It was produced in the early 1980s to reduce the flight crew's work-load by using computer technology to exchange many routine reports and messages between the aircraft and its main base. The ground system is maintained by the company Aeronautical Radio, Inc. (ARINC) and there is a charge for each message sent by ACARS. Some of the information traditionally sent, such as engine exhaust gas temperature (EGT) is recorded as part of the FDM programme so it may be possible to access this data from the QAR instead of using ACARS. This results in a direct reduction in the number of messages sent by ACARS and hence the cost of using ACARS.

5.4.8 Adherence to noise-abatement procedures

Many airports have noise monitors in the areas around the airport to ensure the noise level is within agreed limits. In order to achieve this, airlines are required to follow certain noise-abatement procedures and fly certain tracks. If they deviate from these procedures or tracks and generate unacceptable levels of noise they can be fined by the airport authority. If an airport authority fines an airline for a noise infringement, FDM data can be used to check the track of the flight in question and verify that the airline is actually responsible for the infringement, rather than another airline. Alternatively, procedures at a particular airport can be monitored to ensure they are followed correctly so that there are no noise infringements and hence no fines.

5.4.9 Reduced number of FDR downloads

As mentioned in section 5.3.4 flight data can be used to support the investigation of ASRs of a technical nature. However, if the airline does not have an FDM programme it has to obtain this data from the FDR. There is thus an extra cost involved in terms of the man-hours required to access the FDR and perform a download. With an FDM programme in place, this data will automatically be downloaded and analysed and this cost can be avoided.

5.5 *Further benefits*

As well as the safety and cost benefits described above, there are other benefits which can arise from an FDM programme that may be advantageous to an airline. Some of these are discussed below.

5.5.1 Improvements to infrastructure

Some airlines use FDM data to measure the condition of a runway surface so that they can advise the appropriate authorities when resurfacing needs to be carried out. United Airlines, British Airways and KLM have all cited instances where they have done this, and the following example is taken from one of them.[26]

Almaty (Alma-Ata) Airport in Kazakhstan was known to have a bad runway surface and this mandated a higher frequency of landing gear inspections for aircraft operating to this airport. The airline used their FDM data to pressure the airport authority into resurfacing the runway. After this was done, the FDM data proved the improvement in runway surface and with this information the gear inspection restriction was quickly lifted. As well as improving the runway surface at the airport, this had the additional direct benefit to the airline of reducing the number of landing gear inspections required on the Boeing 767 fleet which were operated to the airport.

5.5.2 Monitoring of franchisees

A major airline may have several franchisees which operate under its name and brand. As part of the franchise agreement, the franchisee will have to conduct its operations in a safe manner and this will be monitored by the franchiser. This monitoring can be performed more reliably if the franchisee has an FDM programme to which the franchiser is given access.[25]

5.5.3 Research

Another area where benefits can arise from an FDM programme is in the area of research projects. For example, US Airways and Alaska Airlines have been submitting data from their FDM programmes to the FAA as part of the FAA's Structural Loads Program. This is part of an Aging Aircraft Airborne Data Monitoring

Systems Program and it aims to collect data on the external loads experienced by the airframe during operation. This will provide a database of information to continuously update and validate the FAA's certification standards regarding flight and landing loads as well as providing information for design criteria of future aircraft.

Other examples of projects that have made use of data from FDM programmes include the introduction of autoland capability on new aircraft types, analysis of cosmic radiation at altitude and a study to improve runway utilisation by monitoring the time aircraft spend on the runway under different wind conditions.

5.5.4 Consultancy

The final area where an airline can benefit from having an established FDM programme is in consultancy work. This involves selling the expertise of the airline to other, smaller operators who may not have the capacity to run a full FDM programme on their own. QANTAS and Air Lib both provide FDM consultancy services to airlines operating in their region. This is obviously a source of revenue to an airline and it arises from the overall expertise gained in running an FDM programme, rather than the detailed knowledge obtained from the programme.

