Chapter 2
Human Innovation

Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object.

Archimedes

In Greek mythology, Icarus takes to the sky on wings of feather and wax. All goes well until he flies too close to the sun, his wings melt, and he plunges into the sea and drowns. Despite Icarus' difficulties, flight under our own power has intrigued man throughout time. The birds make it look so easy. How can it be that this talent eludes us?

The simple answer is that birds are made to fly. From their structurally sound hollow bones to the special-purpose feathers covering their wings, birds are ideally suited to flight. Humans are not. Our bones are solid, not only adding to the mass we must lift but also putting an additional burden on the muscles we would use for flight. Because of this, the aerodynamic principles at work in the four forces of flight simply do not work in self-powered human flight to the same effect as they do in flight in birds. This hasn't kept humans from trying to achieve heavier-than-air flight under their own power, however.

The first human who fashioned wings out of palms or other plant material, lashed them to his arms, and ran as fast as he could with arms flapping, must have looked incredibly foolish as he tried to rise into the air. He was also doomed to fail since there was no possible way he could generate enough *lift* to overcome the forces of *gravity*. Likewise for the first human who lashed similarly fashioned wings to his arms and leapt off a high bluff with arms flapping. He may have looked like he was flying for a moment or two, but in actuality he was just "falling with style" the entire time. The wings he'd fashioned could not possibly generate enough lift to overcome gravity and keep him aloft. It's also doubtful that the wings he fashioned could provide *thrust*—the force needed for forward movement.

G. Hagler, *Modeling Ships and Space Craft: The Science and Art of Mastering the Oceans and Sky*, DOI 10.1007/978-1-4614-4596-8_2,

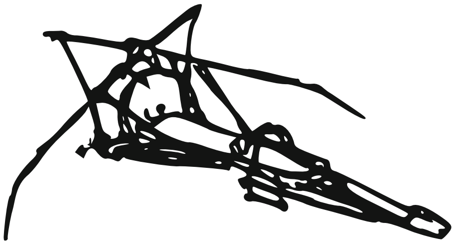

Fig. 2.1 da Vinci ornithopter. da Vinci sketched his ideas for an ornithopter in the early 1500s

Leonardo da Vinci correctly concluded that man was not going to fly with a simple set of wings attached to his arms. In the early 1500s da Vinci sketched his ideas for an *ornithopter* (Fig. 2.1). The ornithopter closely mimicked the anatomy of a bird, and the idea was that a human would lie on the base of the ornithopter and cause the wings to flap by maneuvering a series of levers and pulleys. The model looked good, but it would not have worked. The wings simply could not generate enough lift to get the contraption off the ground, let alone sustain flight and provide the necessary thrust for forward motion.

Giovanni Battista Danti, a contemporary of da Vinci's, thought he had the solution for self-powered human flight. He glued feathers to his arms and flapped his arms up and down as he ran. His only accomplishment was to repeatedly crash onto the roof of Saint Mary's Church by Lake Trasimeno near Perugia, Italy. In the 1600s, an Italian named Paolo Guidotti built wings of whalebone, covered them with feathers, and curved them into a wing shape with the use of springs. It took a fall through a roof and a broken thigh to convince him that feathers held no magic.[1]

While it's true that bird feathers alone do not possess magic, we now know that they do play a vital role in the aerodynamic functioning of a bird's wings as a bird balances the four forces of flight: *lift, gravity, thrust, and drag*. The *scapular feathers* facilitate "a streamlined transition in the aerodynamic contour of the bird between body and wings."[2] Without this specific type of feather atop the shoulder portion of the human body, there would be protrusions and interruptions in the streamline that would create resistance and impede flight.

Likewise, without the *secondary feathers*, a true *airfoil* would not be attained because "the cross-section of this portion of the wing creates the airfoil that provides lift for a bird in flight."[3] Without an airfoil, Bernoulli's Principle would never come into play because there would be no reason for air to move quickly up and over the cambered portion of the airfoil while moving more slowly beneath the flat portion of the airfoil. As a result, *lift* would not be created.

