

# A LIGHT AIRCRAFT AS A LOW-FREQUENCY SOUND SOURCE FOR ACOUSTICAL OCEANOGRAPHY

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## **Abstract**

The sound from a propeller-driven aircraft is largely generated by the propeller itself. Its acoustic signature consists of a series of harmonics, the lowest of which, the fundamental, is typically in the region of 100 Hz, with the higher harmonics appearing at multiples of the fundamental. Experiments have recently been conducted off the coast of southern California, using several different types of single-engine, light aircraft, which show that the first 10 or so propeller harmonics are detectable not in the atmosphere, in the water column and also on sensors buried to a depth of about 1 m in the seabed. The Doppler-shifted comb of frequencies produced by an aircraft propeller is the basis of a recently developed technique for making point measurements of the low-frequency sound speed and attenuation in marine sediments.

## **1. Introduction**

Most measurements of sound speed and attenuation in sediments are performed using a travel path between a source and a receiver or between two receivers (Buckingham and Richardson, 2002). At low frequencies, however, below about 5 kHz, such techniques are difficult to implement because of the long (several wavelengths) travel path required.

An alternative technique (Buckingham *et al.* 2002, Buckingham *et al.* 2002a) overcomes the travel-path problem by using just a single receiver buried to a depth of about 1 m in the sediment. An airborne source, in the form of a light aircraft, provides a Doppler-shifted signal at the buried phone. The difference between the up- and down-shifted frequencies on approach and departure, respectively, returns a measure of the sound speed in the sediment; and the amplitude of the received signal as a function of time yields the attenuation.

## **2. Propeller harmonics**

Propeller-driven aircraft produce an acoustic signature consisting of a sequence of tones, the lowest being the fundamental, with higher harmonics at multiples of the

fundamental. These tones are produced mainly by the propeller; and the frequency of the fundamental, typically about 100 Hz, is determined by the rotation rate and the number of propeller blades.

It has long been known that the sound from a large propeller-driven aircraft can be detected beneath the sea surface (Urick 1972, Medwin and Hagy 1972, Medwin Helbig and Hagy 1973, Richardson *et al.* 1995). Only recently, however, has it been shown that the propeller harmonics from a light aircraft are detectable on hydrophones in the water column and also on sensors buried to a depth of about 1 m in the sediment (Buckingham *et al.* 2002, Buckingham *et al.* 2002a). In these experiments, the water depth was about 20 m.

As the aircraft flies over the sensor station, the frequency of each harmonic is Doppler-shifted, upwards on the approach and downwards on departure. The difference frequency scales with the speed of the aircraft, the unshifted frequency of the harmonic, and the reciprocal of the speed of sound in the layer (atmosphere, ocean or sediment) in which the sensor is located. Thus, the difference frequency on a microphone in the atmosphere is approximately five times greater than that on a hydrophone in the water column. This dependence on the local speed of sound is a direct consequence of Snell's law. Examples of the Doppler-shifted signals received on acoustic sensors in the atmosphere, ocean and sediment during the overflight of a Diamond Star DA 40 single-engine, light aircraft with a three-blade propeller is shown in Fig. 1. On this occasion, the aircraft was flying at a speed in the vicinity of 60 m/s and an approximate altitude of 60 m.

### **3. Geoacoustic inversions**

As the difference between the Doppler-shifted frequencies on approach and departure depends on the local sound speed, it seems plausible that a light aircraft could provide a means of making low-frequency (100 - 500 Hz) point measurements of the speed of sound in marine sediments. Several inversion techniques for obtaining estimates of the sediment sound speed from the Doppler shifted harmonics are currently being developed. These include full-wave theoretic inversions of the Doppler-shifted signals received on sensors located in either the water column or the sediment. The basis of these techniques is a full-wave, forward propagation model of the sound field created in a three-layer waveguide (atmosphere, ocean and sediment) by a fast-moving airborne source. The same model could also provide the basis of an inversion technique for obtaining the attenuation in the sediment.

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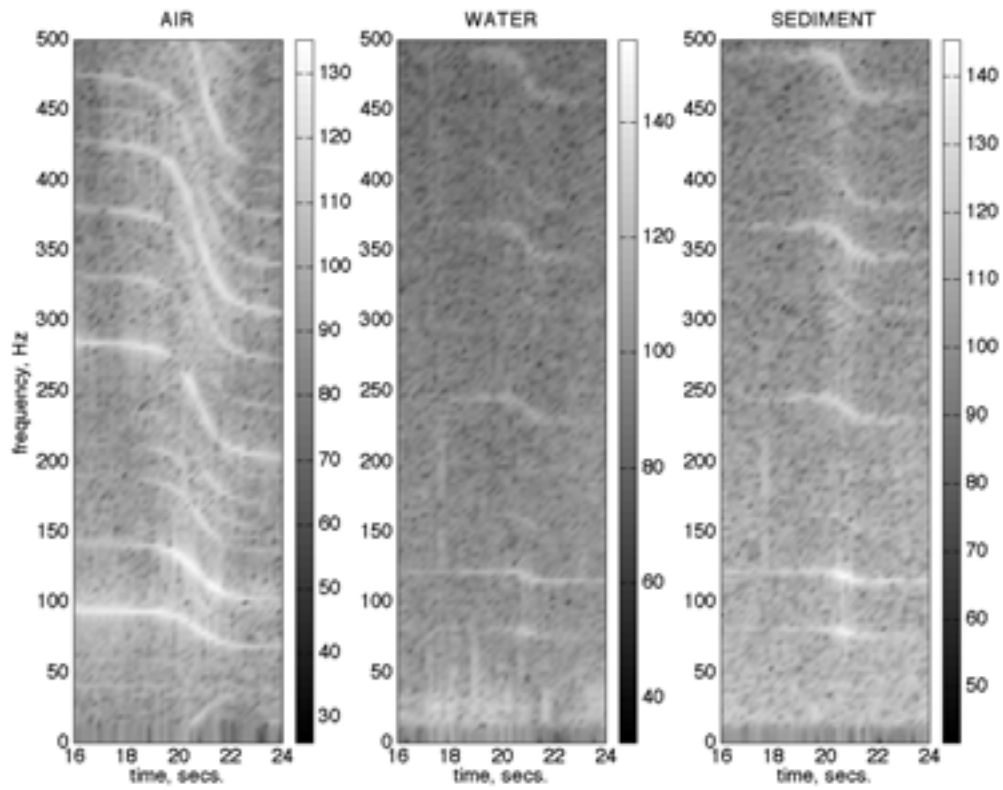


Fig. 1. Spectrograms showing the Doppler-shifted harmonics from the flight of a Diamond Star DA 40 on 20 October 2003. The grey-scales are in dB re  $1 \mu\text{Pa}^2/\text{Hz}$ .