Safety Science xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Redefining the incidents to learn from: Safety science insights acquired on the journey from black boxes to Flight Data Monitoring

Guy Walker

Heriot-Watt University, Edinburgh EH 14 4AS, UK

ARTICLE INFO

Article history:
Received 31 March 2016
Received in revised form 16 February 2017
Accepted 25 May 2017
Available online xxxx

Keywords:
Leading and lagging indicators
Data recording
Flight Data Monitoring
Safety management systems
Risk triangle

ABSTRACT

The reason Flight Data and Cockpit Voice Recorders (FDRs and CVRs) exist is to learn from incidents. Probably no other single invention has yielded such significant improvements in aviation safety. Indeed, they have been so effective that we now need to redefine what is meant by the term 'incident' and the uses to which data recording technologies are now put. The paradox is that at no previous point in history have we collected so much data, yet safety performance is such that it is rarely used for its original purpose: as a lagging indicator of problems following an accident. In this paper the history of black boxes is briefly surveyed and connected to the underlying safety science knowledge base. Flight Data Monitoring (FDM) is then presented as an exemplar of the paradigm shift from lagging to leading indicators needed in order to continue learning from incidents. In many industries the pre-requisites for comparable Data Monitoring processes are already in place. The benefits to be accrued by following the example set by the aviation industry are considerable.

1. Introduction

1.1. Where are the Incidents?

2010 represented a landmark year in European aviation safety. This was the first year in the entire history of European aviation that no fatal commercial air transport incidents occurred at all (EASA, 2010). Whether it takes into account exposure by distance (0.01 fatalities per 100 million miles) or number of flights (3.1 fatalities per 10 million) the risk to the travelling public within the European aviation sector is exceedingly low (EASA, 2010). In everyday terms the probability of a fatal air crash in European airspace is approximately equal to winning second prize on the Euro Lottery (a jackpot of over €0.5 million). The highest risk for most travellers stems from the car journey to the airport (approx. 1 in 20,000 chance of a fatal accident; WHO, 2016) and using the escalators once inside the terminal building (65% of all such accidents occur in transport facilities; Schminke et al., 2013).

This safety science success story has, to a very considerable degree, benefitted from a device the sole purpose of which, was to help the industry learn from incidents. This device is the humble 'black box', or to put it more correctly, the combined features of a Cockpit Voice Recorder (CVR) and Flight Data Recorder (FDR). This paper takes the opportunity of a Special Issue on Learning from Incidents to present the brief history of black boxes and the often unstated relationships it has with fundamental safety science principles. It also reveals a strong paradox instructive for other domains. Never before has there been access to so much data, and the ability to learn from incidents, yet serious fatal incidents from which to learn have (in the aviation sector at least) almost disappeared. Powerful trends in the safety science domain are discussed, including the role of lagging, coincident and leading indicators and a new role for black boxes described. Instead of a post hoc accident analysis tool, something that needs an accident as a 'lagging indicator' of future risks, black boxes can be used as a predictive safety assurance tool, a supplier of 'big data' from which leading indicators of strategic risks can be derived in novel ways.

2. Brief history of the black box

2.1. Origins

The act of automatically recording data on system parameters over time is referred to as "data logging" or "data recording". In the aviation industry it falls under the specific heading of Flight Data Recording, which comprises several individual procedures and devices. The most prominent device is colloquially termed a 'black box'. This represents the combination of a Flight Data Recorder (FDR) and a Cockpit Voice Recorder (CVR). Other systems under the heading of Flight Data Monitoring include various Aircraft Con-

http://dx.doi.org/10.1016/j.ssci.2017.05.010
0925-7535/

Please cite this article in press as: Walker, G. Redefining the incidents to learn from: Safety science insights acquired on the journey from black boxes to Flight Data Monitoring. Safety Sci. (2017), http://dx.doi.org/10.1016/j.ssci.2017.05.010

dition Monitoring Systems (ACMS), such as engine health monitoring (e.g. the Rolls Royce EHM programme) and the wide range of parameters available from modern avionics (e.g. ARINC 573) via so-called 'Quick Access Recorders' (QARs).

Data logging can trace its formal origins to the allied fields of metrology, instrumentation, telemetry, predictive maintenance and functional performance. (Campbell, 2007). The use of data logging as a tool in post-accident analysis, and safety more generally, is a comparatively recent development. It was led by the invention of the original 'black box' by Dr. David Warren working for what would become the Australian Defence Science and Technology Organisation (DSTO) in the early to mid-1950s.

The DeHavilland Comet crashes of 1953 and 1954 provided particular motivation for the use of FDRs. The DeHavilland Comet was the world's first commercial jet airliner. It revealed itself to have problems with metal fatigue resulting in catastrophic failure of the pressurised fuselage. At the time there was very little data to inform subsequent investigations. Numerous technical committees were instituted to examine the crashes and a report entitled "A Device for Assisting Investigation into Aircraft Accidents" (1954) was produced. It suggested that *"anything which provides a record of flight conditions, pilot reactions,* etc. *for the few moments preceding the crash is of inestimable value*" (Warren, 1954).

Devices for in-flight condition monitoring did exist at the time. Early examples included the NACA2 V-g recorder. This was a device used in transport and bomber aircraft during World War II to assess operational loads (Campbell, 2007). These so-called 'analogue/analogue' FDR devices relied on film exposed to light traces or styluses leaving a physical impression on rolls of Incanol steel. So called 'scratched foil' technology continued to be used in early FDRs well into the 1950's, appearing on Boeing 707 s from 1958 onwards and pre-dating mandatory fitment by a number of years. Despite their safety benefits, these early recorders were not durable, measured only a few parameters, required significant effort to interpret and could not record voice transcripts. Further development was necessary.