The *primary feathers* are equally important because these are the feathers that provide the *thrust* necessary for forward motion. Similarly, the *alula feathers* are essential to flight because they work to keep the bird in flight as the angle of attack increases in excess of 16 degrees and a stall results.

For a bird, all four types of feathers are essential to the production of the four forces that allow flight. *Lift* must be generated to overcome *gravity*. *Thrust* must be sufficient to overcome *drag*.[4]

For a bird, the structure of the wing alone is not enough; the feathers must also be present. For a human, neither the structure nor the feathers, or even the combination of the two, are enough to do the job. We are anatomically incapable of flight as achieved by the birds. We simply cannot generate the four necessary forces on our own. Unfortunately, it would take many more failed attempts and an additional 100 years for this to be fully understood.

The Kite

Through all mankind's experimentation with flight, the lowly kite has served as both entertainment and a testing mechanism for aerodynamically sound design. The Wrights used kites to test their wing warping theory. They also used kites to test the design of their gliders and powered airplanes by flying them unmanned, as kites, from 1900 to 1903. The kite is an excellent choice for this because it is subject to the four forces of flight and provides a straightforward way for observing the results of changes in those forces.

Because the weight of a kite is negligible, generating sufficient lift to get it aloft is not that difficult. Neither is it difficult to keep it aloft. Once in the air, it's possible to vary the *aspect angle*—the angle of the kite to the wind (Fig. 2.2) and observe the effects. In fact, since a kite is a flat surface, rather than a cambered one, the lift on a kite is largely generated by the aspect angle, and to a limited amount, by the Bernoulli effect. It's simple to understand when expressed in terms of Newton's Third Law. This law states that the mutual forces of action and reaction between two bodies are equal, opposite, and collinear. So, when the air strikes the face of the kite that is attached to the string and at an angle to the ground, that air is deflected downward. As it is pushed downward, it in return pushes back against the kite, moving it upward. The Bernoulli effect has nothing to do with this aspect of lift, since that effect is created by the air as it passes over the top of the kite while passing beneath the kite.

For a long time, theorists believed that all of the lift generated by an object was generated by the action of Newton's Third Law. This is not the case in most instances; certainly not with the configuration of the modern fixed-wing aircraft we know today. As for the kite, the shape of the kite doesn't matter. The forces acting on it are the same no matter what the kite looks like. It may be necessary to control the kite with some variations due to the design of the kite but the *thrust* necessary for forward movement is supplied by the tension in the line that is attached to the kite. With the wind blowing parallel to the ground, *drag* is in the direction of the wind. *Lift* is perpendicular to the wind. Both of these forces act on the *center of pressure* of the kite—the spot where lift, drag, and gravity combine. This center of pressure is what makes the kite fly straight.

Lift in a kite is generated by the deflection of the wind by the kite. The wind strikes the bottom surface of the kite and is deflected down at the angle of attack. In accordance with Newton's Third Law, the kite moves upward because the downward

