Flying Machines

For thousands of years, human beings vainly sought to fly "like a bird," not realizing that this is literally impossible, due to differences in physiognomy between birds and homo sapiens. No man has ever been born (or ever will be) who possesses enough strength in his chest that he could flap a set of attached wings and lift his body off the ground. Yet the bird's physical structure proved highly useful to designers of practical flying machines.

A bird's wing is curved along the top, so that when air passes over the wing and divides, the curve forces the air on top to travel a greater distance than the air on the bottom. The tendency of airflow, as noted earlier, is to correct for the presence of solid objects and to return to its original pattern as quickly as possible. Hence, when the air hits the front of the wing, the rate of flow at the top increases to compensate for the greater
distance it has to travel than the air below the wing. And as shown by Bernoulli, fast-moving fluid exerts less pressure than slow-moving fluid; therefore, there is a difference in pressure between the air below and the air above, and this keeps the wing aloft.

Only in 1853 did Sir George Cayley (1773-1857) incorporate the avian airfoil to create history’s first workable (though engine-less) flying machine, a glider. Much, much older than Cayley's glider, however, was the first manmade flying machine built "according to Bernoulli's principle"—only it first appeared in about 12,000 B.C., and the people who created it had had little contact with the outside world until the late eighteenth century A.D. This was the boomerang, one of the most ingenious devices ever created by a stone-age society—in this case, the Aborigines of Australia.

Contrary to the popular image, a boomerang flies through the air on a plane perpendicular to the ground, rather than parallel. Hence, any thrower who properly knows how tosses the boomerang not with a side-arm throw, but overhand. As it flies, the boomerang becomes both a gyroscope and an airfoil, and this dual role gives it aerodynamic lift.

Like the gyroscope, the boomerang imitates a top; spinning keeps it stable. It spins through the air, its leading wing (the forward or upward wing) creating more lift than the other wing. As an airfoil, the boomerang is designed so that the air below exerts more pressure than the air above, which keeps it airborne.

Another very early example of a flying machine using Bernoulli’s principles is the kite, which first appeared in China in about 1000 B.C. The kite’s design, particularly its use of lightweight fabric stretched over two crossed strips of very light wood, makes it well-suited for flight, but what keeps it in the air is a difference in air pressure. At the best possible angle of attack, the kite experiences an ideal ratio of pressure from the slower-moving air below versus the faster-moving air above, and this gives it lift.

Later Cayley studied the operation of the kite, and recognized that it—rather than the balloon, which at first seemed the most promising apparatus for flight—was an appropriate model for the type of heavier-than-air flying machine he intended to build. Due to the lack of a motor, however, Cayley’s prototypical airplane could never be more than a glider: a steam engine, then state-of-the-art technology, would have been much too heavy.

Hence, it was only with the invention of the internal-combustion engine that the modern airplane came into being. On December 17, 1903, at Kitty Hawk, North Carolina, Orville (1871-1948) and Wilbur (1867-1912) Wright tested a craft that used a 25-horsepower engine they had developed at their bicycle shop in Ohio. By maximizing the ratio of power to weight, the engine helped them overcome the obstacles that had dogged recent attempts at flight, and by the time the day was over, they had achieved a dream that had eluded men for more than four millennia.

Within fifty years, airplanes would increasingly obtain their power from jet rather than internal-combustion engines. But the principle that gave them flight, and the principle that kept them aloft once they were airborne, reflected back to Bernoulli’s findings of more than 160 years before their time. This is the concept of the airfoil.
As noted earlier, an airfoil has a streamlined design. Its shape is rather like that of an elongated, asymmetrical teardrop lying on its side, with the large end toward the direction of airflow, and the narrow tip pointing toward the rear. The greater curvature of its upper surface in comparison to the lower side is referred to as the airplane's camber. The front end of the airfoil is also curved, and the chord line is an imaginary straight line connecting the spot where the air hits the front—known as the stagnation point—to the rear, or trailing edge, of the wing.

Again, in accordance with Bernoulli’s principle, the shape of the airflow facilitates the spread of laminar flow around it. The slower-moving currents beneath the airfoil exert greater pressure than the faster currents above it, giving lift to the aircraft. Of course, the aircraft has to be moving at speeds sufficient to gain momentum for its leap from the ground into the air, and here again, Bernoulli’s principle plays a part.

Thrust comes from the engines, which run the propellers—whose blades in turn are designed as miniature airfoils to maximize their power by harnessing airflow. Like the aircraft wings, the blades' angle of attack—the angle at which airflow hits it. In stable flight, the pilot greatly increases the angle of attack (also called pitched), whereas at takeoff and landing, the pitch is dramatically reduced.

### Drawing Fluids Upward: Atomizers and Chimneys

A number of everyday objects use Bernoulli’s principle to draw fluids upward, and though in terms of their purposes, they might seem very different—for instance, a perfume atomizer vs. a chimney—they are closely related in their application of pressure differences. In fact, the idea behind an atomizer for a perfume spray bottle can also be found in certain garden-hose attachments, such as those used to provide a high-pressure car wash.

The air inside the perfume bottle is moving relatively slowly; therefore, according to Bernoulli’s principle, its pressure is relatively high, and it exerts a strong downward force on the perfume itself. In an atomizer there is a narrow tube running from near the bottom of the bottle to the top. At the top of the perfume bottle, it opens inside another tube, this one perpendicular to the first tube. At one end of the horizontal tube is a simple squeeze-pump which causes air to flow quickly through it. As a result, the pressure toward the top of the bottle is reduced, and the perfume flows upward along the vertical tube, drawn from the area of higher pressure at the bottom. Once it is in the upper tube, the squeeze-pump helps to eject it from the spray nozzle.

