International Student Challenge Problem in Acoustic Signal Processing 2019

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The Acoustical Society of America (ASA) Technical Committee on Signal Processing in Acoustics develops initiatives to enhance interest and promote activity in acoustic signal processing. One of these initiatives is to pose international student challenge problems in acoustic signal processing (Ferguson and Culver, 2014). The International Student Challenge Problem for 2019 involves processing real acoustic sensor data to extract information about a source from the sound that it radiates. Students are given the opportunity to test rigorously a model that describes the transmission of sound across the air-sea interface.

It is almost 50 years since Bob Urick's seminal paper was published in *The Journal of the Acoustical Society of America* on the noise signature of an aircraft in level flight over a hydrophone in the sea. Urick (1972) predicted the possible existence of up to four separate contributions to the underwater sound field created by the presence of an airborne acoustic source. **Figure 1** depicts each of these contributions: direct refraction, one or more bottom reflections, the evanescent wave (alternatively termed the *lateral wave* or *inhomogeneous wave*), and sound scattered from a rough sea surface. Urick indicated that the relative importance of each contribution depends on the horizontal distance of the source from the hydrophone, the water depth, the depth of the hydrophone in relation to the wavelength of the noise radiated by the source, and the roughness of the sea surface.

The Student Challenge Problem in Acoustic Signal Processing 2019 considers the direct refraction path only. Other researchers have observed contributions of the acoustic noise radiated by an aircraft to the underwater sound field from one or more bottom reflections (Ferguson and Speechley, 1989) and from the evanescent wave (Dall'Osto and Dahl, 2015). When the aircraft flies overhead, its radiated acoustic noise is received directly by an underwater acoustic sensor (after transmission across the air-sea interface). When the aircraft is directly above the sensor, the acoustic energy from the airborne source propagates to the subsurface sensor via the vertical ray path for which the angle of incidence (measured from the normal to the air-sea interface) is zero. In this case, the vertical ray does not undergo refraction after transmission through the air-sea interface. The transmitted ray is refracted, however, when the angle of incidence is not zero. Snell's Law indicates that as the angle of incidence is increased from zero, the angle of refraction for the transmitted ray will increase more rapidly (due to the large disparity between the speed of sound travel in air and water) until the refracted ray coincides with the sea surface, which occurs when the critical angle of incidence is reached. The ratio of the speed of sound in air to that in water is 0.22, indicating that the critical angle of incidence is 13°. The transmission of aircraft noise across the air-sea interface occurs only when the angle of incidence is less than the critical angle; for angles of incidence exceeding the critical angle, the aircraft noise is reflected from the sea surface, with no energy propagating below the air-sea interface. The area just below the sea surface that is ensonified by the aircraft corresponds to the base of a cone; this area can be thought of as representing the acoustic footprint

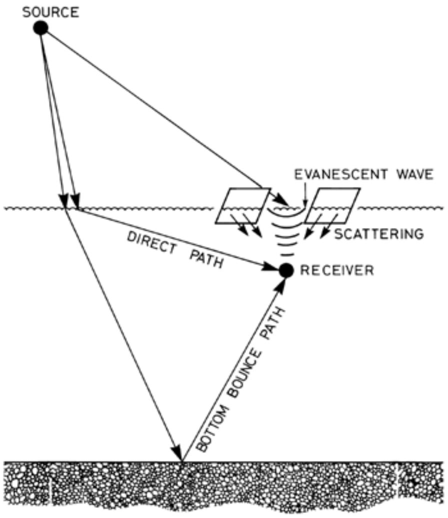

Figure 1.*Contributions to the underwater sound field from an airborne source. After Urick (1972).*

of the aircraft. The base of the cone subtends an apex angle, which is twice the critical angle, and the height of the cone corresponds to the altitude of the aircraft.

The first activity of the Student Challenge Problem is to test the validity of Urick's model for the propagation of a tone (constant-frequency signal emitted by the rotating propeller of the aircraft) from one isospeed sound propagation medium (air) to another isospeed sound propagation (seawater), where it is received by a hydrophone. Rather than measuring the variation with time of the received acoustic intensity as the acoustic footprint sweeps past the sensor (as Urick did), it is the observed variation with time of the instantaneous frequency of the propeller blade rate of the aircraft that is used to test the model. This is a more rigorous test of the model. The frequency of the tone (68 Hz) corresponds to the propeller blade rate (or blade-passing frequency), which is equal to the product of the number of blades on the propeller (4) and the propeller shaft rotation rate (17 Hz). For a turboprop aircraft, the propeller blade rate (or source frequency) is constant, but for a stationary observer, the received frequency is higher (commonly referred to as the "up Doppler") when the aircraft is inbound and lower ("down Doppler") when it is outbound. It is only when the aircraft is directly over the receiver that the source (or rest) frequency is observed (allowing for the propagation delay). The Doppler effect for the transit of a turboprop aircraft over a hydrophone can be observed in the variation with time (in time steps of 0.024 s) of the instantaneous frequency measurements of the received signal, which is recorded in the file Time vs. Frequency Observations. This file can be can be downloaded at acousticstoday.org/iscpasp2019. The first record at time −1.296 s and frequency 73.81 Hz indicates that the aircraft is inbound, and for the last record at time 1.176 s and frequency 63.19 Hz, it is outbound.

