Doppler Football

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In this paper we present a design for a Doppler football. The classic Doppler ball uses a piezo buzzer and 9-V battery inside a foam ball. In our Doppler football, the sound level is enhanced by directing the 2.8-kHz tone of the buzzer through a hollow cylinder to one end of the football, with an on-off switch placed at the other end. We discuss our device within the historical context of Doppler demonstrations that have evolved over the many decades since Doppler's discovery.

Christian H. Doppler (1803-1853) presented his discovery that motion affects observed frequency in 1842. Three years later, the meteorologist Christoph H.D. Buys-Ballot (1817-1890) provided a dramatic experimental test for Doppler's theory with a group of musicians playing trumpets in an open train cart between Utrecht and Amsterdam. The Doppler shift we are accustomed to hearing in traffic with blaring car horns was observed as the train passed by.[1-3] A modern-day demonstration with a high school senior driving a car at comparable speeds and blaring the horn has been cautiously described by John F. Koser[4] to literally "drive this concept home."

The classic version of the Doppler effect using circular motion can be traced back to Ernst Mach (1838-1916) with a device using a reed whistle.[5] In 1865 the instrument builder Rudolph König (1832-1901) rotated a pair of tuning forks mounted on resonant boxes where the Doppler effect produced different beat frequencies.[5]

Both the reed-whistle and beat-Doppler devices became common ways to demonstrate the Doppler effect in physics classes.[6] Variations also included echo Doppler effects with moving reflectors, leading to the

Fig. 1. Doppler Football.

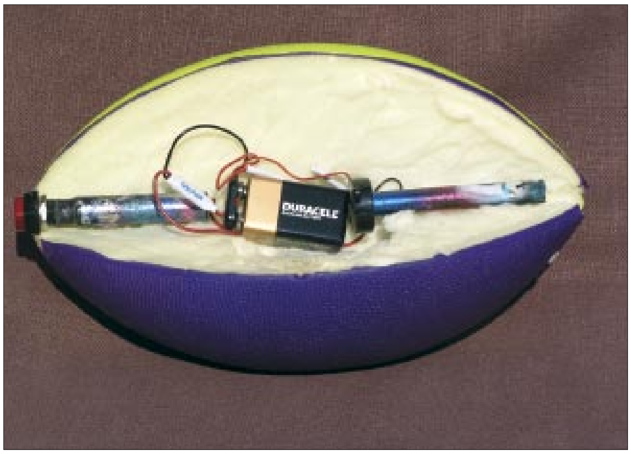

Fig. 2. Cutaway of the Doppler Football. This ball was destroyed so we could photograph the internal arrangement.

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derivation of 16 Doppler formulas for specific cases.[7] Derivations of basic Doppler formulas and pedagogical advances have appeared fairly recently in this journal.[8] Rotating devices continue to be effectively used in class to this day.[9]

It has also become common to swing a sound source over one's head[10] to demonstrate the Doppler effect, a modern version of Mach's idea. Many years ago a UNCA student brought a buzzer from a car's ignition switch to class. The buzzer sounds if you leave your keys in the car and open your door. The student attached a 9-V battery clip to the buzzer, wrapped the buzzer and 9-V battery with masking tape, and tied a rope to it. Swinging it around provided for an effective demonstration.

A Doppler ball[11] was described in 1973, using a sonalert buzzer. The year after, a Doppler tennis ball[12] and Doppler foam car[13] that was pulled across the room appeared in the literature. A Whiffle Doppler ball[14] using a piezo buzzer was described in 1988. The combination of a foam ball and piezo buzzer has become the popular standard.[15,16]

We have used some version of the Doppler football since the early 1990s, being unaware of Drake's similar basic devices.[15] The design of our Doppler football in this paper solves two of the technical problems that have plagued our earlier models. In the past, impact would frequently turn our buzzer off and the tone was not as loud as we desired it to be. Our new design is sturdy. The switch is very stable since you throw the ball with the switch facing the thrower. Second, the sound emanating from the 76-decibel buzzer is enhanced because we direct the sound through a hollow cylinder.

Construction of New Doppler Ball

Our new version of the Doppler ball (see Fig. 1) employs a spongy football (Poof balls) we picked up at Wal-Mart. Our electronic supplies, available from Radio Shack, are the 2.8-kHz piezo buzzer (#273-059), heavy-duty 9-V battery snap (#270-324), push-on-push-off switch (#275-617), and 22-AWG hookup wire (#278-1221). We also employ two hollow cylinders we cut from a pen.

Our arrangement is illustrated in Fig. 2, where we have destroyed a ball to photograph the inside. The surgical challenge with all foam Doppler balls is to cut as little as possible, pull back the foam, insert the electronics, and let the foam close up on itself (adding optional tape or glue).

Here are some construction tips. Pick a groove running down the length of the ball and cut a 10-cm (4-in) slit. Very gently pull the slit open with two fingers from one hand, and make successive slits deeper and deeper into the ball, keeping your 10-cm groove all the way down to the center core. Once you have this giant slit all the way to the middle, it's time to start excavating.

