Noise Doppler-Shift Measurement of Airplane Speed

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This paper illustrates a new and practical experimental technique for studying the Doppler effect where the pitch variation of noise from a passing aircraft is used to calculate its speed. The Doppler effect has many everyday applications that may already be familiar to students. One such application is Doppler echography, used mainly in medical imaging to measure the rate of blood flow through the heart and major arteries. Ultrasonic waves are bounced off of a target object. If the object is moving it changes the frequency of the echoes, and the amount of frequency change depends upon how fast the object is moving. In this way the speed of blood circulating through the imaged area can be measured. Another familiar application of the Doppler effect involves its use for measuring the speed of a vehicle, such as a car traveling on a highway. In this case microwaves are directed at a moving target, and the frequency change of the reflected waves is used to calculate the speed of the vehicle with respect to the radar source.

For the purpose of our experiments, an acoustic or radio source is not required since the target, the aircraft, itself emits audible noise. In order to record this noise we chose an open place near an airport runway extremity (Fig. 1). It is useful to do these measurements during a period when aircraft are taking off or landing in rapid succession. This time can be best chosen by looking at the landing forecast, which can be found on the Internet.

The data acquisition step is very straightforward. The airplane’s noise can be recorded by the students with equipment such as an MP3 recorder or mobile telephone camera. Afterward they can transfer the recorded sound to a computer. The sound file can then be read by signal analysis software that performs a fast Fourier transform (FFT) using small time windows. The sequence of FFTs is plotted as a grayscale of intensity for each value of $t$ and $f$, as can be seen in Fig. 2, for the noise of an airplane. The program allows a manual sampling of time and frequency at the position of the cursor.

Examination of this FFT graph for the Doppler effect was surprisingly straightforward. Inside the multiple frequencies of the full signal in the spectra composed of motor and ambient noises, there are some frequencies that clearly appear with a higher intensity. We suppose that these stronger signals may be due to natural resonant frequencies produced by the rotation
or by resonances of the jet engine that are amplified, producing the patterns shown in the spectrogram. A zoom on one of these strong signals of the spectrogram can be seen in Fig. 3. The Doppler effect can be directly observed as a step shape. The frequency is high, measured at 2.2 kHz, when the airplane approaches and then decreases to 1.5 kHz as it moves away.

When a sound source moves directly away from or toward an observer, the equation for the Doppler shift is

\[ f = \frac{f_0}{1 \pm \frac{v}{u}}, \]

where \( f_0 \) is the frequency of a moving source with constant speed \( v \), the receiver is at rest, and \( u \) is the speed of sound in air (345 m/s for ambient temperature, 23°C). The positive sign pertains to the case when the source is receding from the observer, and the negative sign applies when the source is moving toward the observer.

Consider the case where an airplane’s path is directly over the head of an observer. At times when the horizontal distance of the plane from the observer is large relative to the plane’s altitude, Eq. (1) applies as a good approximation. In this case we can take one frequency \( f_T \) when the airplane is moving toward the detector and another frequency \( f_A \) when it is moving away. When we take the ratio of the frequencies and solve for \( v \), we obtain:

\[ v = u \left( \frac{f_T - f_A}{f_T + f_A} \right). \]

We recorded the noise of 28 airplanes. In more than half of our measurements it was possible to see resonant frequencies and to calculate the speeds of the airplane. For example, for the data shown in Fig. 3 we calculated 235 km/h for the speed \( v \) of a landing airplane. Our results agree with technical data from Ref. 13.

We have presented a new, modern, and inexpensive method for performing experiments at the undergraduate level involving the Doppler shift for sound. The method allows for direct acquisition of noise intensity as a function of time suitable for further analysis by students. Data analysis can be performed to determine the speed of airplanes using the Doppler effect. The commonly found computer sound card has proven to be useful in the scientific measurements presented here. The experiments performed here provide a nice addition to the standard study of the Doppler effect and allows the measure of speeds in a real application, similar to the Doppler ultrasound echography and radar used by police.

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**References**

4. There are three variations in the noise of a machine when it passes by us: the intensity increase and decrease in time, the binaural (or stereo) hearing effect that exploits the difference in sound arrival time at each of the two ears, and a pitch difference.
5. H. Richard Crane, “Folded-path Doppler and the

6. In our experiment, we used directly the sound card of the computer connected to a microphone.


10. Typical in-air accelerations for airplanes are about 0.2 m/s² (interesting GPS time-versus-velocity tracks of jet planes can be seen at http://www.magnalox.net/log/no.php?lid=13395&keywd=Berlin+Tegel+TXL++Stuttgart+Echterdingen+STR, for example), which would reassure us that the small changes in velocity during our experiment do not introduce significant error.

11. Another method to obtain the aircraft speed $v$ and also its minimum distance $d$ to the observer is to adjust Eq. (1) considering the time delay due to the sound travel with $v$, $d$, and $f_0$ as parameters to our experimental data $t$ versus $f$, as is made in Ivan F. Costa and Alexandra Mocellin, “Adjust procedure to measure a passing by acoustical noise source speed and distance using Doppler shift,” *Signal Processing* (to be published). The results from that article agree with the results obtained here.

12. For the data shown in Ref. 3 we calculated 70 km/h for the speed of a car, as expected, using its horn’s sound (instead of its noise).


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