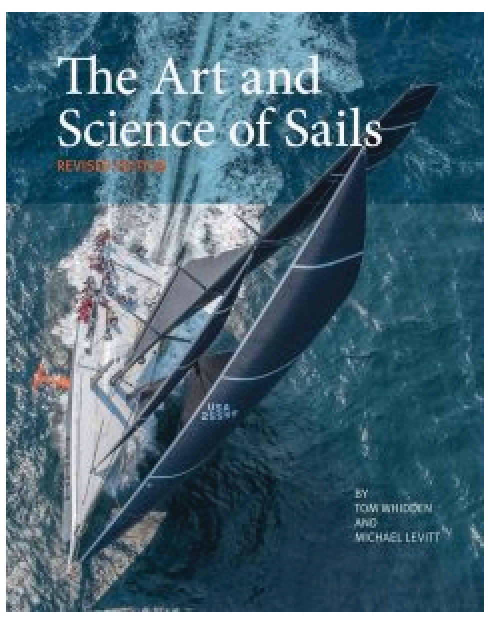
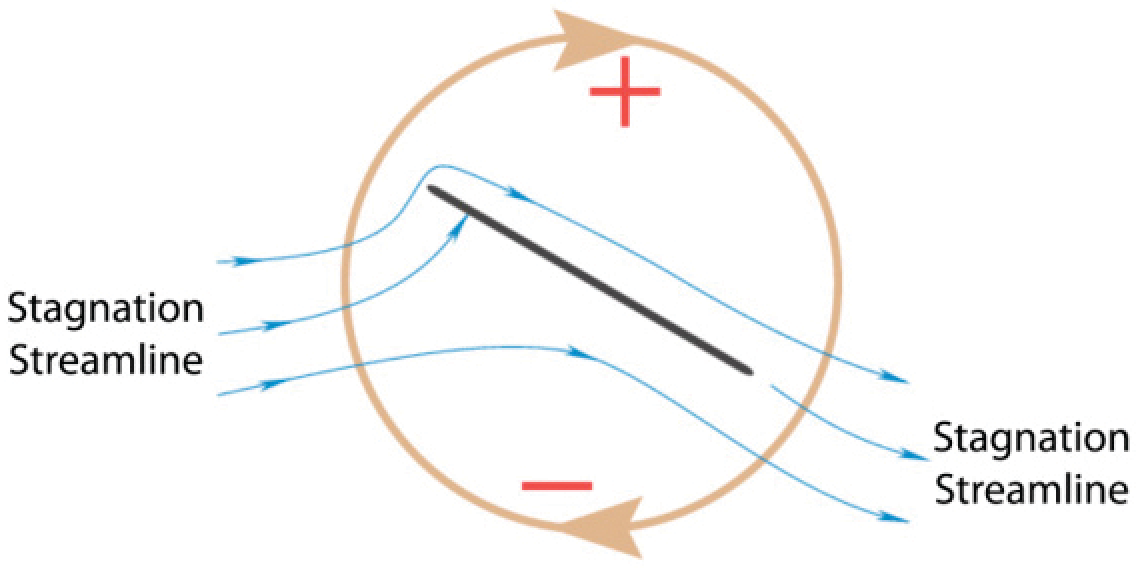
ARVEL GENTRY



