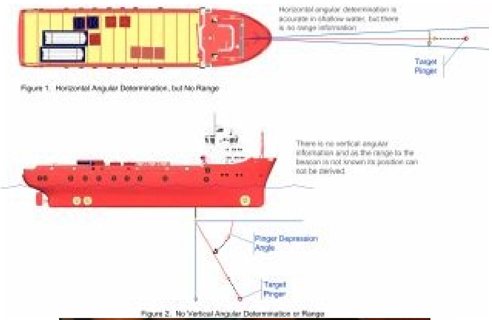
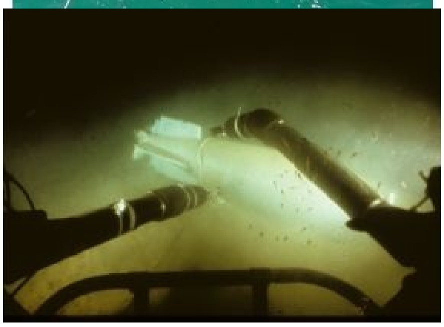
A GAME OF HUNT-THE-PINGER AGAINST THE CLOCK

Deep-water Black-box Retrieval





Restricted operating life, limited range and bearing ambiguity in deep water are the known limitations of current locator beacons mounted on aircraft. These problems raise important questions: what is the best method of locating existing pingers and what can replace them? In deep water, pinger detection equipment could be installed on a submarine. Alternatively, a transponder beacon can provide both range and bearing information, as well as demonstrate a significantly longer listening life. Although heavier and therefore not suitable for light aircraft, commercial aircraft could easily accommodate such beacons allowing easier retrieval of the aircraft black boxes.

In the July/August issue of Hydro International, a news feature was published shortly after the crash of Air France Flight AF 447. Following the research into the crash, this article focusses on the deep-water black box retrieval.

Final moments of Flight AF447.

Underwater Beacons

All commercial air transport (CAT) aircraft are fitted with underwater locator beacons to assist in the relocation of black box flight data recorders (FDRs) and cockpit voice recorders (CVRs). These beacons are free-running pingers transmitting at an acoustic frequency of 37.5kHz with a claimed battery life of at least 30 days. The maximum detection range is determined primarily by the frequency and the transmission power, with an initial source level of 160.5dB re 1µPa @ 1m, which reduces to 157.0dB re 1µPa @ 1m, after 30 days. The quoted maximum detection range is 2-3km, although this is influenced by environmental conditions. The equipment used to search for the beacons can be deployed from a surface vessel, on a remotely operated vehicle (ROV), autonomous underwater vehicle (AUV) or operated by a diver. The detection equipment acts only as a direction finder, however, with no indication being given of the range to the pinger (Figure 1).

Successful Recovery

A successful search and recovery of the FDR and CVR was carried out in 2006 following the loss of an Armavia Airbus A320 in 500m of water in the Black Sea. The operation used a ROV-Homer system comprising an ROV-mounted directional receiver and control software. The received direction information from the pingers was communicated to the surface via the umbilical of the ROV. This information was displayed by a computer, informing the pilot in which direction to turn to move the ROV to the target location. The operation was completed in four days with both black boxes being recovered.

Pinger Limitations

Localising a pinger from the surface in shallow water is relatively easy, as described above. This task becomes increasingly difficult as water depth increases, however, because the direction is affected by both the horizontal bearing and the depression angle to the beacon (Figure 2). When trying to locate a pinger beacon in deep water, the detection equipment should be installed on a self-propelled underwater vehicle (either an ROV/AUV or a manned submersible). However, this presupposes that the position is already known to within the maximum 2-3km detection range. When aircraft debris is scattered over a large area, as with the recent Air France 447 accident off the Brazilian coast in depths up to 3.5km, a grid search must be conducted using underwater acoustic listening equipment. This equipment must be deployed as deep as possible to overcome the bearing/depression angle conflict (such as on the nuclear submarine described in a news feature in the July 2009 issue of Hydro International). The additional time required to mobilise and carry out this search highlights the second major limitation of fitting CAT aircraft with pinger beacons: that of their limited operational life.

Problem Illustration

In July 1980 I was participating in an underwater navigation exercise off the coast of Sicily. The exercise was suddenly terminated, as the vessel operator had been asked to locate and recover an experimental torpedo lost in water depths of 600m during trials off the north-west coast of Italy. A pinger was installed on the torpedo operating at 38kHz and less than 10 days' battery life was remaining.

Four days later, our vessel was on station at the last known position of the torpedo. An acoustic directional receiver was used to confirm the reception of the pinger transmissions at the water surface. As well as the manned submersible, there was a one-atmosphere observation diving bell on the vessel. This was deployed to the seabed for an initial visual search. This was unsuccessful, however, due to the difficulty of determining the location of a pinger in deep water using only bearing information.

LBL Solution

With less than five days' pinger battery life remaining, a further attempt was made to determine the most likely location. Horizontal bearings were taken at the surface from three known positions offset as far as possible from each other in order to reduce the effect of the vertical angle on the signal reception. This resulted in a position fix nearly 500m from the initial estimate. Four transponders were deployed centred on the new location to form a long baseline (LBL) array. These were calibrated using the transponder depths and multiple baseline measurements to provide a local seabed navigation reference frame should the pinger battery fail. The pinger receiver was then mounted at the front of the submersible. Using the ranges measured from an LBL transducer (mounted on top of the submersible, see Figure 3) to these four transponders, the submersible's position could be determined within the array to sub-metre accuracy.