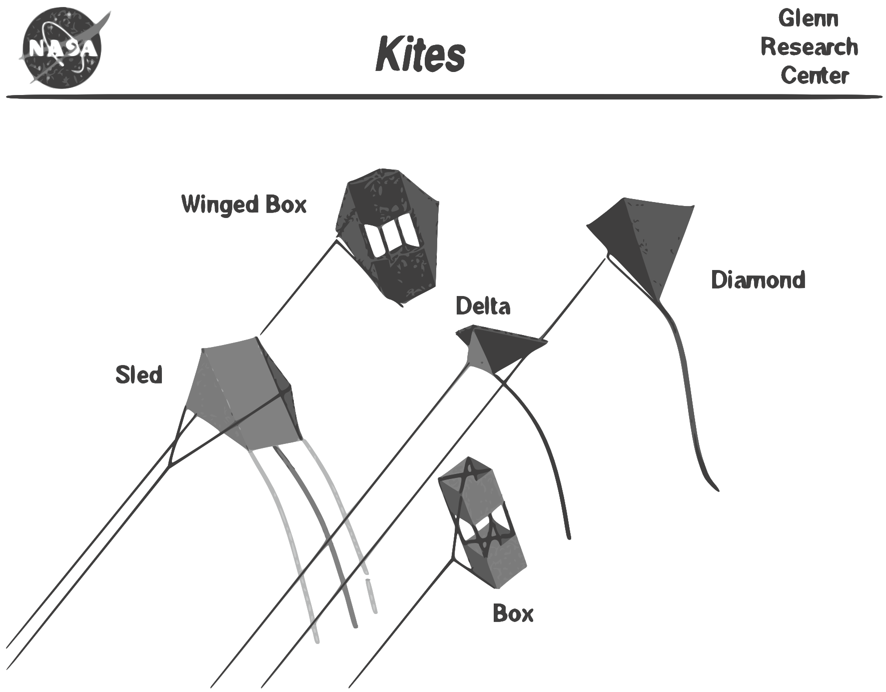

Fig. 2.2 Angle of attack of a kite. The aspect angle is the angle of the kite to the wind

action of the wind has an equal and opposite reaction in the opposite, upward direction. The Bernoulli Principle also applies to kites, though not to the extent it would in a true cambered airfoil. As the air flows up and over the kite, the pressure is less than the pressure flowing beneath the kite. As a result of the low pressure above the kite, the kite rises. The amount of air flowing up and over the kite also depends upon the *aspect ratio* of the kite—the angle of the kite to the wind.

The tail on a kite adds stability and balance. It also acts as *drag*—an increase in the resistance the kite must overcome to stay aloft. Because of the effect of drag, a kite with a tail won't fly as high as a kite without a tail. The trade off in balance and stability comes at the expense of height.

If a standard kite is the equivalent of a bird in flight, a delta-wing stunt kite is the bat of the kite universe. Stunt kites are still subject to the four forces of flight, Newton's Third Law, and the Bernoulli effect, but the way they react differs greatly from a traditional kite. The secret to the stunt kites performance is symmetry of the kite and the ability to control each wing rather than one wing alone (Fig. 2.3). To allow control over both sides of the wing, a stunt kite has two lines that are used to fly the kite. These lines are precut to the optimal length for the performance of the specific kite. This is because the goal of a stunt kite is not simply to rise as high as possible; it's to perform a variety of maneuvers. The entire length of line is let out and the kite is flown with all the line out at all times.

Fig. 2.3 Stunt kite. The secret to the performance of a stunt kite is the ability to control each wing rather than one wing alone. *Source*: Retrieved from http://en.wikipedia.org/w/index.php?title=File:Steve_Hobart_Sport_Kite.jpg&oldid=483266052

The ability to regulate the thrust in two locations versus only one is a key component of the aerodynamic performance of the stunt kite. In the same way that a bat can change the shape of its wings while in flight, a stunt kite can have changes in the aspect ratio and angle of each wing individually, giving them a broader range of movement while in flight.

The strongest wind will be directly in front of the person holding the kite strings. Because of this, most maneuvering will be done to one side or the other. However, in the same way a dihedral wing structure like that of the Turkey vulture corrects for stability, a stunt kite will remain stable as it moves in response to a tug on one string.

Sports

The spirit that led early aviators to take the sky lives on. Today man employs aerodynamic forces to glide in a variety of manners that include gliders, hang gliders, and parasails. With a parasail, rather than begin from a high point and glide to the earth, a boat is used to tow the person wearing the parasail into the wind like a giant kite. When sufficient lift is generated, the person rises into the air. He then glides with a huge air-filled airfoil attached, landing safely after the boat slows and ceases to generate lift (Fig. 2.4).

