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Flight Recorders – Alternative Concept for Commercial Aircraft

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***Abstract* — This paper deals with the issue of deployable flight data recorders. It gives an insight into pros and cons of this solution based on experience gained in military application. Advantages of such solution are at least worth considering as they may help reduce the number of accidents and save lives in the first place. And should the accident happen the location and extraction of evidence is much easier.**

Keywords- Flight Data Recorder; Cockpit Voice Recorder; Deployable Recorders; Safety

I. INTRODUCTION

The airline industry appears to be gravitating toward two midterm solutions for global flight-tracking since Malaysia Airlines Flight 370 (MH370) went missing in March. Individually or together, triggered flight-data transmissions and deployable flight recorders could quickly determine an aircraft's location and basic health, pre- or post-incident.

Both technologies are available today and were highly touted in the aftermath of the crash of Air France Flight 447 in June 2009, when it took five days to find wreckage and nearly two years to recover the recorders. Despite renewed pressure to act following MH370's disappearance, neither technology is yet considered a "near-term" possibility, primarily due to the cost and time to retrofit the equipment into legacy fleets or build up substantial numbers of factory-equipped new aircraft.

While conventional recorders are designed to withstand the pressure at 20,000 feet (6,100 meters) and their pingers are detectable down to 14,000 feet (4,270 meters), CVRs and FDRs lost at extreme depths can be difficult or economically impractical to locate and recover. Recorders from the Air India Boeing 747 that crashed in deep water took months to bring to the surface. The sonic locator on conventional "black boxes" is designed to operate for 30 days. An extended search could lose a recorder on the muddy ocean floor forever.

The same crash forces and circumstances that threaten recorded data also can silence Emergency Locator Transmitters (ELT). ELTs attached to the airframe can be crushed by impact, buried in collapsing wreckage, or burned by sustained fire on land. At sea, the 121.5 and 406 MHz radio signals from submerged ELTs do not penetrate water.

It is necessary to mention that the idea of Deployable flight data recorders and cockpit voice recorders is not that new as it might seem. Flight Data Recorders, Cockpit Voice Recorders and Emergency Locator Transmitters have been combined into a single deployable unit. Military aircraft such as F/A-18, F-104, Tornado and Boeing RC-135 (derived from the commercial Boeing 707) use this technology since late 1960's and it is proven to be very successful when it comes to recovery of the unit itself and the data stored in it.[2][4]

II. DFIRS - DEPLOYABLE FLIGHT INCIDENT RECORDER SET

The deployable flight recorder was developed in response to a suggestion made in the 1960s by the National Research Council of Canada, which expressed concerns about locating aircraft that crashed in remote areas and proposed some form of detachable and automatically activated Emergency Locator Transmitter (ELT) system. [3]

Deployable recorders were developed and have evolved into combined FDR/CVR units that incorporate an ELT. Such units have been installed for 35 years in military aircraft and in helicopters. In the first 25 years of operation about 110 military aircraft equipped with deployable recorders have crashed, and all 110 recorders have been recovered for use by accident investigators.

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Figure 1. Deployable Flight Incident Recorder unit (DFIRU) and the DFIRS bus interface unit (DBIU) [source: http://www.drs.com/Products/C3A/PDF/DFIRS.pdf]

The recorders are housed in an airfoil unit that is automatically ejected when on-board sensors determine that the aircraft is crashing. When deployed at impact the deployable recorder enters the airstream and attains high lift allowing it to clear the airframe and then tumble to a much less severe impact away from the accident site.

