IDENTIFYING THE LOCATION OF FLIGHT DATA RECORDERS USING A SMART ELECTRONIC LOCATION FLARE (SELF) FOLLOWING A MARITIME AVIATION ACCIDENT

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Abstract

This paper seeks to describe an engineering study for accurately identifying the location of flight data recorders using the new concept of a Smart Electronic Location Flare (SELF). The paper utilises a generic maritime aviation accident sequence, where location and recovery of data are explicitly included as risk management controls against future accidents. The paper concludes with recommending a suite of functional requirements for the performance of a SELF in order to satisfy the operating demands in a generic maritime environment.

1. Introduction

"In recent years, the international aviation community has been confronted with some challenging issues involving the location and recovery of lost airplanes and recorders," said NTSB Acting Chairman Christopher A. Hart, last year. "Since there have been so many advancements in both recorder and location technology in the last 15 years, it's clearly time for us to take a fresh look at what the possibilities are for improvements in both of these areas." [8]. Recording flight data has been an intrinsic mitigation in aviation risk management for several decades [6]. However, recording a complete set of data is actually only part of the mitigation solution. As Christopher A. Hart states; both 'location' and 'recovery' are now becoming the challenging issues. All of the current tools available to the aviation industry for data recovery after a maritime air accident heavily rely upon the recovery team having a good understanding of the location of the crash site. However, it is evident from historical and very recent maritime air accidents that this is not always the case.

Malaysia Airlines flight MH370 for example disappeared from air traffic control's (ATC) radar screens at 01:19 Malaysia Standard Time (MST) in March 2014. However, the Malaysian Military radar continued to track the flight as it deviated from its planned flight path until it left the range of the radar at 02:22 MST. Further analysis in the United Kingdom lead by Inmarsat (providers of a satellite communications network) concluded that the aircraft continued the deviated flight until 08:19 MST. However the precise location could not and has not yet been determined, resulting in the search area being around 2.3 million square nautical miles [1]. This search area is roughly 370 times greater than the size of Wales, United Kingdom.

With all of the money and engineering efforts that have been put into the aviation community such as the development and adherence to Safety standards, one would assume that more money would be spent on the location and recovery systems of the aircrafts if and when an aircraft is lost. Although, the Data Recorder stores both the cockpit-voice and flight data efficaciously and has been designed to withstand an immense amount of pressure, impact and temperature deltas; the determination of the location of the Data Recorder is still too complex, or sometimes near to impossible. Why is this; how does the current location beacon system work and where does it fail? What are the solutions? This paper strives to answer these questions.

2. History of Flight Data Recording

The Black Box Recorder (BBR) was invented by an Australian scientist named Dr. David Warren in the 1950s. However, it was not until after an unexplained plane crash in Queensland, Australia that Australia became the first country in the world to make the BBR mandatory for all commercial aircraft, other countries then followed. Although the concept behind a BBR has not necessarily changed, regulations for data recording have been introduced and updated throughout the years as well as the design. Figure 1 depicts a brief overview of the BBR's history [7].

A BBR contains three specific components; a Cockpit Voice Recorder (CVR), a Flight Data Recorder (FDR) and an Underwater Locator Beacon (ULB). As soon as the BBR device has contact with water; (it is activated by a submergence sensor on the side of the BBR) the ULB begins transmission of ultrasonic pulses at a frequency of 37.5 kilohertz (kHz). The ULB continuously transmits to the surface of the water providing that the ULB has not exceeded its transmission depth limit of 4,267 meters. These ultrasonic pulses are readily detectable by sonar and acoustical locating equipment, and thus; providing the recovery team have an awareness of the location of the aircraft they will be able to receive the signals, and eventually recover the BBR [2].

