What's new to prevent the disappearance of an aircraft over oceanic areas

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1. Lessons learned from the disappearance of an aeroplane over an oceanic area

Among the 25 accidents involving large transport aircraft over water in the 21st century, the disappearance of commercial transport aircraft over the sea, though incomprehensible and even unacceptable to the general public, has occurred a few times, with two major occurrences standing out:

- The accident involving the Airbus A330 flight AF447, registered F-GZCP and operated by Air France, which occurred on June 1, 2009, over the Atlantic Ocean. Locating the wreckage required four search phases over 22 months and more than 30 million euros, eventually finding it at a depth of 3,900 meters.
- The accident involving the Boeing 777 flight MH370, registered 9M-MRO and operated by Malaysia Airlines, which occurred on March 8, 2014, probably over the Indian Ocean. Despite several hundred million dollars spent on searches, the aircraft remains missing.

When loved ones disappear at sea, it is even more difficult for families to grieve, highlighting the critical need for technological improvements both on board aircraft and on the ground to enable the aircraft wreckage to be located and the recovery of flight recorder data over oceanic areas.

The purpose of this paper is to summarize all the work initiated as part of the BEA safety investigation following the disappearance of flight AF447, leading to the implementation of systems on board aircraft to prevent the disappearance of aircraft over oceanic areas.

2. Mandatory equipment to prevent disappearance

a. BEA safety recommendations

The AF447 accident highlighted significant challenges in the timely localization and subsequent recovery of the wreckage and flight recorders. In response, the BEA established international working groups to develop optimal solutions, ensuring that future sea searches would not face the same difficulties encountered with AF447.

In the BEA investigation reports, we proposed safety recommendations based on cost-benefit analyses and a comprehensive review of all potential solutions for locating underwater wreckage. These recommendations aimed to facilitate the application of our findings by ICAO.

Some safety recommendations were directed at ICAO, suggesting proposed amendments to ICAO Annex 6 Part I (see below). The BEA has actively followed up all the safety recommendations to ensure their implementation.

- Aircraft tracking: *study the possibility of making it mandatory for aeroplanes performing public transport flights to regularly transmit basic flight parameters (for example position, altitude, speed, heading);*
- Underwater Locator Beacon (ULB): *make it mandatory, as rapidly as possible, for aeroplanes 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) and for a duration adapted to the pre-localisation of wreckage;*
- ULB: *extend as rapidly as possible to 90 days the regulatory transmission time for ULB's installed on flight recorders on aeroplanes performing public transport flights over maritime areas;*
- Flight recorder data recovery: *ask the FLIREC Panel*[1] *to establish proposals on the conditions for implementing deployable recorders of the EURICAE ED-112 type for aeroplanes performing public transport flights;*
- Aircraft in distress location: *make mandatory as quickly as possible, for aeroplanes making public transport flights with passengers over maritime or remote areas, the triggering of data transmission to facilitate localisation as soon as an emergency situation is detected on board;*
- Aircraft in distress location: *study the possibility of making mandatory, for aeroplanes making public transport flights with passengers over maritime or remote areas, the activation of the emergency locator transmitter (ELT), as soon as an emergency situation is detected on board.*

b. ICAO Standards and Recommended Practices

As of today, the ICAO Annex 6 Standards and Recommended Practices (SARPs) include the following requirements:

Aircraft tracking

- *Operators shall track the position of an airplane through automated reporting at least every 15 minutes during in-flight operations over oceanic areas.*

Although Flight AF447 was transmitting its position every 10 minutes, automated reporting every 15 minutes (4D/15) will not provide a precise location but will help identify a search area. This was not the case for MH370. Additionally, ICAO has addressed operator

[1] The FLIRECP is the ICAO group proposing amendments to Annex 6 regarding Flight Recorder Standards and Recommended Practices (SARPs).

procedures for use in the event of a missed 4D/15 tracking report to avoid delays in locating the accident site, an issue highlighted in the BEA's final report on the AF447 accident;

Underwater Locator Beacon

- *Since January 1, 2018, all airplanes on long-range over-water flights must carry a securely attached underwater locating beacon (ULB) operating at a frequency of 8.8 kHz.* This ULB operates at a frequency that can be detected by all vessels in the area of the accident site. The expected detection range is 5 to 10 kilometers, with enough battery power to transmit for 90 days.