Once on the seabed, horizontal bearings were determined to the pinger from three different positions within the local frame of reference of the acoustic transponders. From the high LBL position accuracy, the size of the ‘cocked hat' bearing intersections was reduced to less than 1m. The submersible was then navigated and positioned to visual range of the target location (Figure 4). A further four dives were required to attach a recovery line to the torpedo, using the LBL system each time to navigate back to its location, the pinger battery having by then failed.

Acoustic Transponder

The limitations experienced above (limited battery life and ambiguous bearings in deep water) would not apply if an acoustic transponder had been used as a locating device on the torpedo. A transponder beacon only replies in response to an acoustic signal on its interrogation frequency, hence providing both range and bearing information as well as having a significantly longer listening life.

AODC Beacons

An incident in the North Sea in 1979, involving a diving bell umbilical cable failure, led to the loss of two lives. This tragedy emphasised the need for an efficient and fast diver-based relocation technique. I had successfully used a diver acoustic ranging system, the Rangemeter, to accurately survey gas pipelines in the North Sea (described in the ‘As it Was' in the October 2001 issue of Hydro INTERNATIONAL). The ease with which it could be used to locate and find a transponder led to the recommendation to the Association of Offshore Diving Contractors (AODC) that all diving bells should be marked by transponders (Figure 5). AODC trials unequivocally confirmed the superior operational advantages of using transponders compared with pingers. It was agreed with the AODC that the same reply frequency should be used for the transponders as the transmission frequency of the pingers currently marking aircraft black boxes: 37.5kHz. In view of the local nature, a maximum interrogation range of 500m was considered adequate. A transponder also boasts a listening life in excess of 18 months between battery changes, giving adequate time to locate and recover a lost diving bell.

Beacon Comparison

Table 1 illustrates that, under normal conditions, the existing pinger would not be detectable from the surface in depths exceeding 2km. A transponder, operating at the existing 37.5kHz but at a higher power, would be detectable from the surface in depths down to 5km in normal operating conditions. Alternatively,
a transponder operating at 10kHz would be detectable from the surface down to full ocean depth under most operating conditions. A

transponder-type beacon operating at the same 37.5kHz frequency but with 20dB greater peak acoustic power output (a factor of 100 in power ratio) is about twice the volume of the existing pinger beacon. A 10kHz transponder would be about four times the volume. See Table 1 below.

Recommendations

In January 1961 oceanologist Mike Borrow (managing director of Underwater Marine Equipment Ltd) was asked by the UK Ministery of Aviation to suggest possible solutions for the location and recovery of aircraft lost in deep water. After the Comet crash in the Mediterranean in 1967, an article was published in the *New Scientist* followed by another article after the loss of an Air India 747 in 1985 off Ireland in water depths of over 2km, commenting on the slow development of a suitable solution. This resulted in the Society for Underwater Technology in the UK in 1985 inviting industry (manufacturers, operators, Ministry of Defence, universities and research organisations) to discuss further developments at a conference organised by Mike Borrow at HMS *Dolphin* in February 1986. Notwithstanding, the Civil Aviation Authority has maintained the original specification since 1988 for aircraft-mounted acoustic beacons.

When locating existing pingers in water depths of less than 2km, a vessel can search about 15 square nautical miles per hour. Once a few pings have been detected, a suitable receiver installed on an ROV can then recover the FDR and CVR. This approach is impractical in deeper water, however. The initial grid search could be carried out with detection equipment installed in a deep submergence submarine (as during the search for AF 447) or on a towfish. However, the time required to mobilise and carry out this operation emphasises the serious limitation posed by the 30-day pinger battery life.

This limitation could be overcome by replacing the pingers with more powerful transponders, which would, however, be larger and heavier. Although there might be a reasonable argument against replacing pingers on smaller CAT aircraft, they do not usually fly long distances over deep oceans. The commercial aircraft that do make such journeys could easily afford to carry a heavier, more powerful, transponder beacon, leading to easier black box recovery (Figure 6) should a disaster strike.

Table 1. Typical Detection Range performance

Beacon	Maximum depth of beacon detection (km)	
	Normal conditions	Good conditions
Pinger: 37.5kHz (160.5dB re 1µPa)	1-2	4-5
Transponder: 37.5kHz (180dB re 1µPa)	4-5	6-7
Transponder: 10kHz (180dB re 1µPa)	7-9	17-22

Update 24/05/2016

The black boxes are equipped with underwater beacons to help search teams find the cockpit voice and flight data recorders. The Laplace (French ship) is carrying three hydrophones to help detect the signal (WSJ).

For information regarding the crash of EgyptAirs Flight MS804, continue reading on The Guardian. Below a short summary regarding the latest updates:

- Still no sign of black box. A satellite did spot a 1.2 mile long oil slick, approximate 25 miles from last location of MS804.
- Depth location 8,000 to 10,000 feet (2,500 - 3,000 meters).
- Greece, Italy, US, France, Cyprus and Britain have joined the search.
- Officials say they suspect terrorism but still haven't scanned evidence to make any strong case about what brought the plane down.
- Officials said the plane made several violent “swerves” right before it disappeared, including a 90-degree turn to the left, a plunge from 37,000ft to 15,000ft, and a then a 360-spin.