Having described examples of how benefits can arise from FDM programmes, the following chapter will quantify some of the savings from these benefits.

6 Quantifying the benefits

6.1 Overview

It is widely accepted that an FDM programme can provide airlines with many benefits, as described in the previous chapter. However, benefits arising from increased safety in flight operations, which is the primary advantage of an FDM programme, have traditionally been difficult to quantify. This is because they rely on proving that an event, which would have resulted in a cost to the airline, was prevented from occurring as a direct result of information obtained from the FDM programme.

At present, many carriers with new FDM programmes have found that tangible, quantifiable and repeatable cost benefits due to FDM programmes are elusive. Most of the benefits have been unforeseen, one-time benefits that are difficult to predict in advance. However, airlines with greater experience of FDM programmes are more sophisticated in their use of the flight data and they maintain that the initial capital investment to set-up an FDM programme, and the ongoing running costs, are recovered many times over. This is due to the cost benefits which were described in the previous chapter, rather than the safety benefits.

The remainder of this chapter will attempt to quantify some of the benefits with data obtained from several sources.

6.2 Safety benefits

Although it is difficult to prove that the absence of an accident or incident is directly attributable to the existence of an FDM programme, it is fairly straightforward to quantify what an accident or incident would cost.

6.2.1 Cost of an accident

Approximations of the direct cost of previous accidents can be obtained from various sources, and some examples are listed below.

AMR, the parent company of American Airlines, set aside a USD 41 million provision related to the December 20 1995 accident of an American Airlines Boeing 757 in Columbia. This was to cover the carrier's liability that was not covered by third party insurers.[29] In addition to that, the American Airlines Boeing 757 had been insured for USD 34 million, according to insurance officials in London.[30] So the accident, which involved the complete loss of the aircraft and all on board during the approach to landing, cost the airline at least USD 75 million.[31]

In another example, China Airlines has offered a total of more than USD 83 million in compensation for the victims of the 25 May 2002 crash of one of their Boeing 747 aircraft. The aircraft was insured for USD 20 million.[32]

Aside from the direct cost of an accident, there is also the indirect cost which results from the reduced level of bookings on the airline, as described below:

"A recent accident led to an initial drop of 40% of rider-ship, which stabilised at around minus 19% six months after the event. On the route on which the accident occurred, the load-factors were still down by 50% six months after event. According to the airline's economist, it took close to one year to get the traffic back to normal, thereby turning the balance sheet of the airline upside down."[1]

Attempting to quantify this loss is difficult. After the 12 November 2001 crash of an American Airlines Airbus A300, some analysts estimated that the crash would cause a revenue loss to American Airlines of USD 200 to 250 million.[33]

Apart from the cost of an accident, the cost of an incident can also be considered. One example would be the cost of a tail strike, which was estimated by one study to cost USD 500 000 in maintenance work and lost flying time.[26]

It is apparent from this analysis that if an FDM programme prevents a single major accident it will have paid for itself many times over.

6.2.2 Improved pilot training programmes

The following example quantifies the benefit of the FAA accepting a proposal to extend an airline's SVT cycle from twelve months to thirteen months. The figures and calculations are taken from an Alaska Airlines' presentation.[34]

The total savings are quantified according to the following calculation:
[total number of pilots] ÷ 12 (months in a year) × [number of training days each pilot receives] × [number of hours pilot is paid] × [pilot hourly wage] = total.
Add in [hours of simulator usage per crew] × [hourly simulator upkeep cost].

Example:

- 1100 total pilots.
- 1100 ÷ 12 = 90 pilots trained per month.
- Each pilot receives five days of recurrent training per month.
- 5 × 90 = 450 days of training per month.
- Each pilot receives four hours pay per day of training.
- 450 × 4 = 1 800 hours of paid training per month.
- Captain's pay = USD 145 per hour; first officer's pay = USD 95 per hour. Assume an even split between captains and first officers so that of the 1 800 hours of paid training per month, 900 hours are paid at the captain's rate and 900 hours are paid at the first officer's rate.
- 900 × USD 145 = USD 130 500 per month for training of captains.
- 900 × USD 95 = USD 85 500 per month for training of first officers.
- USD 130 500 + USD 85 500 = USD 216 000 total training costs per month.