Today’s deployable recorders are commonly triggered by frangible switches located on the aircraft nose, wingtips and stabilizers, and by hydrostatic switches under the tail. As a frangible switch crushes on impact or a hydrostatic pressure switch sinks under 3 feet (0.9 meters) of water, the closed electrical circuit releases a spring catch to extend the airfoil into the slipstream. The airfoil flies free of the aircraft with the locator beacon and memory chips, while DFIR processing electronics remain in the aircraft structure. The airfoil unit rises to the water surface and floats indefinitely. The F/A – 18 system (FIGURE 1) uses a small pyrotechnic charge to ensure deployment in a high-speed crash, the DFIRS (FIGURE 3) for the Boeing RC-135 and other large subsonic aircraft uses an electromechanical release. Deployment time is less than 50 milliseconds, regardless of crash attitude and airspeed. Airfoil in F/A – 18 is located on the top on the fuselage between the rudders (FIGURE 2). In case of larger subsonic aircraft such as RC – 135 it is flush-mounted into the vertical fin (FIGURE 4). In both cases it imposes no drag penalty. [1]

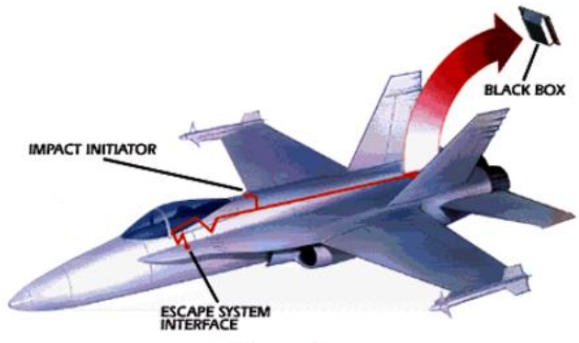

Figure 2. F/A-18 DFIR positioned between rudders [source: http://www.thermodyne1.com/general/Info_02002.html]

In a crash on land, an automatically released airfoil carries the locating transmitter and solid-state recorder memory 100 feet (30.5 meters) or more to clear a possible fireball. At sea, the deployed locator and memory float indefinitely. In situations such as impact at a high angle of incidence, where the time from initiation of deployment to impact of the airfoil is reduced, the airfoil also includes conventional crash survivability protection means allowing it to be able to withstand high levels of fire and impact. Whatever the scenario, the deployable package is mounted on the exterior of the airframe and actual experience has demonstrated that it remains at the outer edges of the crash site, significantly reducing exposure to the crash environment.

Figure 3. Deployable Flight Incident Recorder Set (DFIRS) 2100, Beacon Airfoil Unit (BAU) [source: http://www.drs.com/Products/C3A/Images/Products/dfirs2100Product.jpg]

The deployable recorder’s ELT immediately transmits the aircraft identification number and its longitude and latitude to the COSPAS – SARSAT (Search And Rescue Satellite-Aided Tracking) Programme, the international network that coordinates the detection of distress signals. The high location identification precision of 406 MHZ GPS position encoding equipped units allows identification of the beacon position to within 25 meter accuracy.

III. Deployable versus non-deployable systems

All civilian and military aircraft fly over and occasionally crash into both land and water. For example, domestic civilian and commercial and some military aircraft fly primarily over land while international civilian and commercial and some military (Navy, Marine Corps and Coast Guard) aircraft fly primarily over water. Approximately 7% of all U.S. and Canadian private and air carrier aircraft that operate and crash over North America crash into water (lakes, rivers, and coastal Waters). Approximately 45% of all U.S. Navy/Marine Corps aircraft involved in major accidents crash into water (usually at sea). Most of these crashes occur in water of extreme depth that makes it difficult, if not impossible, to locate and recover an aircraft with a non-deployable ELT/FDR/CVR. Therefore, aircraft with a primary over-the-water operational requirement is driven toward deployable and floatable ELT/FDR/CVR systems. Although overriding operational considerations, there are some obvious and subtle advantages and disadvantages associated with the use of deployable and non-deployable ELT/FDR/CVR systems. These advantages and disadvantages can be categorized and summarized as follows.