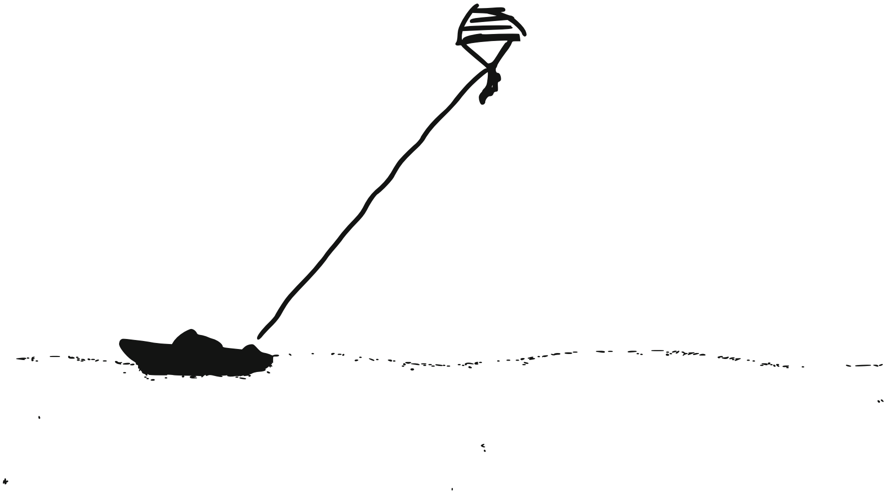

Fig. 2.4 The person wearing the parasail is lifted into the air as if by a giant kite

Modern-day hang gliders control their flights by hanging beneath the wing in a horizontal position. This gives the pilot greater control over the center of gravity of the glider, as well as the ability to make a wider variety of changes in position during flight. Changes in the angle of attack are made by pushing on bar that runs perpendicular to the flyer, beneath the planform of the wing.

In keeping with his quest to move, unencumbered, through the sky, Patrick de Gayardon developed the modern wingsuit during the 1990s. These suits purposefully take advantage of the principles of aerodynamics to enable a human being to leap from a plane or sufficiently high point and fall in a controlled and sustained glide, without any external apparatus, until the point where they must open a parachute to slow sufficiently for a safe landing. They have to use a parachute because it is not possible for the flyer to slow enough to land without injury, due to stalling and falling to the ground.

When wearing a wingsuit, a human mimics a flying squirrel, with flaps of fabric between his legs as well as between his arms and body (Fig. 2.5). The flyer's entire body becomes an airfoil, controlled by the movement of different parts of the wingsuit flyer's body. Flying squirrels have one configuration of skin flaps, legs, and body. Wingsuits come in a number of different configurations that meet the specific purpose of the wearer. Some are designed to sustain the glide for as long as possible; others are designed to permit greater mobility and lift during the glide.[5] The ability to achieve different objectives is based upon the aerodynamic forces at work with a specific type of suit. If greater lift is desired, a greater camber and/or angle of attack will be important. To prolong the glide, the ability to maintain a stable path might be the overriding objective in the design of the suit. It's up to the person wearing the wingsuit (birdman) to select a suit with the characteristics required to achieve the type of flight desired.

Fig. 2.5 A wingsuit allows a human to mimic a flying squirrel

Not everyone who mimics the behavior of birds is interested in taking to the air. Tune in to the Tour de France and you'll find cyclists on the same team following close behind one another, mimicking the behavior of geese in formation. The resistance is greatest for the lead cyclist while those in the middle have to do less work to cover the same ground. After a turn at the lead, that cyclist will drop back and another will buffet the resistance until it is his time to take a "break" at the back.