Add in simulator costs:

- Each crew, comprising two pilots, receives twelve hours in a simulator per month.
- 90 ÷ 2 = 45 crews trained per month.
- Assume simulator time costs USD 160 per hour.
- 45 × 12 = 540 hours of simulator time per month.
- 540 × USD 160 = USD 86 400 total simulator training costs per month.

Grand total = USD 216 000 + USD 86 400 = USD 302 400 training costs per month.

6.3 Cost benefits

6.3.1 Increased aircraft availability

In the example described in the previous chapter, of crews accepting an aircraft with a fuel imbalance due to FDM data showing that the imbalance was within limits, a European airline estimated savings of USD 170 000 per year through reduced delays.[26]

6.3.2 Optimum fuel consumption

Estimates of fuel savings vary widely and depend on the routes being considered and the method used to quantify the savings. For example:

"One large carrier estimates that it saves USD 750 000 annually on one long-haul international route, by identifying specific aircraft that have an exceptionally high fuel-burn rate, thereby being in a position to adjust those aircraft's airframes and/or engines for greater efficiency."[35]

In another study, it was stated that:

"A cost saving of USD13 000 for out of trim conditions was obtainable assuming one in 100 Boeing 737 aircraft have a one degree sideslip and a utilization of 3 000 hours per year. Fuel savings of USD 18 000 were achievable for 100 Boeing 737 aircraft with a utilization of 3 000 hours per year."[31]

The study by Alaska Airlines, quoted above, highlighted two ways to calculate the fuel savings.

1. [Total fuel burn annually in gallons] × [price of fuel] × [expected fuel savings] = total
2. [Total yearly hours on aircraft] × [reduction in fuel burn (documented or assumed)] = [total fuel saved in lbs] ÷ 6.7 = [total fuel saved in gallons] × [fuel price] = total saved (per aircraft per year)

Example 1:

- Total fuel burn for year = 275 222 000lbs.
- 1% fuel savings expected.
- 275 222 000 ÷ 6.7 = 41 077 910 gallons.
- Price of fuel = USD 0.65 per gallon.
- 41 077 910 × USD 0.65 = USD 26 700 641 annual fuel cost.
- USD 26 700 641 × 1% = USD 267 006 fuel savings per year.

Example 2:

- Assume aircraft utilization is 3650 hours per year per aircraft.
- Assume average reduction in fuel burn of 300lbs per hour.
- 3650 × 300lbs = 1 095 000lbs fuel saved per year.
- 1 095 000 ÷ 6.7 = 163 433 gallons fuel saved per year.
- Price of fuel = USD 0.65 per gallon.
- 163 433 × USD 0.65 = USD106 231 fuel savings per aircraft per year.

6.3.3 Avoiding unnecessary engine maintenance

After the cost of the entire aircraft and systems (excluding engines), the engines are the next most costly item of hardware on an aircraft. This in turn means the maintenance of an engine is also costly so this is an area where FDM programmes can have an immediate impact on reducing costs. One method of achieving this is by increasing the amount of time the engine spends on the aircraft and reducing the number of unscheduled removals.

One study estimates that the overall on-aircraft extension time may range from 10% to 35% of the original time. It is also estimated that 1% savings in maintenance costs are possible from reduced unscheduled engine removals.[31] Such savings were estimated to amount to USD 750 000 annually for a fleet of 50 aircraft. [26]

The Alaska Airlines' study[34] quantified the savings as follows: [Engine removal factor] × [average cost of engine removal] × [aircraft out of service cost] = total

Example:

- The cost of removing and inspecting an engine can run anywhere between USD 70 000 and USD 300 000.
- The cost of not having that aircraft available for daily revenue = USD 30 000.
- From average figures, it can be assumed that, after the initial aircraft delivery, when engine reliability is expected to be high, an airline can expect a savings of one engine overhaul every seven years.
- 1 ÷ 7 = 0.14 engine removal factor (annual engine overhaul saving).
- Average engine overhaul cost = [USD 300 000 – USD 70 000] ÷ 2 = USD 230 000 ÷ 2 = USD 115 000 + USD 70 000 = USD 185 000 average engine removal cost.
- Assume two days to remove and install an engine.
- 2 days × USD 30 000 for aircraft out of revenue service = USD 60 000.
- Total cost = USD185 000 + USD 60 000 = USD 245 000
- Total savings = USD 245 000 × 0.14 = USD 34 300

Another study by The FLIGHT DATA Company (now known as Spirent Systems) quantified savings on the UK Royal Air Force's fleet of Lockheed Tristar aircraft or GBP 24 per operating hour per engine.[36] For a typical aircraft utilisation of 3 000 to 4 000 hours per year, this leads to a saving of around USD 300 000 annually for a twin-jet aircraft.

6.3.4 Other maintenance activity

Two areas of savings will be considered: savings due to reduced brake wear and savings from reduced numbers of hard landing inspections.

6.3.4.1 Savings from reduced brake wear

Various sources have estimated that brake changes can be reduced by 1% annually, through a pilot awareness programme and monitoring brake usage.[31,34] The method used by Alaska Airlines to quantify this saving is as follows:

[Number of annual flights] ÷ [number of cycles before brake removal and overhaul] × [cost to overhaul brakes] × [percentage expected reduction in brake changes] = total

Example:

- Average number of flights per day = 430.
- 430 × 365 = 156 950 flights annually.
- Number of cycles (flights) between brake changes = 790.
- Cost to change and overhaul brakes = USD 5 000.
- 156 950 ÷ 790 = 198 brake changes annually.
- 198 × USD 5 000 = USD 990 000 annual cost of brake changes.
- USD 990 000 × 10% = USD 99 000 saving in brake changes.

Another study quoted the annual brake wear savings for a fleet of 50 aircraft to be USD 180 000. [26]

6.3.4.2 Savings from reduced hard landing inspections

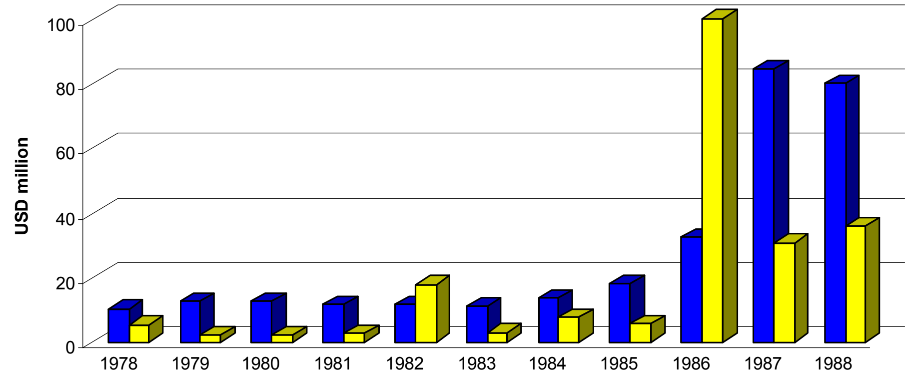
If an aircraft experiences a touchdown where the vertical acceleration is above a certain limit, the aircraft must have a hard landing inspection carried out on it to check for any structural damage. By using data from the FDM programme hard-landing inspections may be reduced by 10%.[31] This has been estimated to result in savings of USD 90 000 annually for a fleet of 50 aircraft. [26]

6.3.5 Reduced insurance premiums

One study estimated that annual savings of USD 60 000 were possible for a fleet of 50 aircraft, as a result of reduced insurance premiums.[26]