DK180 photo credit Dukane Seacom Inc

SID88 photo credit Novega

It is challenging to determine if all long-range aircraft are equipped with this device. The two companies manufacturing the low-frequency ULB have sold a number that corresponds to the number of aircraft performing long over-water flights. In the case of MH370, with the loss of all communication capabilities, the 8.8 kHz ULB is currently the only device capable of making a difference in locating the wreckage underwater for aircraft built before January 1, 2024.

But there is a caveat for Boeing aeroplanes. The 8.8 kHz ULB is mounted on the forward side of the nose pressure bulkhead. Boeing selected this location after more than 50 distinct configurations were evaluated. These evaluations were based on safety to passengers, flight and ground crew, and certification focused tests and analysis in order to meet regulator requirements. The 8.8 kHz ULBs are installed in all Airbus families since January 1, 2018.

As for the 37.5 kHz ULBs attached to flight recorders, since January 1, 2018, these ULBs must operate underwater for a minimum of 90 days. Only 90-day 37.5 kHz ULBs are now sold by manufacturers. From BEA's past experience, the 37.5 kHz ULB can be detected by a hydrophone operated from sea level up to a depth of 1,500 meters. At sea level, the ULB can be detected horizontally up to 3,000 meters from the vertical position of the ULB. Hydrophones operated from sea level are not operational below a depth of 1,500 meters. The extended underwater operation of the 37.5 kHz ULB gives more time to use hydrophones such as the Towed Pinger Locator (TPL) if the wreckage is deeper than 1,500 meters. Two TPL hydrophones were lent to the BEA by the US government to search for the AF447 wreckage at a depth of 3,900 meters, but each TPL represents about 20 tons of equipment, making it difficult to bring on site.

Flight recorder data Recovery

- *All airplanes with a maximum certificated take-off mass of over 27,000 kg and authorized to carry more than nineteen passengers, for which the application for type certification is submitted to a Contracting State on or after January 1, 2021, must be equipped with a means, approved by the State of the Operator, to recover flight recorder data and make it available in a timely manner.*

One way to comply with this standard is the installation of deployable flight recorders. Airbus plans to install deployable recorders on A-321XLR, A-330neo and A-350.

Flight recorder installation on Airbus A350 (Credit: Leonardo and Airbus)

Another means of compliance is the transmission of flight recorder data to the ground. EASA has conducted a study to evaluate the capability of transmitting all flight recorder data to the ground. The overall objective of the project was to identify and assess a series of candidate solutions for the wireless transmission of flight recorder data from commercial air transport aircraft in the event of an accident in a remote area on land or an oceanic area. This assessment considered the challenges, constraints, and limitations of each technical solution, as well as the demanding conditions of an accident.

The evaluation of the candidate solutions addressed technical feasibility and maturity, performance and related constraints, and cost indicators compared to current flight data recorder installations. A legal study was also included. The complete study can be found at:

https://www.easa.europa.eu/en/research-projects/quick-recovery-flight-recorder-data

Nevertheless, the manufacturers may need ICAO or the regulatory authorities to carry out additional work to better define who owns the flight recorder data, which entity can store the data on the ground to avoid any conflict of interest, etc.

Location of an Aircraft in Distress

As part of the AF447 investigation, the BEA launched the international Triggered Transmission of Flight Data Working Group (TTFD), which included over 120 members from various countries, representing a broad range of stakeholders: accident investigation authorities (BEA, NTSB, AAIB, TSB, ATSB, ASC, etc.), regulatory authorities (ICAO, EASA, FAA, etc.), airframe manufacturers (Airbus, Boeing), service providers, equipment and satellite manufacturers (Astrium/Star Navigation, Inmarsat, Iridium, FLYHT, etc.), and international associations (IATA, COSPAS-SARSAT, etc.). The working group was created to assess the technical feasibility of triggering in-flight transmission of data based on indications of an emergency, to help locate the wreckage after accidents of fixed-wing aircraft over maritime or remote areas. The work provided performance-based values (4 NM and transmission at least once a minute).