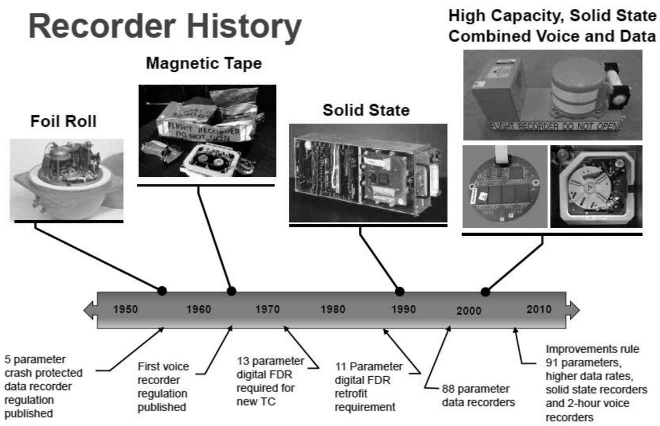

Figure 1: Flight data recorder history

3. Limitations and Concerns of the Underwater Location Beacon

As previously mentioned; the ULB does not begin transmission until it impacts water. However, this activation is not 100% guaranteed. According to research conducted by Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA) who are the French authority that are responsible for Safety investigations into accidents or incidents in civil aviation; the device has a 90% survival rate spanning 27 air maritime accidents. In layman's terms this results in 10 aircraft that cannot be recovered for every 100 aircraft maritime accidents [3]. The nominal technical failure rate requirement of a passenger aircraft is of the order of $1x10^{-9}$ per flight hour. The ULB has a failure rate of $1x10^{-1}$ per demand. It is agreed that this particular device has no impact on the Safety and Airworthiness of the aircraft and thus does not require the same development rigour as other equipment on board. However, from a more abstract view; if the data cannot be recovered then how can the manufacturers be confident that an error in their system has not caused the crash? Therefore, one could say that the recovery of the data could indirectly affect the Safety and Airworthiness of other contemporary and future aircraft.

With that in mind, it is also apparent that due to limitations of the ULB's acoustic frequency of 37.5 KHz the quoted maximum detection range is between 1.5-1.8 miles, although the environment in which the device is in can positively or negatively impact this range. Therefore, if the aircraft crashes into the sea which on average has a depth of 14,000 feet - 2.65 miles [11]; it can be very difficult and costly to locate the BBR. It is worth noting here that in 2009 the BEA recommended that the manufacturers should "make it mandatory, as rapidly as possible, for airplanes performing public transport flights over maritime areas to be equipped with an additional ULB capable of transmitting on a frequency for example between 8.5 kHz and 9.5 kHz" [3], thus vastly increasing the detection range.

Furthermore, not only does the ULB have a limitation on the transmission distance, but it also has an additional limitation on the time it can emit that signal, which is currently only for 30 days. Therefore, if the recovery team are not fully aware of the location of the crash site (e.g. MH370), they also have a time limit of 30 days before transmission runs out. It is also worth noting here; that the BEA also recommended in the aforementioned interim report; that the ULB's transmission period should be increased to 90 days [3], thus vastly increasing the chance of recovery of the BBR.

A review of recent historical maritime air accidents and the time taken to locate the accident site is presented in Table 1 below [14], which is sorted by the duration (in days) for the successful recovery of the BBR. The source data presents 31 maritime accident events in total, Table 1 presents those that have taken longer than 30 days to locate. From this data, it may be observed that the recovery of the BBR has occurred quickly after the identification of the location. It is the locating task that has been most difficult, and therefore has the most influence on the data retrieval sequence.

Days to Recover	Days to Locate	Depth (m)	Date	Location
Not yet located			08-03-14	Indian Ocean
Not located			02-10-96	Peru
Not located			02-03-93	Venezuela
2555	2555	3500	27-06-80	Italy
840	840	4400	28-11-87	Mauritius
700	670	3900	01-06-09	Atlantic Ocean
239	20	1800	01-01-07	Indonesia
150	150	92	10-10-85	Australia
77	77	100	09-04-08	Australia
60	1	1200	30-06-09	Comoros

Table 1 Days to recover FDR in maritime accidents.