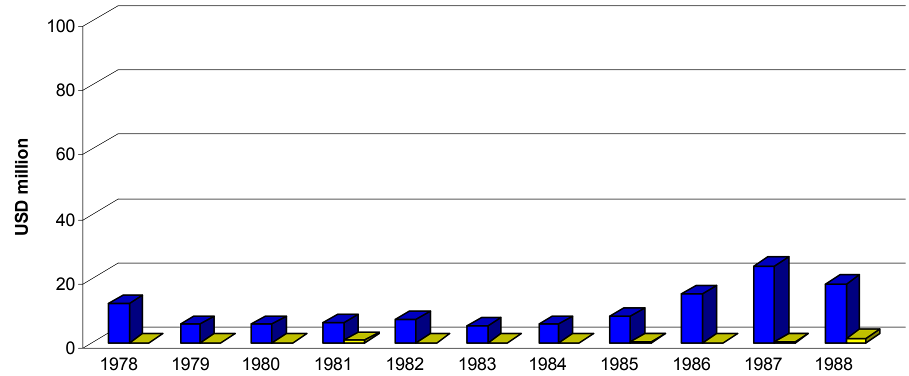
The following figures compare the premiums and claims of two aviation organisations, one with a high level of hull losses and one with a low level of losses.

Figure 11 - Major Aviation Organisation with High Loss Experience



	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Premiums	10.4	12.6	12.6	11.6	11.5	11.03	13.7	18	32.5	84.5	80
Claims	5.4	2.11	2.11	2.54	17.8	3.01	7.8	5.77	362.35	30.67	36.07

Figure 12 - Major Aviation Organisation with Minimal Loss Experience



	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Premiums	12.02	5.75	5.75	6.05	7.05	5.37	5.84	8.25	15	23.8	18.36
Claims	0	0	0	0.8	0	0	0	0.15	0	0.24	1.5

Source: Schmidlin[1]

If a carrier uses its FDM programme to reduce the number of hull losses it experiences, and can prove this with data, it could be assumed that they will also be able to benefit from reduced insurance premiums as illustrated by the example above.

6.3.6 Reduced ACARS messages

ACARS messages typically cost around USD 1 per message. The study quoted above estimated that reduced ACARS traffic could lead to a saving of USD 70 000 annually for a fleet of 50 aircraft. [26]

6.3.7 Adherence to noise-abatement procedures

The British Airports Authority (BAA) charges fines of up to GBP 1 000 for each breach of their noise regulations. From 1993 to 2000 they raised over GBP 1.25 million (approximately USD 250 000 annually) in noise fines at Heathrow airport alone.[37] These fines could be avoided if pilots followed the required departure procedures.

6.3.8 Reduced FDR downloads

An FDR download typically costs around USD 800. One European airline receives over 8 000 ASRs annually and if it is assumed that FDM data can be used for 10% of these, instead of replaying the FDR, it amounts to a saving of USD 640 000 annually.

6.4 Summary of savings

As part of their FDM demonstration project DEMOPROJ the FAA estimated the benefits to airlines in setting up an FDM programme. The estimates covered benefits from fuel, engine maintenance and safety savings for a fleet of 15, 50 and 100 aircraft.[38]

Fuel and engine maintenance savings were estimated on the basis of discussions with an airline participating in the demonstration project. Safety savings were estimated on the basis of information from a European airline which had a long-term FDM programme.

The estimates of the savings were based on an assumption of 3 000 flight hours per aircraft per year. Fuel savings and engine savings figures were based on estimates of a 0.5% reduction in fuel consumption and a 1% reduction in engine maintenance costs. The safety savings were based on a hypothetical 1% reduction in the annual costs incurred from accidents. UTRS based the safety savings calculation on a loss rate of two aircraft per million departures at a cost of USD 150 million for each loss. The results are summarised in Table 9 below.

Table 9 - Estimated total annual savings by fleet size for an airline with an FDM programme.

Fleet size (no. aircraft)	**15**	**50**	**100**
Fuel savings (USD)	145 800	486 000	972 000
Engine savings (USD)	300 000	1 000 000	2 000 000
Safety savings (USD)	49 500	165 000	330 000
Total annual savings (USD)	**495 300**	**1 651 000**	**3 302 000**

In 1999 a European airline also carried out a study into the savings it had experienced from its FDM programme and found the results shown in Table 10.[26]

Table 10 – European airline's estimate of annual savings from its FDM programme.

