# Underwater Locator Beacon Signal Propagation on Tropical Waters


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***Abstract* — In the last 12 years, about 16 crashes involving commercial aircraft have ended in sea-crashes and dozens of maritime accidents resulting in sunken vessels occur every year. At the instant the aircraft Flight Data Recorder (FDR), or the ship Voyage Data Recorder (VDR), comes in contact with water, a locating device called ULB (Underwater Locator Beacon) starts a continuous emission of acoustic signals, or pings, for a minimum period of 30 days. After the crash of the Air France 447, in 2009, a discussion began about the effectiveness of the pingers in assisting in the location of "black boxes" and whether they should undergo some kind of modification to improve its capabilities. In order to understand the propagation of the pulses emitted by the ULBs in regions of past accidents, two fundamental aspects of the irradiated signal quality are analyzed: the components and specifications of pingers used in "black boxes" – as for example the acoustic intensity and the emitted waveform shape – and the physical characteristics of the medium and in what form it influences in the transmission of the pulses during its propagation by the ocean. This work has as main objective to contribute to the quantification of the detection capability of ULBs emitted pings in different scenarios /configurations and hopefully being able to clarify major issues regarding ULBs signal propagation assisting in the improvement of search and rescue (SAR) operational methodologies and in the development of "black box" acoustic signals detection instruments**



***Keywords—ULB; pinger; black box; FDR; VDR; SAR; Underwater acoustic propagation;***


## I. Introduction

Data from the last communication and from the "black box" of the Airbus A330 AF-447, which was on the Rio-Paris route, indicated that at 01:45 on June 1st, 2009, the aircraft was passing through a region of moderate atmospheric instability. Investigations conducted by the french Bureau of Investigation and Analysis (BEA) for Civil Aviation Safety point to the formation of ice crystals in pitot tubes and erroneous readings of velocities that culminated in the crash of the plane in the Atlantic Ocean about 650 km from the archipelago of Fernando de Noronha [1].

As soon as a black box comes in contact with water, a device called Underwater Location Beacon (ULB) (Fig. 1) is activated and starts emitting acoustic pulses at a regular interval and a specific frequency. When triggered, an ULB must remain sending pulses for a minimum of 30 days, but soon to be extended to 90 days [2]. This is the time that the search and rescue (SAR) teams will have to locate the black box and thus retrieve the data with the necessary information to clarify the exact reasons for the accident.

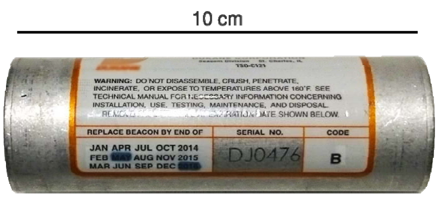


Fig. 1. Underwater Locator Beacon (ULB) device.

Within 30 days of the date of the AF-447 crash, no acoustic locator signal had been detected. From that moment the search process became even more complex, succeeding to find the plane almost two years after the accident. As a result of the difficulty in locating the signals emitted by the Airbus ULBs, it was established that as of March 1, 2015, all ULBs must have a minimum lifetime of 90 days [2] and from January 1, 2018 all aircraft with takeoff weight of more than 27,000 kg shall have a Low-Frequency ULB (8.8 kHz) installed in their fuselage [3].

In order to measure the detectability of the acoustic pings, a characterization of the properties of the emitted signals was made and how they interact with the ocean. Two levels of complexity were used to understand signal propagation and attenuation at sea. Firstly, the decay of signal intensity was studied using a simplified model, considering transmission losses by geometric spreading and media absorption. Then, by means of a computational approach, a numerical model of ray tracing by gaussian beams was used.

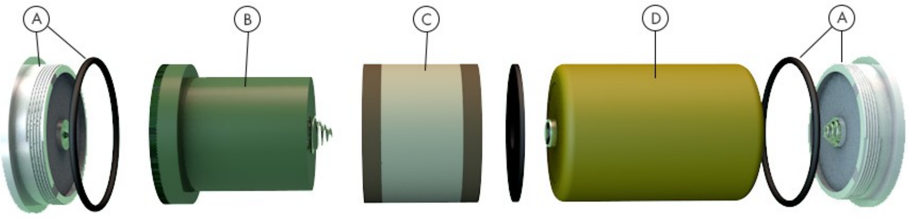


Fig. 2 – Exploded view of an ULB

## II. The Anatomy of an Underwater Locator Beacon (ULB)

In order to understand how ULBs operate and how they generate the acoustic pulses used in SAR operations, it is presented below some physical, electrical and operational details of these devices. ULBs are also known as pingers due to the emission of pings at regular intervals and it is a mandatory device in any type of commercial aircraft, airplane or helicopter, flying over water and passenger vessels or ships with gross tonnage exceeding 3000 Ton [3]. In the case of aircraft the ULB is attached to a Flight Data Recorder (FDR), and in the case of vessels, it is coupled to a Voyage Data Recorder (VDR).