As is the case of Canada geese flying in v-formation, the cyclists following the leader are taking advantage of several aerodynamic forces. They are following the cyclist in front of them and enjoying a reduction in the resistance (friction) they encounter as they proceed in a process known as *drafting*. This resistance plays a significant part in the speed a cyclist can attain. Just how great a part was illustrated by two-time Olympic cyclist John Howard when "he mounted a wind-breaking shield on the back of a race car and rode his bicycle behind it, so that he was effectively riding in zero wind. He quickly got up to such a high speed that he couldn't turn his pedals fast enough, even in his top gear. So he went home and built a special bike with enormous gears, then tried it again. Using only the power of his legs but without any air resistance to fight, he hit 152 mph. A few years later Fred Rompelberg of the Netherlands gave it a whirl and got up to 170 mph."[6] The difference between the fastest they could to without the shield and the speeds they attained when riding behind the shield can all be attributed to the effects of *resistance*, the effect of drag—or friction—generated by the air flowing around the cyclist and his bicycle (Fig. 2.6).

By riding in a single file, arms tucked and legs in rhythm, the cyclists at the Tour de France are trying to achieve a similar advantage. They are also minimizing disruption to the air as it flows around them. The *streamline*, or flow around the cyclists, will have less turbulence when the cyclists are in their tucked positions

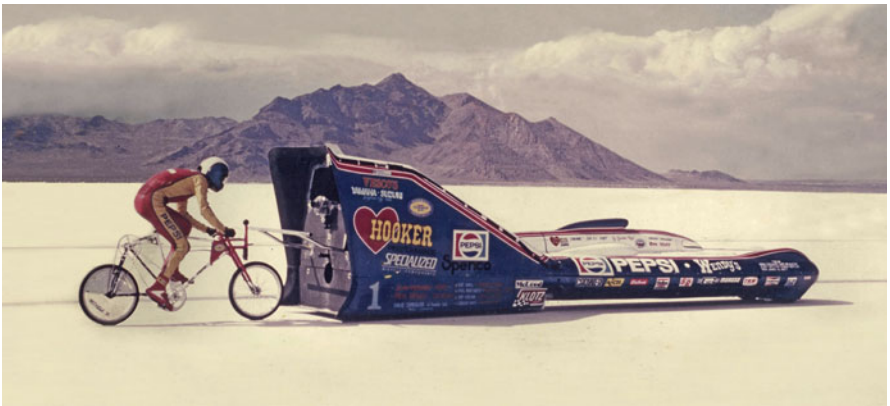

Fig. 2.6 Bike behind barrier. Olympic cyclist John Howard reached a speed of 152.284 mph while riding behind this wind-breaking shield on July 20, 1985. *Source*: Courtesy of John Howard

than it would if the cyclists were sitting straight up, their heads at varying heights, and their elbows jutting out to the sides. Anything they can do to form an aerodynamically sound "structure" will require less effort on their part and increase the speed they can attain.

Man hasn't just turned his understanding of aerodynamic principles to the sport of cycling. He's also invested considerable energy into the advantageous use of aerodynamics in baseball. For pitchers, an understanding of aerodynamics and a variant of Bernoulli's Principle have resulted in the ability to achieve a different outcome each time the ball leaves their hand.

When a pitcher throws a new, regulation baseball, he's throwing a completely round object that is smooth except for the slightly raised stitches that hold the ball together. "The fact that a baseball has low density, meaning its weight is low for its size, increases the aerodynamic effect."[7] "It's all about the spinning which is how a pitcher puts his 'stuff on the ball': by spinning the ball in different directions as he releases it, the pitcher can throw a slider, a curveball, a cutter, or, if he manages to throw it with no spin at all, a knuckleball."[8] If the ball is a tiny, immaculate orb without a nick or mark, where does it get its aerodynamic properties? The stitches.

