letters

Sailing and the physics of lift

Thank you for Bryon Anderson's interesting and informative article, "The Physics of Sailing" (PHYSICS TODAY, February 2008, page 38). I especially enjoyed learning that the keel, not just the sail, acts to provide lift.

The article appears to adopt the traditional model: "An airplane wing is designed to cause the air moving over its top [the longer path] to move faster than the air moving along its undersurface." In that model, the "cause" is often based on the assumption that flows over the top and underside of the wing are isochronal. That assumption has been shown to be false; the flow time over the top of the wing is considerably shorter than that predicted by the dictum of equal time. Thus the model does not explain why a longer path should lead to higher flow speed.

Other difficulties arise with the traditional model. It does not explain the vital concave-downward curvature of the flow. It does not accurately predict observed average speeds near asymmetrical, symmetrical, inverted, or thin airfoils. The model does not predict point-to-point speeds—that is, from low speed near the leading edge over the top of the wing, to high speed in the region of maximum airfoil curvature, to free-stream speed near the trailing edge. The possibility of directly measuring the pressures of interest, rather than circuitously using the Bernoulli principle to calculate them from flow speeds, is not addressed. Additionally, the traditional model calculates pressure gradients from the very air speeds that are caused by those pressure gradients. Thus the traditional model seems to suffer from circular reasoning.

The article mentions an alternative model—"turning of the fluid flow." Indeed, airfoils are designed for establishing pressure gradients, which in turn result in observed changes in flow speed and direction, according to Newton's second law. Reversing that statement to claim that the changes of flow speed and direction above and below the airfoil result in pressure gradients is simply not correct. Thus the idea that the higher-speed air over the wing causes lower pressure above it by the Bernoulli principle reverses the correct assignment of cause and effect. Likewise with Newton's second law, net force causes acceleration; it is not correct to say that acceleration causes net force.

The model using Newton's second law in impulse and momentum form provides a consistent explanation of lift by deflection of the air stream, a fact that is lost with the use of the scalar Bernoulli equation. In addition, when the correct cause and effect are used, the Bernoulli principle becomes irrelevant to the explanation of pressure gradients established by airfoils.

Parenthetically, Anderson's question "whether the pressure difference arises entirely from the Bernoulli effect or partly from . . . redirection of the air" seems not to be meaningful. By any model, air must be deflected as a third-law reaction to lift.

Evan Jones
(revwin@yahoo.com)
Sierra College
Rocklin, California

Letters and opinions are encouraged and should be sent by e-mail to ptletters@aip.org (using your surname as "Subject"), or by standard mail to Letters, PHYSICS TODAY, American Center for Physics, One Physics Ellipse, College Park, MD 20740-3842. Please include your name, affiliation, mailing address, e-mail address, and daytime phone number on your attachment or letter. You can also contact us online at http://www.physicstoday.org/pt/contactus.jsp. We reserve the right to edit submissions.

Bryon Anderson's article on the physics of sailing provides a good introduction to the topic, but his discussion of wind-generated lift in sails, the effect that allows sailing to windward, leaves out the important concept of circulation. Anderson emphasizes the Bernoulli principle by explaining that the pressure difference between the upwind and downwind sail surfaces is due to the higher air speed on the downwind side. Anderson notes that "classic wing theory" ascribes the path length difference to asymmetry in the airfoil; however, the asymmetric airfoil is not a good model for sails because the path lengths along the upwind and downwind sides are almost the same. He points out that there are difficulties with classic wing theory and refers the reader to a NASA website. It is, however, well known by aircraft designers, and more recently by sailmakers, that lift is produced by circulation of air around the airfoil or sail and that viscosity plays a key role in its production.[1]

The simplest example of circulation-induced lift is the spinning ball, an effect exploited by baseball pitchers and known as the Magnus effect. Instead of spinning, a sail produces circulation by its shape and angle of attack to the wind. Because of the angle of attack, initially the upwind-side airflow attempts to turn sharply around the sail's trailing edge to rejoin the downwind flow. That sharp turn is resisted by the air's viscosity, producing a starting vortex near the trailing edge. By the Helmholtz theorem, a counterrotating, or bound, vortex must be induced around the sail. The strength of the circulation around the sail is such that the air flows smoothly off the trailing edge, an effect known as the Kutta condition. When the Kutta condition is established, the starting vortex disconnects from the sail and is left behind. Circulation causes air that would otherwise flow upwind of the sail to be deflected to the downwind side; this upwash effect results in the longer path length responsible for the higher downwind-side air speed and pressure drop.

Reference

1. C. A. Marchaj, *Aero-Hydrodynamics of Sailing*, Dodd, Mead, New York (1980); D. C. Wilcox, *Basic Fluid Mechanics*, 2nd ed., DCW Industries, La Cañada, CA (2000), chap. 10.

Arne W. Fliflet
(arne.fliflet@nrl.navy.mil)
Alexandria, Virginia

Anderson replies: I agree with almost everything in these two letters