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Figure 4. DFIRS in RC – 135 is flush-mounted into the vertical fin [source: http://blog.trentonsystems.com/small-footprint-rackmount-systems-airborne-surveillance/]

A. Complexity, Reliability, and Maintainability

There are obviously considerable reliability differences between ELT/FDR/CVR system manufacturers. For example, some U.S. air carrier aircraft still carry obsolete-technology analog metal foil type FDRs' that have poor reliability. Most aircraft, however, carry digital magnetic tape type FDR's or Solid State FDR's that have good to excellent reliability. Therefore, for the purposes of this analysis, it will be assumed that the overall functional reliability of systems is equal or can be designed to be equal. The deployable system, however, has more equipment that must function reliably, i.e., the ejection system itself. Consequently, one reliability problem peculiar to deployable systems has been inadvertent deployments. The U.S. Navy/Marine Corps aircraft with deployable ELT/FDR/CVR systems (220 totals) experienced approximately 60 (27.4%) inadvertent ejections between 1979 and 1982 [5]. It was determined that approximately 5% of these inadvertent ejections were caused by component reliability failures; i.e., 95% were human operational errors while only 5% were true reliability errors. Non-deployable systems, of course, do not have any of these ejection problems. A similar reliability problem peculiar to non-deployable Emergency Locator Transmitters (ELT's) is inadvertent activations or false alarms. A sample of 361 incidents of ELT's or General Aviation aircraft between 1979 and 1981 indicated 99 (27.2%) false alarms [6]. It was found that the most common causes of these false alarms were accidental operation of the control or remote switch, switch malfunction, and inadequate installation/handling. Also, non-deployable FDR/CVR systems may have an "over reliability" problem in that, upon an accident or crash, the systems will continue to record until the engines stop or until a special sensor stops the recording. Continued recording after an accident or crash could, in time, erase the critical data required for crash analysis.

B. Survivability

The overall survivability requirements for both de*ployable and* non-deployable ELT/FDR/CVR systems to be the same; i.e., the ELT radio beacon transmits after the accident or crash and all the data stored in the FDR/CVR are recoverable for analysis after the accident or crash. The primary difference between deployable and non-deployable systems is the test requirements and consequent design requirements for survivability. The survivability test requirements for non-deployable systems are generally more severe than those for deployable systems in the areas of penetration resistance, static crush, and fire protection. The theory behind these differences is that non-deployable systems remain with the crashed aircraft and are subjected to more severe mechanical and thermal environment than do deployable systems that depart the aircraft and clear the crash and fire. As a result of the more stringent survivability test requirements, non-deployable systems must be designed with crash hardened armor thus increasing weight, volume, power requirements, and cost. A Crash Research Institute analysis of U.S. and Canadian general aviation aircraft crashes containing non-deployable ELT systems indicates that approximately 65% survive; i.e., the ELT activates and transmits after the crash [7], [8]. The primary reason for operation malfunction of the non-deployable ELT systems was determined to be caused by mechanical or thermal destruction damage. It should be noted that a non-deployable ELT on an aircraft submerged in water is virtually useless for SAR aircraft location because HF/VHF/UHF radio beacon signals transmitted through water cannot be received by SAR aircraft radio equipment. A similar analysis of U.S. and Canadian military aircraft crashes containing deployable ELT systems indicates that approximately 99% survive. [5][9] These data also include ELT survival from inadvertent deployments.

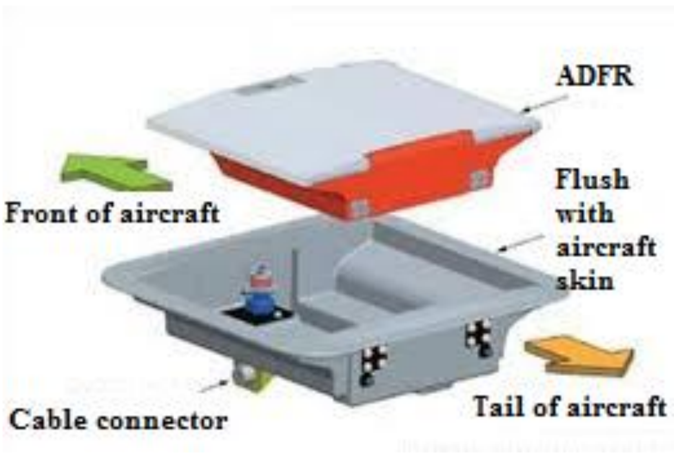

Figure 5. ADFR with mounting casing [source: https://qzprod.files.wordpress.com/2014/04/adfr1-1.jpg]