The Famous Bathtub Experiment

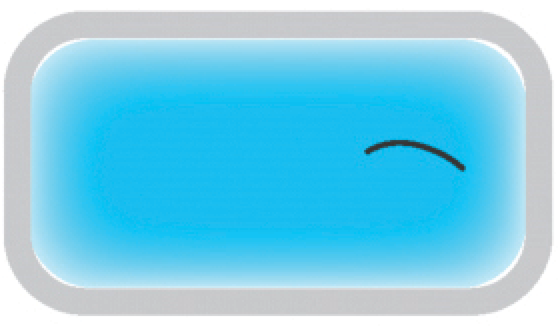
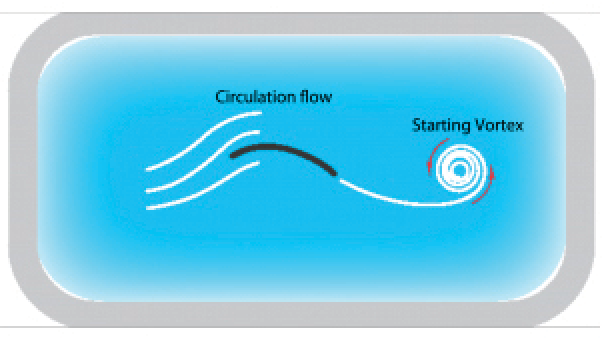
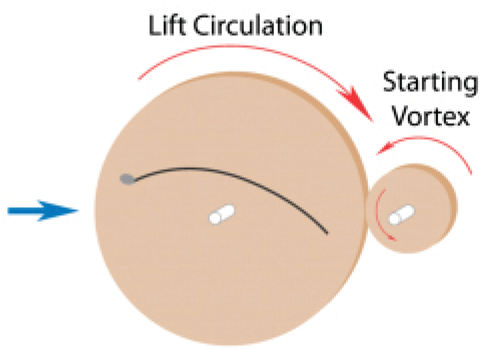
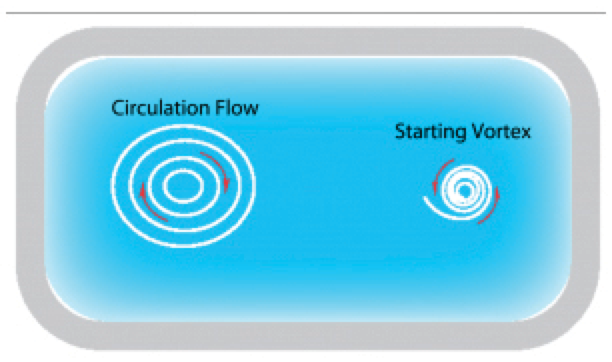
In the first edition of the *Art and Science of Sails*, written by Tom Whidden, president of North Sails Group, LLC, and Michael Levitt, and published by St. Martin's Press, the authors used Arvel Gentry's now famous Bathtub Experiment to demonstrate the existence of Circulation, or a second force, that operates around an airfoil, like a sail, wing, or keel etc.



Big picture: it's the combined effort of these two forces that makes the wind speed up on the leeward side — and thus show low pressure — and slow down on the windward side of a sail — high pressure. Gentry was the Boeing engineer who first taught sailors aerodynamics. These diagrams first appeared in Gentry's *Sail* magazine articles. In the Revised Edition, the authors used computer testing to show where the wind speeds up around a sail plan and where it slows down. And why and by how much? Nevertheless, Gentry's experiment is the standard — still popular on the web — and it was left it out of the Revised Edition with trepidation, but we linked in the book to this web page.

Circulation

What if there are *two* flows — rather than one — around an airfoil like a sail, wing, keel, or rudder? To that end, mathematicians added another type of flow, called circulation, to the normal wind velocity. Circulation is a special mathematical solution where a second flow rotates around the airfoil. The circulation flow is greatest near the foil and progressively less moving away from it. In the mathematical solution, circulation air speeds are adjusted so that the Kutta condition at the trailing edge, or leech, is satisfied; that is, the calculated airflow speeds and pressures are the same off both sides of the trailing edge. Gentry's Bathtub Experiment looks like this:

	A card with shape and an angle of attack is placed in a bathtub.
	Starting vortex (spinning counterclockwise) is formed.
	As the card reaches the center, the Circulation Flow appears
	These two forces look something like this: The smaller Starting Vortex wheel, which spins counterclockwise, and the bigger Circulation wheel, which spins clockwise.
	Back to the bathtub. As the card nears the end, it is removed from the bathtub. Remaining are the Circulation Flow and the Starting Vortex.

Circulation alone can't cause lift, exactly in the same manner as the linear, or non-circulating, flow can't cause lift. Trying to prove that linear flow alone produces lift has confused sailors for decades. It has given rise to such impenetrable statements as "air passing over the curved upper surface has to travel a longer distance than the air passing under the flat lower surface, and since it has to go farther, it has to go faster to reach the trailing edge at the same time as its 'brother' particle."

The formula for lift requires that the two flows be added together on the top, or lee side, of the foil, and the two flows somewhat cancel each other out on the bottom, or weather, side. This gives the speed differential, top to bottom, the pressure differential, and then the lifting force.

With the combined efforts of the two flows, airplanes can fly upside down. An upside-down wing isn't an optimum shape— from the perspective of preventing separation—but it will work. Similarly, even though a sail is a thin membrane with almost no measurable difference in distance from one side to the other, the combination of the circulating flow and noncirculating flow allows a sailboat to sail to weather.

Above: Photo U.S. Air Force/Staff Sgt. Richard Rose Jr.