Because the stitches are the only raised part of the ball, a pitcher who holds the ball so that the stitches are at a specific position when he begins his pitching motion can generate a state of disequilibrium as the ball moves through the air upon release. Especially for a curve ball, the air will be flowing more quickly over the stitches, creating what is known as a *Magnus force* (Fig. 2.7). It's not the same as the Bernoulli effect but it is based on the same principle. With the Magnus force, it's the stitches on the spinning ball that force the ball to move more quickly on one side than on the other. This creates an area of low pressure on the side with the faster movement. The path of the ball will curve in that direction as a result (Fig. 2.8). It wouldn't curve if

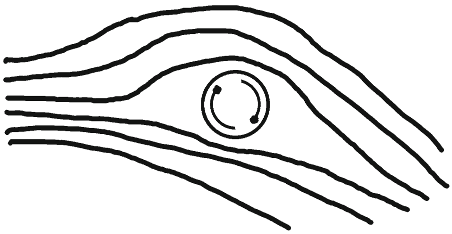

Fig. 2.7 The Magnus Force is the force that causes a curve ball to curve

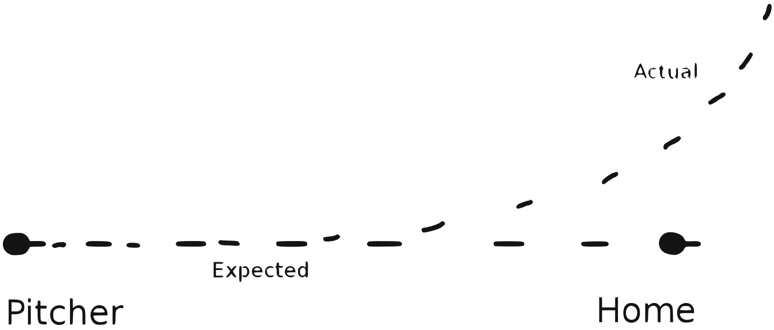

Fig. 2.8 Curveball. For years people argued about whether or not the path of a curveball really curves

the stitches weren't held in precisely the correct position and spin wasn't applied at the release. And so, the pitcher controls the flight of the ball by taking advantage of the aerodynamic properties of the raised stitches.[9] The different grips and releases result in different pitches because the aerodynamics differ with the extent of the Magnus force involved. The Magnus force is the force "directed at right angles to the direction of the air velocity and to the axis of spin."[10]

Since the batter can't see the orientation of the stitches as the pitcher releases the ball, he's left to observe the flight of the ball as it comes toward him at speeds of around 100 mph. If the pitcher "throws a 99 mph fastball, the ball is going to reach the batter in less than four tenths of a second, 395 milliseconds (ms). By comparison, it takes 400 ms—four tenths of a second—to blink your eye completely.

A lot has to happen in those 400 milliseconds. It takes the first 100 for the batter to see the ball in free flight and get an image to his brain. The brain then needs 75 ms to process the information and gauge the location and speed of the ball. In the next 25 ms—a fortieth of a second—he has to decide whether to swing, and then he's got only 25 ms more to decide if the ball is going to be high or low, inside or outside. If the decision was made to swing, another 25 ms are needed for the legs to react and begin the first motions of the swing. That leaves a grand total of 150 milliseconds for the batter to get the bat around and make contact."[11]