Deployable recorders over water do not present a radio beacon transmission and SAR radio reception problem because the ELT floats and transmits an omnidirectional VHF or UHF signal at ranges up to 50 miles. Empirical crash survivability data for FDR/CVR systems are even more limited than that for ELT systems. The U.S. National Transportation Safety Board (NTSB) compiled crash survivability data (1959 to 1973) on 509 U.S. air carrier aircraft crashes with non-deployable FDR/CVR systems [10]. Of the 509 crashed systems, 409 (81%) fully survived, 33 (6%) partially survived, and 67 (13%) either did not survive or were not recovered. The NTSB data indicate that the location of non-deployable FDR/CVR systems in the aircraft is critical to recorded media survivability, i.e., media survivability is increased considerably if the FDR/CVR is located as far aft in the aircraft as possible. There are no known cases of deployable FDR/CVR not surviving a crash. The best sample comes from Federal Republic of German F-104G aircraft crashes with deployable FDR/CVR systems. Out of 10 (1977 to 1981) catastrophic high-speed crashes into land, all ejected FDR/CVR systems survived and the data were recovered and analyzed [11].

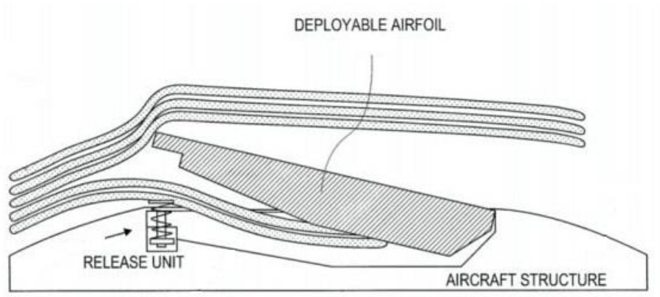

Figure 6. Deployment of ADFR from its mounting structure [source: http://i.kinja-img.com/gawker-media/image/upload/s--PWdpWl-A--/c_fit,fl_progressive,q_80,w_636/qtyyxkrv0s9tibgpj7yg.jpg]

C. Search And Rescue (SAR)

The SAR requirements for both deployable and non-deployable ELT/FDR/CVR systems are the same. Obviously, successful SAR operations are highly dependent on proper ELT radio beacon activation/transmission and the ability of the SAR aircraft to receive the radio signal, find and visually locate the downed aircraft, and recover survivors and the FDR/CVR systems. There is a considerable difference between deployable and non-deployable system capability to adequately accomplish the SAR mission. Deployable ELT systems have an excellent activation, survivability, and transmission record. The problem with deployable systems has been the inadvertent deployments that require unnecessary recovery, sometimes repair, and reinstallation of the ejected package. Non-deployable ELT systems, on the other hand, have a poor activation, survivability and transmission record. The primary reasons for this poor record are inadequate actuation sensors (usually acceleration switches), poor crash survivability, and inability to transmit VHF/UHF emergency signal through wreckage obstruction or through water. Therefore, deployable systems have a clear advantage over non-deployable systems for SAR operations.

D. Weight, Volume, and Power Requirements

As with any avionics equipment, it is a design and operational objective to minimize weight, volume, and power requirements of ELT/FDR/CVR systems. Commercial non-deployable magnetic tape systems are relatively heavy (13 to 23 kg), voluminous (26 to 40 dm3), and drawing 60 to 100 W power. Existing deployable systems tend to weigh less (9 to 16 kg), be less voluminous (20 to 30 dm3), and require less power (40 to 70 W). The latest deployable and non-deployable systems using digital solid state technology and new lightweight crash protection materials have reduced system weight, volume, and power requirements considerably, i.e., weight (2,5 to 8 kg), volume (9 to 16 dm3), and power (5 to 45 W).

E. System Safety

The only safety considerations for ELT/FDR/CVR systems are batteries (ELT operation) and ejection systems. Many ELT systems use lithium batteries because of their long storage life (up to 5 years) and their lightweight and small volume. Some lithium batteries (not currently in ELT systems) have proven to be hazardous by exploding under high temperature conditions. Considerable development and evaluation has been accomplished in this area and it was found that lithium batteries present no hazard if they are designed and tested to current specifications.