Take your time with digging your "pocket" inside the ball. Since you don't have much room to work with, patiently make small cuts with a hobby knife, cutting small chunks of foam and removing them with your finger or small spoon. Keep in mind that the cavity needs to be centered as much as possible to reduce wobble when throwing the ball later. You only need to fit a battery and buzzer inside, so don't go overboard; otherwise, you will have things bouncing around inside the ball.

Next, hollow out two paths from each tip of the ball in order to insert two hollow cylinders. We use hollow parts from a pen (see Fig. 2) for our cylinders. The left cylinder contains wires that lead to the switch glued at one end. The other cylinder is glued to the buzzer and serves as a guide for the sound waves out the other end of the ball. Without this guide, the sound would be too low to easily hear in class. Be sure to place one end of the plastic guide 1 or 2 cm from the tip (see Fig. 2), so the foam can provide shock absorption on impact. Otherwise, the glue connection to the buzzer can break, negating the critical benefit of tube-directed sound. As an optional step to keep the slit closed during tossing, you can mount (with superglue) Velcro to both inner sides of the ball at the opening.

Our new Doppler design is sturdy for dramatic use in class. Bringing the ball to class immediately attracts attention. Tossing the football around in our 180-seat auditorium with a typical class size of 80 makes this one of the semester's finest and most memorable demonstrations. If you can take the class outside, that is even better.

References

1. A. Roguin, "Christian Johann Doppler: The man behind the effect," *Brit. J. Radiol.* **75,** 615 (2002).
2. Craig F. Bohren, *What Light Through Yonder Window Breaks? More Experiments in Atmospheric Physics* (Wiley, New York, 1991). The musicians didn't believe the effect would occur since the noise of a passing train does not change. However, noise is a mixture of many frequencies, so the effect is camouflaged.
3. For an approaching train at 60 km/h (40 mi/h) ≈ 20 m/s with the speed of sound u = 340 m/s, the Doppler-shifted frequency is
$$f = f_s\left(\frac{u}{u - v_s}\right) = f_s(340/320) = (17/16)f_s.$$
A pitch ratio of 17/16 is approximately the 12th root of two, which indicates a half-step (semitone).
4. John F. Koser, "Doing the Doppler: How to drive this concept home," *Sci. Teach.* **43,** 40 (Sept. 1990).
5. J.W.S. Rayleigh, *The Theory of Sound*, 2nd ed. (Dover Publications, New York, 1945), pp. 154–156. The first edition of Lord Rayleigh's book appeared in 1877 and the second edition was first published in 1894.
6. Francis E. Fox, "Demonstration of the Doppler effect," *Am. J. Phys*. **12**, 228–229 (Aug. 1944).
7. O. Perrine, "The Doppler and echo Doppler effect," *Am. J. Phys*. **12**, 23–28 (Feb. 1944).
8. William E. Dibble, "A pedagogical note on the Doppler-effect formulas," *Phys. Teach.* **38**, 362–363 (Sept. 2000); Robert Alt and Sam Wiley, "A generalized wave diagram for moving sources," *Phys. Teach.* **42**, 526–527 (Dec. 2004). Also see Bernhard Rothenstein, "Teaching the Doppler shift using a machine gun analogy," *Phys. Teach.* **39**, 468–469 (Nov. 2001); and Daniel Hoyt, "A different viewpoint on Doppler-effect calculations," *Phys. Teach*. **40,** 14–16 (Jan. 2002).
9. For two examples spanning 40 years, see Hans Weltin, "Demonstration of the Doppler effect," *Am. J. Phys.* **29**, 713–714 (Oct. 1961) and Marcelo M. F. Saba and Rafael Antônio da S. Rosa, "The Doppler effect of a sound source moving in a circle," *Phys. Teach*. **41,** 89–91 (Feb. 2003).
10. Harry E. Stockman, "Demonstration of the Doppler effect," *Am. J. Phys*. **30**, 307–308 (April 1962); Paul Doherty and Don Rathjen, *The Exploratorium Science Snackbook* (Exploratorium Store, San Francisco, 1991).
11. Frank S. Crawford, "Simple demonstration of Doppler effect, interference, and radiation resistance using a sonalert," *Am. J. Phys.* **41**, 727–730 (May 1973).
12. Ian Firth, "Doppler with a sounding tennis ball," *Phys. Educ.* **9,** 63 (Jan. 1974).
13. George Barnes, "A Doppler experiment," *Am. J. Phys.* **42**, 905–909 (Oct. 1974).
14. H. Richard Crane, "The Doppler ball: A novel use of the piezo-electric effect," *Phys. Teach*. **26**, 120–121 (Feb. 1988).
15. Dee Drake, "Doppler ball effects," *Sci. Teach.* **58**, 62 (Feb. 1991). A Nerf football is recommended.
16. A spherical Doppler foam ball is available from Arbor Scientific, http://www.arborsci.com (Product ID: P7-7120).

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Product Physics Warning, II

"WARNING: This product warps space and time in its vicinity."[1]

1. "Zero Gravity," *A.P.S. News*, February 2000, p. 5