Task 1

Given that a turboprop aircraft is in level flight at a speed of 239 knots (123 m/s) and an altitude of 496 feet (151 m); that the depth of the hydrophone is 20 m below the (flat) sea surface; that the isospeed of sound propagation in air is 340 m/s; and that in seawater, it is 1,520 m/s, the students are invited to predict the variation with time of the instantaneous frequency using Urick's two isospeed sound propagation media approach and comment on its goodness of fit to the measurements in the file.

Task 2

Figure 2 is a surface plot showing the beamformed output of a line array of hydrophones as a function of frequency (0 to 100 Hz) and apparent bearing (0 to 180°). This plot shows the characteristic track of an aircraft flying directly over the array in a direction coinciding with the longitudinal axis of the array. The aircraft approaches from the forward end-fire direction (bearing 0°; maximum positive Doppler shift in the blade rate), flies overhead (bearing 90°; zero Doppler shift), and then recedes in the aft end-fire direction (180°; maximum negative Doppler shift). For this case, the bearing corresponds to the elevation angle (ξ), which is shown in **Figure 3**, along with the depression angle (γ) of the incident ray in air. The (frequency, bearing) coordinates of 32 points along the aircraft track shown in **Figure 2** are recorded in the file Frequency vs. Bearing Observations, which can be downloaded at the above URL. Each coordinate pair defines an acoustic ray. Similar to the previous activity, for Task 2, the students are invited to predict the variation with the elevation angle of the instantaneous frequency of the source signal using Urick's two isospeed media approach and to comment on its goodness of fit to the actual data measurements. The aircraft speed is 125 m/s, the source frequency is 68.3 Hz, and the sound speed in sea water is 1,520 m/s.

Task 3

To replicate Urick's field experiment, a hydrophone is placed at a depth of 90 m in the ocean and its output is sampled

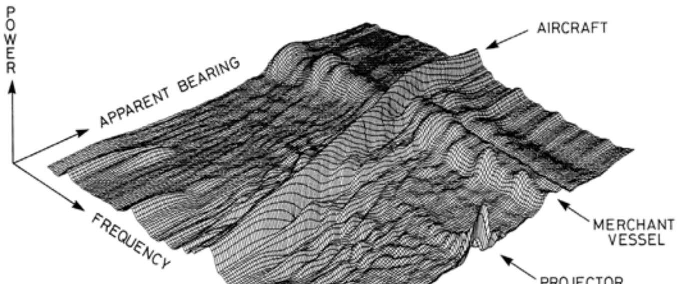

Figure 2. *Variation with frequency and apparent bearing of the output power of a line array of hydrophones. Prominent sources of acoustic energy are labeled. After Ferguson and Speechley (1989).*

at 44.1 kHz for 2 minutes, during which time a turboprop aircraft passes overhead. The sampled data are recorded in Waveform Audio File format (WAV) with the file name Hydrophone Output Time Series, which can be downloaded at the above URL. The students are invited to estimate the speed of the aircraft (in meters/second), the altitude of the aircraft (in meters), the source (or rest) frequency (in hertz), and the time (in seconds) at which the aircraft is at its closest point of approach to the hydrophone (i.e., when the source is directly above the sensor).

The deadline for student submissions is September 30, 2019, with the finalists and prize winners (monetary prizes: first place \$500; second \$300; third \$200) being announced at the 178th meeting of the Acoustical Society of America in San Diego, CA, from November 30 to December 4, 2019.

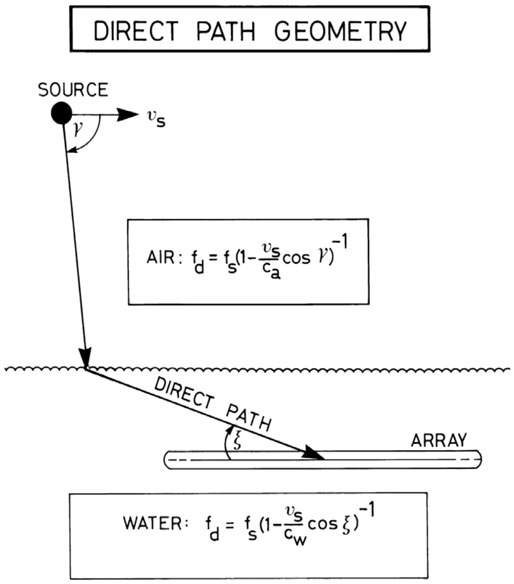

Figure 3. *Direct refraction acoustic ray path and mathematical descriptions of the Doppler frequency (f_d), where f_s is the source frequency, v_s is the source speed, ξ is the elevation angle of the refracted ray, γ is the depression angle of the incident ray, and c_a and c_w are the speed of sound travel in air and water, respectively. The Doppler frequency and elevation angle are unique to each individual acoustic ray. After Ferguson and Speechley (1989).*

References

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