A carburetor works on a similar principle, though in that case the lower pressure at the top draws air rather than liquid. Likewise a chimney draws air upward, and this explains why a windy day outside makes for a better fire inside. With wind blowing over the top of the chimney, the air pressure at the top is reduced, and tends to draw higher-pressure air from down below.

The upward pull of air according to the Bernoulli principle can also be illustrated by what is sometimes called the "Hoover bugle"—a name perhaps dating from the Great Depression, when anything cheap or contrived bore the appellation "Hoover" as a reflection of popular dissatisfaction with President Herbert Hoover. In any case, the
Hoover bugle is simply a long corrugated tube that, when swung overhead, produces musical notes.

You can create a Hoover bugle using any sort of corrugated tube, such as vacuum-cleaner hose or swimming-pool drain hose, about 1.8 in (4 cm) in diameter and 6 ft (1.8 m) in length. To operate it, you should simply hold the tube in both hands, with extra length in the leading hand—that is, the right hand, for most people. This is the hand with which to swing the tube over your head, first slowly and then faster, observing the changes in tone that occur as you change the pace.

The vacuum hose of a Hoover tube can also be returned to a version of its original purpose in an illustration of Bernoulli's principle. If a piece of paper is torn into pieces and placed on a table, with one end of the tube just above the paper and the other end spinning in the air, the paper tends to rise. It is drawn upward as though by a vacuum cleaner—but in fact, what makes it happen is the pressure difference created by the movement of air.

In both cases, reduced pressure draws air from the slow-moving region at the bottom of the tube. In the case of the Hoover bugle, the corrugations produce oscillations of a certain frequency. Slower speeds result in slower oscillations and hence lower frequency, which produces a lower tone. At higher speeds, the opposite is true. There is little variation in tones on a Hoover bugle: increasing the velocity results in a frequency twice that of the original, but it is difficult to create enough speed to generate a third tone.

**Spin, Curve, and Pull: The Counterintuitive Principle**

There are several other interesting illustrations—sometimes fun and in one case potentially tragic—of Bernoulli’s principle. For instance, there is the reason why a shower curtain billows inward once the shower is turned on. It would seem logical at first that the pressure created by the water would push the curtain outward, securing it to the side of the bathtub.

Instead, of course, the fast-moving air generated by the flow of water from the shower creates a center of lower pressure, and this causes the curtain to move away from the slower-moving air outside. This is just one example of the ways in which Bernoulli’s principle creates results that, on first glance at least, seem counterintuitive—that is, the opposite of what common sense would dictate.

Another fascinating illustration involves placing two empty soft drink cans parallel to one another on a table, with a couple of inches or a few centimeters between them. At that point, the air on all sides has the same slow speed. If you were to blow directly between the cans, however, this would create an area of low pressure between them. As a result, the cans push together. For ships in a harbor, this can be a frightening prospect: hence, if two crafts are parallel to one another and a strong wind blows between them, there is a possibility that they may behave like the cans.

Then there is one of the most illusory uses of Bernoulli’s principle, that infamous baseball pitcher’s trick called the curve ball. As the ball moves through the air toward
the plate, its velocity creates an air stream moving against the trajectory of the ball itself. Imagine it as two lines, one curving over the ball and one curving under, as the ball moves in the opposite direction.

In an ordinary throw, the effects of the airflow would not be particularly intriguing, but in this case, the pitcher has deliberately placed a "spin" on the ball by the manner in which he has thrown it. How pitchers actually produce spin is a complex subject unto itself, involving grip, wrist movement, and other factors, and in any case, the fact of the spin is more important than the way in which it was achieved.

If the direction of airflow is from right to left, the ball, as it moves into the airflow, is spinning clockwise. This means that the air flowing over the ball is moving in a direction opposite to the spin, whereas that flowing under it is moving in the same direction. The opposite forces produce a drag on the top of the ball, and this cuts down on the velocity at the top compared to that at the bottom of the ball, where spin and airflow are moving in the same direction.

Thus the air pressure is higher at the top of the ball, and as per Bernoulli's principle, this tends to pull the ball downward. The curve ball—of which there are numerous variations, such as the fade and the slider—creates an unpredictable situation for the batter, who sees the ball leave the pitcher's hand at one altitude, but finds to his dismay that it has dropped dramatically by the time it crosses the plate.

A final illustration of Bernoulli's often counterintuitive principle neatly sums up its effects on the behavior of objects. To perform the experiment, you need only an index card and a flat surface. The index card should be folded at the ends so that when the card is parallel to the surface, the ends are perpendicular to it. These folds should be placed about half an inch (about one centimeter) from the ends.

At this point, it would be handy to have an unsuspecting person—someone who has not studied Bernoulli's principle—on the scene, and challenge him or her to raise the card by blowing under it. Nothing could seem easier, of course: by blowing under the card, any person would naturally assume, the air will lift it. But of course this is completely wrong according to Bernoulli's principle. Blowing under the card, as illustrated, will create an area of high velocity and low pressure. This will do nothing to lift the card: in fact, it only pushes the card more firmly down on the table.

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