### *A. General Characteristics*

The minimum operating requirements [1,4], that an ULB must meet is presented in Table I:

Table I. Minimum operational requirements

| | |
|---|---|
| Operating frequency | 8.8 / 37.5 ± 1 kHz |
| Operating depth | 6,096 meters |
| Operating life | 30 / 90 days |
| Acoustic output | ≥ 160.5 dB re 1μPa @ 1m |
| Acoustic output after 30/90 days | ≥ 157 dB re 1μPa @ 1m |

In the schematic diagram of Fig. 2, the main elements that internally make up an ULB are represented: the metal envelope including the end caps and a switch (A) when in contact with water, activates the pulse generation circuit which it is embedded in a urethane cylinder (B). The circuit drives the piezoelectric ceramic that will transform the electric pulses into pulses of acoustic pressure (C). And, the power source for the device comes from a non-rechargeable lithium battery (D).

### *B. Signal Characteristics*

When the end caps contacts are immersed in water, the circuit is energized, generating a low voltage pulse train modulated by a square wave with 1 second period and 10% duty cycle. This signal, when injected into a transformer, is raised to the level necessary to excite the piezoelectric cylinder. Finally, the ceramic generates a mechanical wave that will propagate through the housing to the environment [6].

Despite the simple characteristics of acoustic pulse generation and transmission, the marine environment poses challenges in the detection of these signals. In Fig. 3Fig.  it is shown a preliminary measurement of the signal, and the acoustic spectrogram, of a pinger in Guanabara Bay, Rio de Janeiro, with its various sources of natural and anthropic noise.

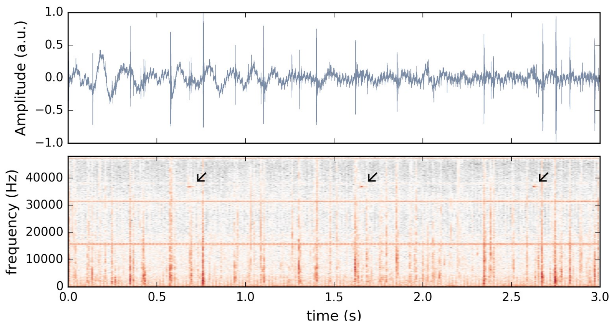


Fig. 3. Time series and spectrogram of a brief period of the submarine acoustic landscape near Urca beach, Rio de Janeiro. The ULB was placed at a distance of 150 m from the hydrophone. Detected pings are indicated by arrows.

After looking the form of the signal emitted by the source (ULB), the next step is to try to understand how a ping will propagate through the water and how much energy will be lost to the medium.

### *C. Simplified Model*

This first approach uses a simpler method that considers only the factors that degrade the signal in the direct path from the source to the detector. The pinger emits a signal with a certain intensity and directivity (Source Level - SL and Directivity Index - DI). During propagation, this signal loses part of its energy to the medium (Transmission Loss - TL) under certain ambient noise conditions (Noise Level - NL). The relationship between these terms which is expressed by the passive sonar equation [7] and it is illustrated in the Fig. 4:

$$RL = SL + DI - TL - NL \tag{1}$$

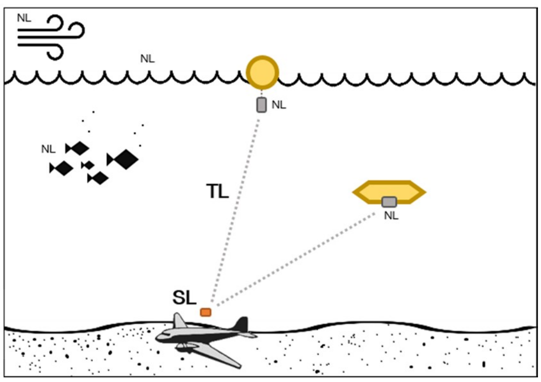


Fig. 4. In the diagram are illustrated two autonomous platforms (in yellow) equipped with acoustic receivers capable of capturing the signals emitted by the pinger (in orange) whose intensity (SL) is "degraded" by the medium (TL) and the noise of several sources (NL).