The working group's report can be found on the BEA website: TTFD report.

Real-time analysis of flight parameters by onboard equipment and using data transmission triggered through logical equations was a well-established mechanism in 2010. However, the BEA had no criteria for detecting a distress situation based on flight parameters. The concept of triggered flight data transmission involves detecting an imminent distress situation using flight parameters and automatically transmitting data from the aircraft until the distress ends or the aircraft collides with the ground or water. Buffered data from moments preceding the distress could also be sent.

The TTFD WG aimed to determine if triggered transmission could help locate debris after aircraft accidents at sea or in remote areas, with two main criteria: maximizing the probability of detecting an imminent catastrophic event (ideally 100%) and minimizing unnecessary triggered transmissions (ideally 0%). It was essential for the system to be smart enough to prevent false positives and maintain credibility. The group also examined whether satellite connections and transmission times were compatible with the alert times provided by the emergency detection criteria, and if current or future satellite antenna technology allowed continuous transmission, even for aircraft in unusual attitudes and subject to high pitch and roll rates.

Using anonymized cases provided by group members, the BEA established a database of flight data files containing 68 sets of flight parameters from real accidents and incidents, as well as 621 sets of flight parameters for "normal" flights. The study demonstrated that criteria based on a limited set of recorded flight parameters could detect 100% of all 68 accidents and incidents in the database. It also showed that these criteria could be adjusted to avoid unnecessary transmissions. For certification purposes, this database was made available to all manufacturers wishing to develop criteria for detecting distress situations.

The study proved that developing reliable emergency detection criteria was feasible. The robustness of the detection could be further improved with more elaborate criteria and additional parameters available on modern aircraft data buses, which were not available for this study.

A simulation for all accidents in the study and around the Earth compared alert times with transmission capability using the geostationary earth orbit Inmarsat constellation. The results showed that, for 85% of cases, data transmission would be possible before impact with the surface. Additionally, the corresponding search area at the point of impact would be contained within a radius of 4 nautical miles. Moreover, the Cospas-Sarsat medium earth orbit (MEO) constellation could provide even better coverage with more satellites in view.

An analysis of the operation of automatic fixed ELT (ELT-AF) on board large transport aircraft showed that ELT-AF worked as designed during accident sequences. This means that ELT-AF were triggered after survivable accidents and were destroyed during high-energy accidents. Thus, developing ELT-AF that would be triggered in-flight before impact was considered a promising solution to precisely locate an accident site regardless of the severity of the impact. After discussions with Cospas-Sarsat, it was decided to further study the possibility of offering a new class of ELT which will be triggered in flight (ELT-DT) before an accident.

Based on all these results, the BEA concludes that determining the position of debris within a radius of 4 nautical miles is technically feasible through triggered flight data transmission via satellite communication systems and/or activation of distress beacons (ELT-DT) before impact. Therefore, based on the work of this working group, the BEA issued a safety recommendation in July 2011:

The BEA recommended that EASA and ICAO make mandatory as quickly as possible, for aeroplanes making public transport flights with passengers over maritime or remote areas, triggering of data transmission to facilitate localisation as soon as an emergency situation is detected on board.

Based on the work of the BEA working group and after the disappearance of MH370, ICAO created the Global Aeronautical Distress Safety System (GADSS) concept. The ICAO document Doc 10165 should be published in 2024 to detail all the benefits of this concept. One of the main outputs of the GADSS concept is the development of SARPs dedicated to the precise location of an accident site:

As of 1 January 2025, all aeroplanes of a maximum certificated take-off mass of over 27 000 kg for which the individual certificate of airworthiness is first issued on or after 1 January 2024, shall autonomously transmit information from which a position can be determined by the operator at least once every minute, when in distress, in accordance with Appendix 9.