Another perceived hazardous component is the explosive squib release mechanism used on some deployable systems. The squibs used on deployable systems are completely enclosed devices of the type that have been used on aircraft for years and, in fact, pose no hazard to aircraft or personnel. One real hazard does exist, however, with the mortar type deployable system. When fired or ejected, the deployable package departs the aircraft at about 100 ft/sec. Therefore, if ejected inadvertently while the aircraft is on the ground, the package could be hazardous or fatal to nearby personnel. For this reason alone, the mortar type ELT/FDR/CVR deployable systems are not being used.

F. Cost

Acquisition costs (including development, test, evaluation and installation) tend to be higher for deployable ELT/FDR/CVR systems due to their additional complexity. Cursory cost analysis indicates that the acquisition cost of a non-deployable magnetic tape system should be less than $20,000 per system while a deployable magnetic tape system should be less than $30,000 per system. Digital solid state memory technology has initially increased these acquisition costs because of their state-of-the-art development; however, costs have decreased as more semiconductors and systems were produced. It should be noted that solid state technology has increased reliability, maintainability, survivability, and operability while reducing weight, volume, and power requirements.

G. Cost/Benefits

Several cost/benefit analysis of ELT/FDR/CVR systems on U.S. Navy aircraft have established very high net results. These positive net cost/benefits are derived primarily from projected reductions of aircraft and aircrew losses, SAR missions, and recovery operations through the use of recorded flight data. Obtaining information immediately after an aircraft accident or incident permits rapid determination of cause and immediate implementation of appropriate corrective action to prevent recurrence. In addition to providing significant economic benefits, such system capabilities can enhance fleet operational readiness by reducing or not requiring the grounding of aircraft. ELT radio beacon transmissions from a downed aircraft can reduce SAR flying hours. In cases where the approximate location of a downed aircraft is unknown and even when a wide area must be searched, fewer SAR flying hours are required through the use of ELT locating. ELT transmission and SAR aircraft receiving provide rapid location of surviving aircrew and passengers. SAR operations indirectly derive benefits from the FDR/CVR systems since recorded information can be used to reduce accidents/incidents and thus a reduction in SAR missions. The deployable ELT/FDR/CVR provides more cost effective benefits to the SAR operation due to its high reliability, survivability, and water recovery capabilities.

IV. CONCLUSION

There are ways that can make air transport even safer and more enhanced than it is nowadays. The comparison of relatively common system of Deployable Flight Incident Recorder used in military and the FDR and CVR used in commercial aircraft has shown that the deployable recorders have better survivability as they are deployed away from the crash site and are spared the tough conditions inside the fuselage.

Because of the Emergency Location Transmitter (ELT) integration into deployable recorder, the crash site can be easily and promptly located which helps rescuing potential survivors. The rescue mission is far more economical because the ELT provides accurate coordinates, so no resources are being wasted. This is very advantageous in case of ditching or over-the-ocean accident. Flight recorder is deployed away from the aircraft and it floats on the water surface and at the same time it transmits the emergency signal for COSPAS-SARSAT network. Recorders are easily retrieved from the surface providing valuable information almost immediately. Furthermore considerable resources are saved as the need for the underwater extraction of recorders is eliminated.

The higher costs of deployable systems are attributed to the additional complexity, ejection hardware, and installation. Even though the production and servicing costs of deployable recorders might be higher at first sight, the 99% survivability rate gives place for savings from costly SAR missions when the position of the aircraft is not certain and/or the flight recorders are sunk deep in the ocean. However the primary benefit is the reduction of aircraft and aircrew losses through the use of recorded data from aircraft accidents and incidents.

Even though some might argue that the future is in real-time data transmission from aircraft to the ground station, we believe that this is a technology of a more distant future because as we know the number of parameters recorded by a FDR and CVR in single aircraft is around 1000, and when we consider how many flights are simultaneously airborne, the data load is too huge to be barred by the existing data network without limiting other services such as navigation or communication. Therefore we believe that the implementation of deployable flight recorders into commercial aircraft would be advantageous at least until the real-time data streaming becomes more secure and reliable.

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