*1) Source Level (SL) and Directivity Index (DI):* refers to the intensity level of the signal emitted by the source (in dB relative to 1 μPa at 1 m), which for the pinger is SL = 160.5 dB (Table I). The emission pattern of ULBs can be considered isotropic meaning a directivity index equal to 0 dB.

*2) Transmission Loss (TL):* considering a homogeneous and isotropic environment and the geometric scattering as spherical we can obtain the transmission losses, in units of dB/km, through:

$$TL = \text{Absorption} + \text{Spreading} \quad (2)$$

*a) Underwater Sound Absorption:* The main cause of acoustic absorption in water at sub-MHz frequencies is due to the ionic relaxation of some molecules dissolved in water. One of the Mullen models [8], which predicts the contribution of this phenomenon, to the Atlantic Ocean region, was used to calculate the absorption constants:

$$\alpha_{8.8k} = 0.7 \text{ dB/km}$$

$$\alpha_{37.5k} = 10.1 \text{ dB/km}$$

*b) Geometrical Spreading:* When sound rays converge or diverge, the variation of the separation between two very close rays can be used to estimate the sound transmission loss. This phenomenon is known as geometric scattering [9] and can be expressed by*:*

$$S = N \log_{10}(R) \quad (3)$$

A spherical spreading (N=20) was used, intending conservative results. Combining the values found above we obtain TL values for each of the frequencies of interest (Fig. 5):

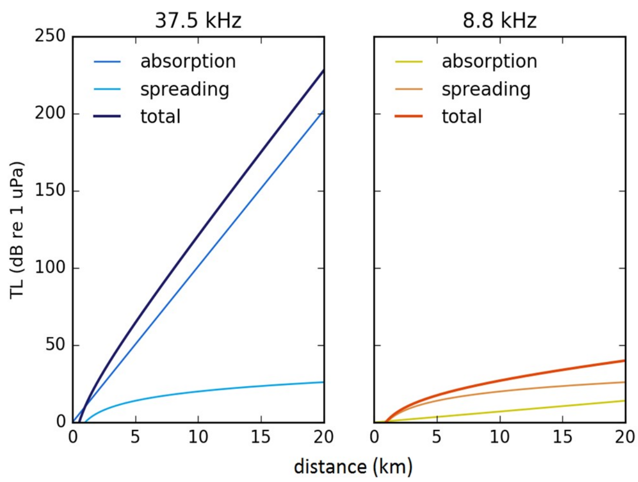


Fig. 5. Transmission loss (TL) values for 37.5 kHz ULB (left) and 8.8 kHz LF-ULB (right).

*3) Noise Level (NL):* Based on the work of Wenz, 1963 [10], the noise level in each of the frequencies was calculated for a state of sea 1 (SS 1) and assuming a system with a 2 kHz bandwidth, resulting in the following values:

$$NL_{8.8k} = 67 \text{ dB re } 1\ \mu\text{Pa}$$

$$NL_{37.5k} = 61 \text{ dB re } 1\ \mu\text{Pa}$$

With all the terms of the sonar equation calculated, we can find the intensity of the pings in relation to the distance. By replacing the previously found values, we can define the sound pressure level (SPL) at the receiver as:

$$RL = 160.5 - [\alpha_f(r) + 20\log_{10}(r/1000)] \quad (4)$$

Running this equation through a range of values up to 100 km we obtain the receiver level curves for the LF-ULB and the regular ULB displayed on Fig. 6.

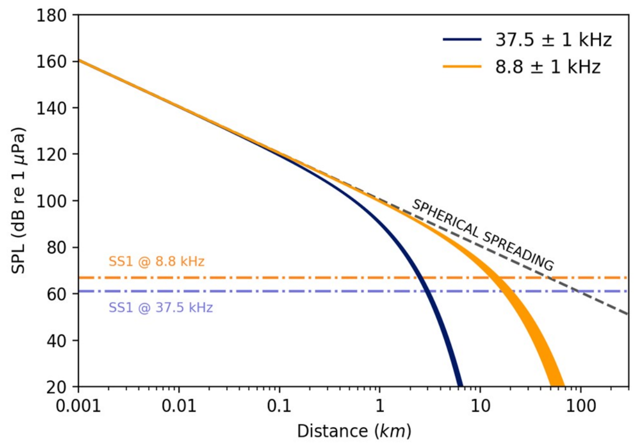


Fig. 6. Sound pressure levels against distance. The curve for a regular ULB (37.5 kHz) is depicted in blue and for an LF-ULB in yellow.