European regulations are well aligned with ICAO SARPs.

Additionally, EUROCAE documents have been published in line with the work conducted by the BEA on triggered transmission of flight data. The first EUROCAE document, ED-62B, is the Minimum Operational Performance Standard (MOPS) for Aircraft Emergency Locator Transmitters (ELT) operating at 406 MHz, including specifications for ELT-DT. The second EUROCAE document, ED-237, is the Minimum Aviation System Performance Specification (MASPS) for Criteria to Detect In-Flight Aircraft Distress Events to Trigger Transmission of

Flight Information. Both documents are referenced by ICAO SARPs. Both documents are referenced by the ICAO Annex 6 SARPS.

The ICAO Standard for locating an aircraft in distress is performance-based which means that autonomous distress tracking (ADT) systems such as the ELT-DT or SatAuth GCP, comply with the Standard. Nevertheless, all aircraft manufacturers have decided to install ELT-DTs by January 1, 2025, on new built aircraft from January 1, 2024. They have developed triggering criteria using, in particular, the database of 68 accidents and incidents compiled by the BEA for triggered transmission of flight data.

One of the main benefits of ELT-DT is a precise location of accident site over water with the objective to locate and save potential survivors by Search And Rescue (SAR) assets.

As of end of June 2024, more than 380 Airbus aircraft have been delivered with ELT-DT, including models from the A320 family, A330, A220 and A350.

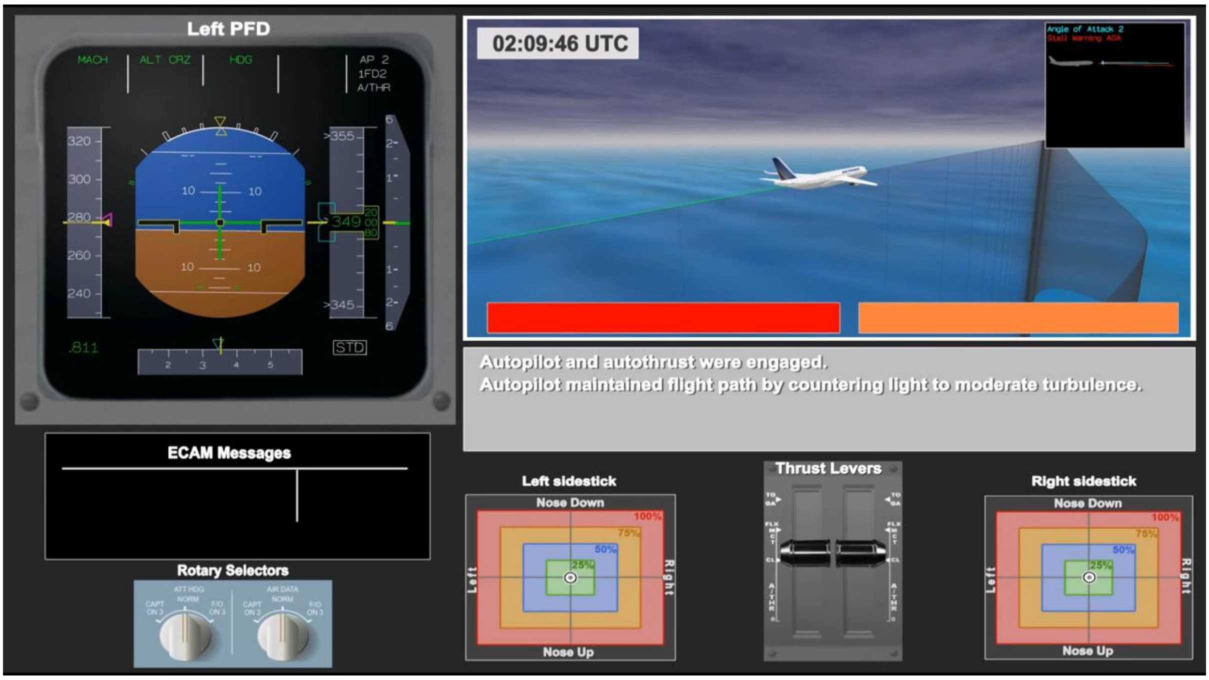
All ELT-DT messages will be sent to COSPAS-SARSAT, with a repository in the local relevant RCC and simultaneously sent to the Location of an Aircraft in Distress Repository (LADR). This repository will be managed by Eurocontrol.