4. Contribution of Historic Information in Mitigating Future Events

We have evaluated the relationship of the locating and recovery events in a generic maritime accident sequence. Our approach has been to represent the accident based on it being caused from either an emergent system behaviour, or non-emergent, i.e. something that is (or should be) known.

For paper brevity, a multi-layered, populated fault-tree representation has not been constructed. Rather, a simple, more generic fault tree has been developed to assist in thinking and communicating about the problem and research space. It is not intended to be perfect, but more illustrative in nature. Figure 2 presents the consideration.

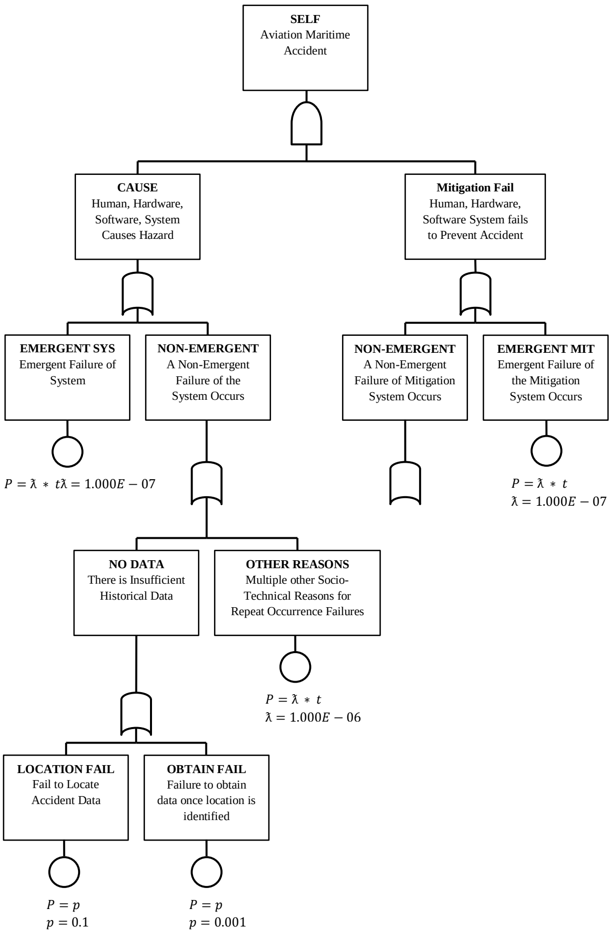

Figure 2: Fault tree representation showing Location Fail event.

The 'Location Fail' event has been given a probability of 0.1, as detailed in the research information from BEA [3] and Boeing [14]. In this representation of the accident sequence, with the logic gates as shown the 'Location Fail' event does propagate a long way through the fault tree. A full calculation is not shown as there are several other events where the probability is not relevant to this paper's research.

5. Providing a Solution with Available and Current Technology

With over 1,107 Civilian communication satellites currently orbiting the earth [4], it is initially difficult to comprehend why these satellites are not utilised in the location, and therefore, recovery of Civilian Aircraft. However, as the BBR sinks with the aircraft there is no current technology that can communicate with a satellite underwater, and thus although this communication technique is ideal, it is not a viable option.

However, many different industrial sectors are utilising these communication satellites such as oceanographers and meteorologists. Additionally, there are also many different satellite constellations that can be used for such communications; one of them being the Iridium Constellation. Iridium is the world’s only truly global mobile satellite communications company, with voice and data solutions covering every inch of the Earth’s surface [9]. Two examples that utilise this network constellation are; the Height Altitude Balloon Tracking [12] and, perhaps far more relevant the Kraken Ocean Drifter Buoy project [13]. The principle condition for success of these projects has been direct line of sight between the transmitters and the satellite. In a maritime situation, this is achieved by the transmitter floating on the surface.