Factor	**Approximate annual savings (USD)**
Engines	4 500 000
Punctuality	1 200 000
Maintenance hours	1 700 000
Operations / fuel	100 000
Sending data by ACARS	100 000
Total savings	**8 200 000**

A further study by a consultancy company, in conjunction with a US carrier, looked at the cost-benefits from an FDM programme over a five-year period. The results are summarised in Table 11 below.

Table 11 – Estimate annual savings from an FDM programme over five years.

Item	Year 1	Year 2	Year 3	Year 4	Year 5
Reduced engine removals	125 000	500 000	500 000	500 000	500 000
Engine on-wing extension	412 500	1 650 000	1 650 000	1 650 000	1 650 000
Detection of out-of-trim conditions	3 141	12 563	12 563	12 563	12 563
Fuel savings	14 692	58 769	58 769	58 769	58 769
Brake wear reduction	6 000	24 000	24 000	24 000	24 000
Insurance savings	0	0	1 250	5 000	5 000
AQP SVT training savings	0	0	162 667	162 667	162 667
Total benefits	561 333	2 245 331	2 409 248	2 412 998	2 412 998

Source: Cobert[39]

7 Conclusions and recommendations

FDM programmes are now becoming more widely used by airlines. This thesis has explained what an FDM programme is, how it is run, what the main costs are and where an airline can obtain benefits from such a programme. The main conclusions and recommendations resulting from this study are detailed below.

7.1 Conclusions

These are considered in three areas: general conclusions, costs and benefits.

7.1.1 General conclusions

- FDM programmes are currently recommended practice by ICAO and they are likely to be made mandatory in some countries over the next several years.
- The largest air transport industry, the US industry, does not intend to mandate FDM programmes in the foreseeable future.
- The number of airlines running FDM programmes has increased dramatically in the last five years.
- Airlines with new FDM programmes typically use them to improve the safety of their operations but they do not exploit the full range of benefits, particularly cost-benefits, which can arise from a well-managed FDM programme.

7.1.2 Costs

- The initial start-up costs of an FDM programme are significant, particularly for small regional airlines with a small fleet size.
- The annual running costs of an FDM programme are predominantly related to manpower costs.

7.1.3 Benefits

- There are several benefits that can be obtained from running an FDM programme. The most important benefit is the improved safety in the airline's operations.

- If an FDM programme improves the airline's operations such that a single accident is avoided it will have paid for itself many times over.
- The cost-benefits of an FDM programme can save an airline several hundred thousand dollars or more per year, which more than covers the annual running costs of the programme.
- Most cost-benefits are difficult to predict in advance and are not repeatable. However, the more experience the airline gains in identifying cost-benefits, the greater will be its ability to realise future cost-benefits.
- Most airlines do not monitor or quantify the savings they obtain from their FDM programmes.

7.2 Recommendations

This thesis has provided an overview of FDM programmes and examined the costs and benefits associated with such a programme. There is scope for further study of this topic, and the following areas are recommended for future work:

- Investigate how to make more effective use of the data currently collected. This includes improved analysis and presentation of the data for safety purposes.
- Study ways of reducing the costs of running an FDM programme. The use of new technology, such as wireless data transfer, for instance, would help reduce running costs.
- Look into altered procedures for running an FDM programme. Examples would include optimising the number of sectors that the recording media spend on the aircraft, in order to minimise the number of media removals performed.
- Investigate the use of statistical sampling methods to reduce the volume of data that must be analysed. For a large airline, it may be possible to note trends from looking at data from forty aircraft, rather than sixty, for example. This will have cost advantages for the airline.
- Perform a detailed study of actual cost-benefits achieved by an established user of an FDM programme, including quantification of those benefits.