In June 2024, ICAO released State Letter 2024/016, requiring States to request aircraft operators, air traffic services (ATS) units, rescue coordination centres (RCC), and State representatives to register in the Ops Control Directory to receive notifications that distress messages have been sent to the LADR. Accident Investigation Authorities (AIA) may also register.

The LADR is a critical component of the GADSS, providing the means to store and make available all information related to the position of an aircraft in distress, as described in ICAO Annex 6, Part I Standard 6.18.

Benefits of ELT-DT Case Study: AF447

AF447 reported its position every 10 minutes while cruising at FL 350 and Mach 0.82. Although the SARPs requirement for position reporting every 15 minutes over oceanic areas might not have significantly improved localization, without this reporting and in the absence of low-frequency ULB, ADS-B, or ELT-DT it would have been impossible to locate the AF447 wreckage.

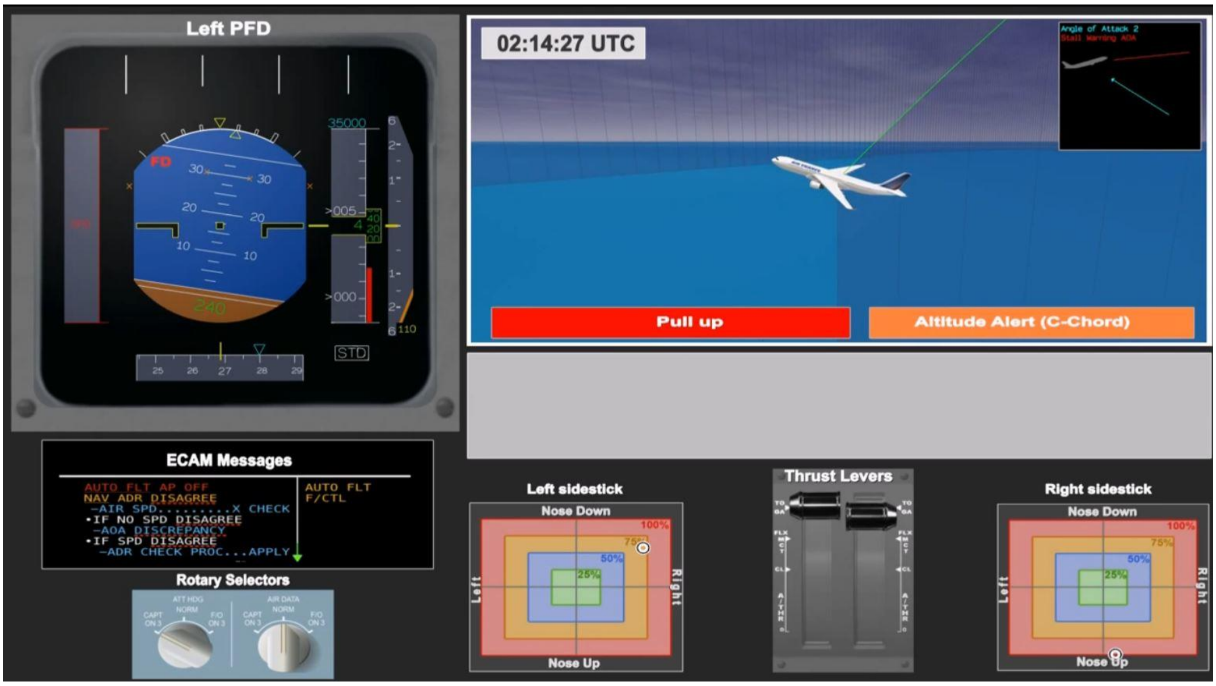


Parameter information of the AF447 flight while in cruise

The activation of a system to precisely locate the point of impact, based on triggers associated with conditions likely to result in an accident if left uncorrected, aims to provide high-frequency transmission while minimizing false positives to limit costs.