5.1 Automatic Deployable Flight Recorders

These devices are already in service with several thousand attached to or built into the surface of aircraft. They take the form of a duplicate BBR and have the design of either a thick flat disc or a large square aerofoil [15]. These floating devices have duplicate feeds of all flight data and typically use strain gauges to detect a catastrophic failure of the airframe. They then activate their deployment mechanism pre-ground or pre-sea impact and activate their emergency locator transmitter. However, whilst none have deployed unnecessarily, they do add to the residual risk profile of flight; and they are relatively complicated and expensive to fit, and prohibitively expensive for any retrofit application. The equipment also still has to meet the rigorous EUROCAE-RTCA standards for minimum operation performance of flight data recorders and flight voice recorders ED-122-RTCA DO-306 [5].

5.2 Real-Time Data Streaming

There are existing flight performance requirements for regular reporting of aircraft health status and altitude data. However, the quantity of data and the 'regularity' of reporting are not specifically defined. Automatic Dependent Surveillance (ADS) already exists and this may be further developed to provide enhanced handshake data exchange and real-time data streaming of pre-defined health status indicators [10]. However, this may require additional connected-in equipment and data band widths may be the limiting factors.

As enthusiastic engineers, we decided to look into designing and manufacturing a solution for identifying the location of all the existing good data by exploiting the Iridium Constellation with reference to previously mentioned case studies. Our proposal; the Smart Electronic Location Flare (SELF).

6. Requirements for a SELF

From our engineering study and information evaluation, our list of Key System Requirements (KSR) for a SELF is as shown in Table 2 below.

KSR	Requirement	Justification
001	The SELF must be able to float for 30 days.	This maintains line of sight contact to satellite.

KSR	Requirement	Justification
002	The SELF must give positive details about its location.	It is much easier to locate when you know the location to search.
003	The SELF must allow a location accuracy of 1km to 100km.	This gives a maximum search area of approx. $31{,}000^2$km. (Only 1.5 times the area of Wales!)
004	The SELF must be lightly housed outside the pressurised hull.	Avoids tamper and allows easy separation from debris.
005	The SELF must tolerate a 200G deceleration.	This is the typical deceleration of terminal velocity into water.
006	The SELF must tolerate 350 temperature and pressure cycles to 30,000ft when dormant	This is approximately a daily flight for one year.
007	The SELF must tolerate 30 days in salt water with temperatures of -5^{o}C to $+30^{o}$C	Typical seawater conditions around the remote parts of the world.
008	The SELF must have enough power to remain dormant for 1 year	This should fit in with a typical maintenance and replacement cycles.
009	The SELF must have enough remaining power to transmit hourly for 30 days once activated	30 days on the surface should be enough to provide a positive location.
010	The SELF must not activate during normal and abnormal flight conditions	This is suggested as +/- 5G from typical landing gear design performance.
011	The SELF must activate upon break-up of the aircraft	This is suggested that any forces outside +/- 10G must activate.
012	The SELF must be cost effective for retro-fit, installation and maintenance	A nominal $1000 per SELF is proposed.
013	The SELF and its batteries must not affect the performance of the aircraft or aircraft systems	The EM signature must be passive; the batteries must not be able to cause fire

Table 2: KSR for the SELF

7. Conclusions

This engineering study has identified the importance of locating the flight data and black box recorders following a maritime aviation accident event.

We have identified that the time taken to positively locate the crash site has been a strong influence on the time taken to obtain the flight data.

We have shown that there are some existing commercial building blocks for a potential solution to obtaining a quick positive location of the flight accident site.

We have determined a suite of key system requirements to enable the identified commercial building blocks to be further matured by the industry in order to satisfy the demands of the aviation maritime and flying environment.

The next stages for our study are for us to develop a working prototype as a concept demonstrator; to register any particular design features for protection; and to develop a proof testing programme for the prototype. We will endeavour to keep the conference community informed of any notable progress.

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