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Appendix A – Airlines with an FDM programme

Table A-1 – List of airlines with an FDM programme sorted by start date

	Airline	Start date
1	British Airways	1966
2	Air France	1974
3	All Nippon Airways	1974
4	Japan Airlines	1982
5	TAP Air Portugal	1985
6	Qantas	1989
7	Air Canada	1990
8	Adria Airways	1991
9	Air Liberte	1991
10	Cathay Pacific Airways	1992
11	Britannia Airways	1993
12	Singapore Airlines	1993
13	China Airlines	1994
14	EVA Airways	1994
15	Canadian	1995
16	Continental Airlines	1995
17	Meridian Airlines	1995
18	United Airlines	1995
19	US Airways	1995
20	Biman Bangladesh Airlines	1996
21	China SouthWest Airlines	1996
22	Gulf Air	1996
23	Aero Lloyd	1997
24	British International Helicopters	1997
25	Delta Air Transport	1997
26	GB Airways	1997
27	Lufthansa	1997
28	Swissair	1997
29	Turkmenistan Airlines	1997
30	Wideroe Flyveselskap	1997
31	Air Macau	1998
32	Alaska Airlines	1998
33	British Midland	1998
34	Cargolux	1998
35	China Eastern Airlines	1998
36	Delta Air Lines	1998
37	Dragonair	1998
38	El Al Israel Airlines	1998
39	KLM	1998
40	Monarch Airlines	1998

	Airline	Start date
41	TWA	1998
42	Air China International	1999
43	Asiana Airlines	1999
44	China Xinhua Airlines	1999
45	Hainan Airlines	1999
46	Jet Express	1999
47	Korean Air	1999
48	Thai Airways	1999
49	Virgin Atlantic	1999
50	Air Hong Kong	2000
51	America West Airlines	2000
52	Braathens ASA	2000
53	KLM uk	2000
54	Maersk Air UK	2000
55	Mount Cook Airline	2000
56	MyTravel Airways	2000
57	Northwest Airlines	2000
58	Philippine Airlines	2000
59	TACA International Airlines	2000
60	UPS Airlines	2000
61	Air 2000	2001
62	Alitalia Express	2001
63	British Regional Airlines	2001
64	National Jet Italia	2001
65	Polar Air Cargo	2001
66	Southwest airlines	2001
67	DHL	2002
68	European Aviation	2002
69	Malev Hungarian Airlines	2002
70	Novair Nova Airlines	2002
71	Silkair	2002
72	Aeris	
73	Aeroflot	
74	Air Algerie	
75	Air Austral	
76	Air Littoral	
77	Air Méditerranée	
78	Air Tahiti	
79	Airlinair	
80	Alitalia	

Table A-1 – List of airlines with an FDM programme sorted by start date (continued)

	Airline	Start date
81	Alpi Eagles	
82	Ansett Airlines	
83	Atlas Air	
84	Britair	
85	CCM airlines	
86	China Northwest Airlines	
87	China Southern Airlines	
88	China United Airlines	
89	Comair	
90	Condor	
91	Corsair	
92	Deutsche BA	
93	Egyptair	
94	Emirates	
95	Ethiopian Airlines	
96	Euralair horizons	
97	Europe airpost	
98	Excel Airways	
99	Futura	
100	Garuda Indonesia	
101	Iberia	
102	Japan Air System	
103	Jet Blue	
104	JMC Airlines	
105	Kuwait Airways	
106	Maersk	
107	Mandarin	
108	Martinair	
109	MEA	
110	Regional Airlines	
111	Royal Air Maroc	
112	Royal Jordanian Airlines	
113	SAA	
114	Sabena	
115	Saudia Arabian Airlines	
116	Scandinavian Airlines System	
117	Sichuan Airlines	
118	Star Airlines	
119	Sunexpress	
120	TAM	
121	Thomas Cook Belgium	
122	Tunisair	
123	Xinjiang Airlines	
124	Yunnan Airlines	
125	Zeijiang Airlines	

Source: compiled by the author from various sources.