During the AF447 event, a combination of EUROCAE ED-237 criteria (unusual attitude/unusual speed) should have triggered the transmission of ELT-DT messages every 5 seconds. At that time, the altitude was 37,500 ft, Mach 0.68, and angle of attack 5°, meeting the triggering criteria for the distress condition and stall warning. Analysis shows that the trigger would have been active for 216 seconds between the distress condition trigger and the time of impact.

Based on the ACARS position messages transmitted every 10 minutes, the most probable accident zone for AF447 on June 1, 2009, was within a 40 NM radius of the last known position transmitted by ACARS. The first debris were found six days later. Unknown currents between June 1 and June 6, 2009, and imprecise retro drift calculations complicated the search. **With ELT-DT, the last reported position would have been around 0.1 NM from the point of impact.** At the time of AF447's impact with the water, the trigger would still have been active, in addition to the proximity to terrain trigger.



Parameter information of the last seconds of the AF447 flight

ADS-B would have provided similar resolution. However, ELT-DT may be a more robust system for pinpointing the location of the impact. During the accident sequence of the Airbus A320 flight MS804, registered SU-GCC and operated by Egyptair, which occurred on May 19, 2016, over the Mediterranean Sea, ADS-B transmission stopped a while before impact, but the ELT-AF provided the accident site's position within 6 NM. In the event of a fire, as suspected in the case of flight MS804, thanks to the GNSS receiver embedded in ELT-DT, an ELT-DT equipped aircraft would trigger transmission upon signal loss at the ELT-DT's entrance.

Additionally, in situations involving the loss of all communication, such as with MH370, the ELT-DT is designed to be resilient to deactivation from the cockpit. If the computer that calculates the triggering criteria is turned off, the ELT-DT will still be triggered.

3. Sources of position information

In the future, for accidents over water, accident investigation authorities may receive various positions of the crash site from different sources:

- ADS-B based on ground antennas: This information is public, but more detailed information can be obtained from operators like FlightRadar24, FlightAware, or other ADS-B service providers. It will happen if the aircraft is less than 200 NM from the shore.
- ADS-B based on satellites (AIREON): There is no free access to position information outside Europe, but European accident investigation authorities may have access to this data. The main advantage of ADS-B based on satellites is that it provides position information over oceanic areas. Many airlines use ADS-B based on satellites to comply with ICAO SARPs.

- Secondary radar information from the ATS unit: If the aircraft is close enough to the shore.
- Aircraft tracking every 15 minutes from the operator.
- ELT-DT position information from the nearest SAR authority or Eurocontrol.

When an accident occurs over water, the first task of the investigating authorities is to locate the accident site. Local authorities may receive various position data from different sources, and selecting the most accurate one is crucial, in coordination with the AIA of the State of Occurrence and the accredited representatives of the AIA involved in the investigation.

The BEA's experience highlights that the initial position selected for deploying search vessels may not always be the appropriate one. Despite ULBs now operating for up to 90 days, time remains critical. The accident site must be located as soon as possible to allow search authorities time to find the flight recorders and any wreckage parts.

4. Conclusion

One of the many reasons why aviation maintains a high level of safety is the willingness to learn important lessons from events where there have been catastrophic consequences. It took two major fatal accidents at sea and substantial international efforts to introduce new provisions ensuring better localization of wreckage and recovery of flight recorder. With the up-to-date ELT-DT system along with all the new systems on-board new aircraft it is hoped that no State will have to face the disappearance of a large transport aircraft again.