It is worth noting that this is a simplification of a complex environment and does not take into account facts such as multipath, refraction and diffraction/scattering effects of sound by suspended particles, bubbles, and plankton in the water column, etc.

## *D. Numerical Model*

In order to compare the signal intensity variation with the results found with the simple propagation model, a computational approach was used to analyze the ULBs pings propagation under the condition of the AF-447 crash site.

The BELLHOP model [11], suitable for high-frequency sources, was used. This model is capable of computing acoustic fields in ocean environments using a gaussian ray tracing. As input parameters for the model we used bathymetric data from ETOPO1, sound speed profiles calculated from the TS profiles of the GDEM-V 3.0 base, and the background sediment structure data, which are composed basically of clay was extracted from the BST v2.0 database.

Simulations were performed for the two frequencies of interest: 8.8 and 37.5 kHz. The resulting graphs from each simulation (Fig. 7) present the values of the sound pressure levels as a function of distance.

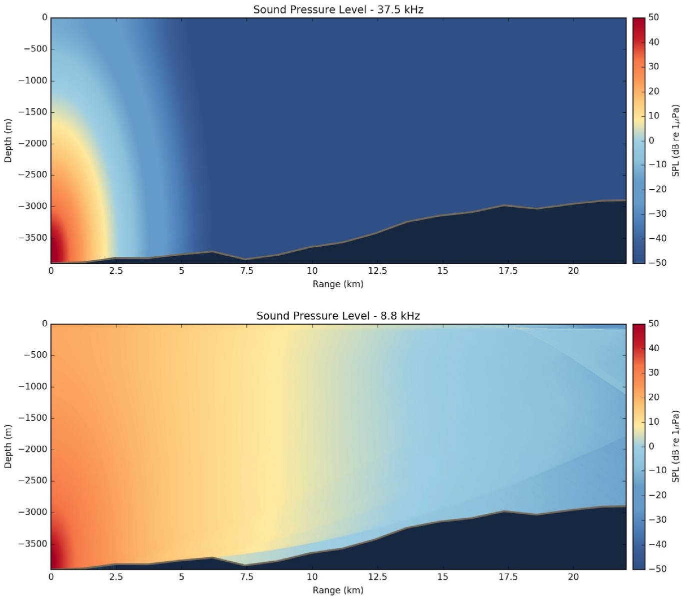


Fig. 7. Sound pressure level field simulations of a signal at 37.5 kHz (top) and 8.8 kHz (bottom).

### *E. Models Comparison*

In order to compare the outputs obtained between the simplified model and the numerical model, the results are shown in Fig. 8, exposing the difference between the results of the computational method and the simplified method.

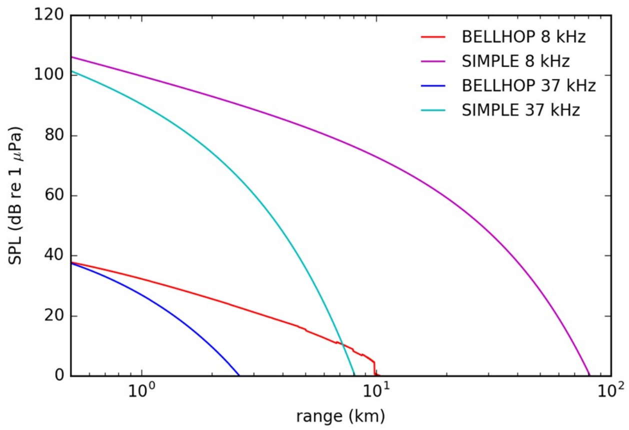


Fig. 8 – Combined results of the simplified model (magenta and cyan) and the numerical model (red and blue).

## III. CONCLUSION

Following the two simulation exercises practiced in this study, it is quite clear that the decision made by the aeronautical administrators to adopt the use of a low-frequency ULB in the fuselage of airplanes was justified. Despite the differences between the two methods, both agree on higher pressure values at longer distances for the 8.8 kHz pings, as expected. The numerical model indicates the possibility of detection (SPL > 10 dB [12]) at distances of ~8 km for the 8.8 kHz signal, while for the 37.5 kHz signal the detection distance was ~2 km.

Probably the best way to assess the validity of the previous models is through a field test using a real source and a real detector (hydrophone) in a condition similar to those used to run the theoretical models. Therefore, such endeavor should be conducted in the future with the necessary rigor to generate enough information to allow further comparison to this study.

## ACKNOWLEDGMENT

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