Table A-2 – Alphabetical listing of airlines with an FDM programme

	Airline	Start date
1	British Airways	1966
2	Adria Airways	1991
3	Aeris	
4	Aero Lloyd	1997
5	Aeroflot	
6	Air 2000	2001
7	Air Algerie	
8	Air Austral	
9	Air Canada	1990
10	Air China International	1999
11	Air France	1974
12	Air Hong Kong	2000
13	Air Liberte	1991
14	Air Littoral	
15	Air Macau	1998
16	Air Méditerranée	
17	Air Tahiti	
18	Airlinair	
19	Alaska Airlines	1998
20	Alitalia	
21	Alitalia Express	2001
22	All Nippon Airways	1974
23	Alpi Eagles	
24	America West Airlines	2000
25	Ansett Airlines	
26	Asiana Airlines	1999
27	Atlas Air	
28	Biman Bangladesh Airlines	1996
29	Braathens ASA	2000
30	Britair	
31	Britannia Airways	1993
32	British International Helicopters	1997
33	British Midland	1998
34	British Regional Airlines	2001
35	Canadian	1995
36	Cargolux	1998
37	Cathay Pacific Airways	1992
38	CCM airlines	
39	China Airlines	1994
40	China Eastern Airlines	1998
41	China Northwest Airlines	
42	China Southern Airlines	
43	China SouthWest Airlines	1996
44	China United Airlines	
45	China Xinhua Airlines	1999
46	Comair	
47	Condor	
48	Continental Airlines	1995
49	Corsair	
50	Delta Air Lines	1998
51	Delta Air Transport	1997
52	Deutsche BA	
53	DHL	2002
54	Dragonair	1998
55	Egyptair	
56	El Al Israel Airlines	1998
57	Emirates	
58	Ethiopian Airlines	
59	Euralair horizons	
60	Europe airpost	
61	European Aviation	2002
62	EVA Airways	1994
63	Excel Airways	
64	Futura	
65	Garuda Indonesia	
66	GB Airways	1997
67	Gulf Air	1996
68	Hainan Airlines	1999
69	Iberia	
70	Japan Air System,	
71	Japan Airlines	1982
72	Jet Blue	
73	Jet Express	1999
74	JMC Airlines	
75	KLM	1998
76	KLM uk	2000
77	Korean Air	1999
78	Kuwait Airways	
79	Lufthansa	1997
80	Maersk	

Table A-2 – Alphabetical listing of airlines with an FDM programme (continued)

	Airline	Start date
81	Maersk Air UK	2000
82	Malev Hungarian Airlines	2002
83	Mandarin	
84	Martinair	
85	MEA	
86	Meridian Airlines	1995
87	Monarch Airlines	1998
88	Mount Cook Airline	2000
89	MyTravel Airways	2000
90	National Jet Italia	2001
91	Northwest Airlines	2000
92	Novair Nova Airlines	2002
93	Philippine Airlines	2000
94	Polar Air Cargo	2001
95	Qantas	1989
96	Regional Airlines	
97	Royal Air Maroc	
98	Royal Jordanian Airlines	
99	SAA	
100	Sabena	
101	Saudia Arabian Airlines	
102	Scandinavian Airlines System	
103	Sichuan Airlines	
104	Silkair	2002
105	Singapore Airlines	1993
106	Southwest airlines	2001
107	Star Airlines	
108	Sunexpress	
109	Swissair	1997
110	TACA International Airlines	2000
111	TAM	
112	TAP Air Portugal	1985
113	Thai Airways	1999
114	Thomas Cook Belgium	
115	Tunisair	
116	Turkmenistan Airlines	1997
117	TWA	1998
118	United Airlines	1995
119	UPS Airlines	2000
120	US Airways	1995

Source: compiled by the author from various sources.

	Airline	Start date
121	Virgin Atlantic	1999
122	Wideroe Flyveselskap	1997
123	Xinjiang Airlines	
124	Yunnan Airlines	
125	Zeijiang Airlines	