2.2. Early black boxes

The technical capability for a more advanced FDR, one that included voice transcriptions, arose from a piece of consumer audio technology called the Miniphon. Manufactured by a West German electronics company called Protona GmbH, the Miniphon used a fine coil of stainless steel wire that passed from one reel to another over a magnetising "head". This enabled low quality, but nonetheless intelligible and durable voice recordings to be made. The prototype 'black box' (at this point referred to formally as a 'Flight Memory Unit') used parts from a Miniphon recorder combined with other electronics that could superimpose signals from some of the aircraft's primary controls onto approximately 30 feet of metal wire, at a rate of eight signals per second. The device was configured so that the metal wire looped continuously, storing four hours of voice and data and continually over-writing itself. It was then installed into a 'crash survivable' enclosure which could be removed from an aircraft and the recordings interpreted in the laboratory.

In 1958 the UK Air Registration Board became aware of the Flight Memory Unit. Due to the national importance of the UK jet aviation industry and the potential safety barrier the Comet crashes represented for continued foreign sales the concept was considered important enough to warrant further development. A clock manufacturer named S. Davall and Sons acquired production rights and developed the first commercial 'black box'. This became known as the "Red Egg" and is formally called the "Davall Type 1050" (Fig. 1). Notable improvements made by Dr. Warren and his team now enabled readings to be captured at a rate of 24 per second, and assured greater accuracy in the data collected from aircraft instruments and controls. It also became possible to to record voice or data, or both together. To do this up to 40 miles of stainless steel wire was needed as a recording medium.

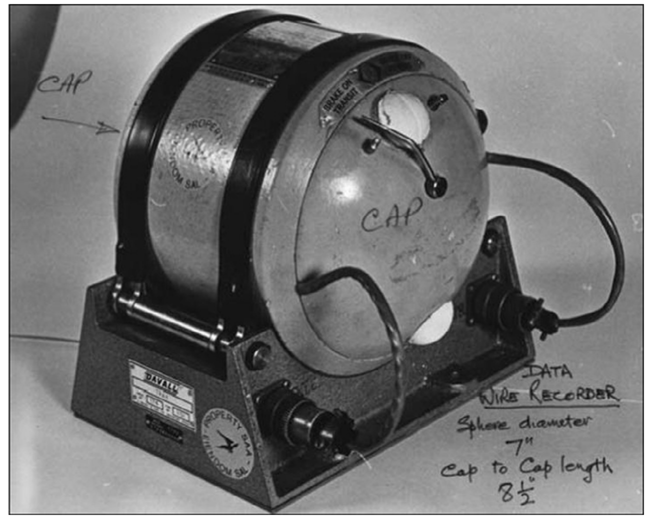

Fig. 1. The Davell Type 1050 Flight Data Recorder, or 'Davell Red Egg', so called because the London clock making firm of S. Davall & Sons Ltd manufactured it and its (red coloured) spheroid shape contained an improved magnetic wire recorder. The shape was adopted due to its location in the unpressurised tail sections of early jet airliners, and to give it sufficient strength to be crash survivable. This was the first commercial Flight Data Recorder (Source: Campbell, 2007).

Australia was the first country to make the use of Cockpit Voice Recorders (CVRs) mandatory (DSTO, 2005). The USA was quick to follow with regulations appearing in 1960 making it mandatory to carry a flight data recorder on passenger-carrying aircraft (Morcom, 1970). Similar developments were underway in the UK and changes were made to the Air Navigation Order as early as 1960, although a lengthy period of consultation and evaluation ensued. The first crash investigation, in the UK, to make substantial use of the data provided by an FDR occurred in 1965, the year they became mandatory. This accident involved a BEA Vanguard fitted with a Davell Type 1050 'red egg' which crashed in poor weather at London's Heathrow airport.

In the UK the mandatory installation of CVRs took longer. Proposals to install the devices were drawn up in 1969 by the Directorate of Flight Safety and the Department of Trade & Industry, in conjunction with the Air Accidents Investigation Bureau (AAIB), but were met with opposition. A Working Party was formed in 1970 to examine the issues further. Based on this advice the Civil Aviation Authority (CAA) proposed amendments to the Air Navigation Order to make their installation mandatory by 1975. The Staines air crash in 1972, involving a BEA Trident proved decisive. The judge who oversaw the public inquiry was frustrated by the absence of CVRs and concluded the following: *"The investigator is still left in the dark as to what was passing between the crew members by way of orders, comment or exclamation. [..] It seems to us that a requirement for the installation of cockpit voice recorders in airline aircraft (i.e. those over 27,000 kilograms all-up weight) is overdue*" (AIB, 1973, p. 56).

2.3. Development of the black box

Early FDRs were relatively stand-alone devices. The recorder carried its own sensors and, apart from an electrical supply, operated relatively independently of the host aircraft (Campbell, 2007). As a result calibration proved to be a problem. The actual state of

Please cite this article in press as: Walker, G. Redefining the incidents to learn from: Safety science insights acquired on the journey from black boxes to Flight Data Monitoring. Safety Sci. (2017), http://dx.doi.org/10.1016/j.ssci.2017.05.010