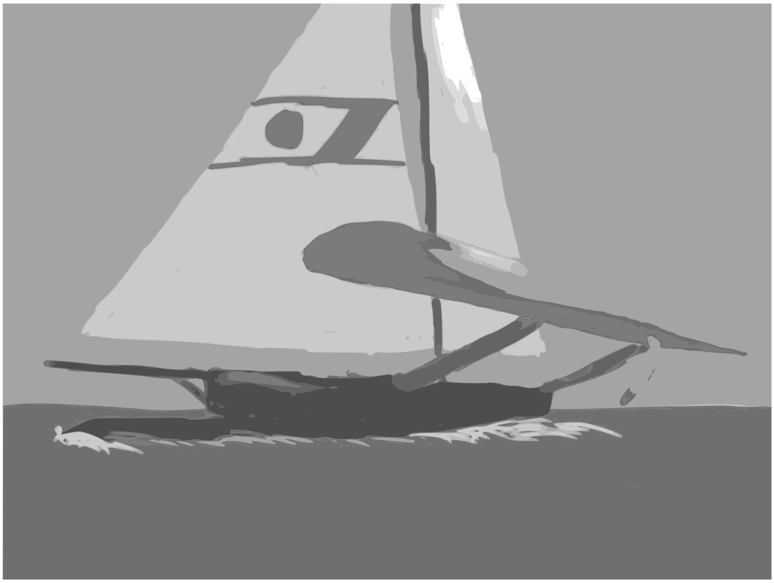

Fig. 2.9 America's Cup yacht. The trimaran hull on this America's Cup yacht affords a minimum of resistance

Fig. 2.10 The wetted surface of a vessel is the surface beneath the water. It is a source of resistance

All of that is complicated enough, but "if the ball's actual path over the last fifteen feet doesn't match their mental extrapolation, the ball isn't going to end up where they think it will be."[12] And that is where the distance from the mound to the plate makes all the difference. Both are situated so that the Magnus force will cause the ball to curve, or sink, or move in an unanticipated manner within those last crucial feet, causing the batter to swing and miss.

The designs of America's Cup racers also take full advantage of hydrodynamic principles to reduce resistance and maximize speed. One way this is done is by the use of a trimaran hull (Fig. 2.9). This design minimizes the amount of the hull that forms the *wetted surface* at any given time. This is significant because the wetted surface is a major source of resistance. With anything moving through a fluid, there will be a wetted surface. This is the portion of the object that is in direct contact with the fluid. With an airplane, the entire plane is in contact with the fluid at all times. With a ship or boat, the portion of the vessel below the waterline is the only part of the vessel in direct contact with the water, while the rest of the vessel is in contact with the air (Fig. 2.10).

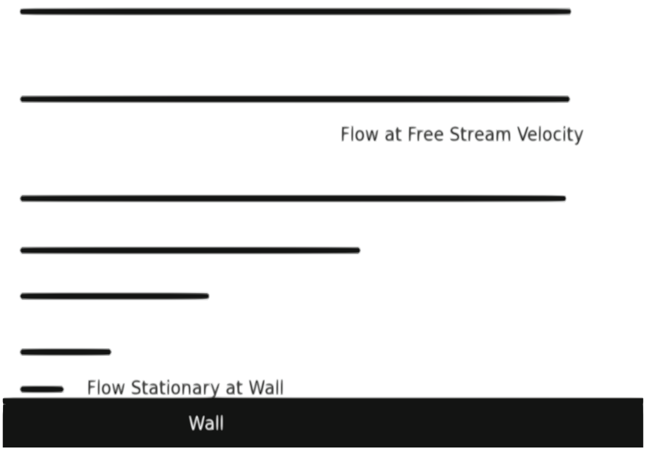

Fig. 2.11 The boundary layer is the area of greatest friction in a fluid flow

The fluid flowing past an object flows in a *streamline*. If no protrusions or other impediments are encountered, the fluid will flow smoothly, and there will be minimal turbulence. In an *ideal* (imaginary) *fluid* there would be no turbulence if there were no obstacles because the fluid in question would have no *viscosity.* Viscosity is the friction in a fluid. It determines how easily a fluid pours. Water is less viscous than honey, for example. And warm honey is less viscous than cold. When a viscous fluid flows past a wetted surface, a *boundary layer* is created. This boundary layer is an area where the forces of friction are so strong that the fluid moves very slowly, if at all. The slowest portion of the fluid slows the fluid directly beside it, and that portion in turn slows the portion beside it. The farther you move from the boundary layer, the weaker the force of friction and the more swiftly the fluid flows. At some point you will reach the portion of the flow that is unimpeded by the force of friction (Fig. 2.11).

In a vessel that rides low in the water because of a heavy load or a weighted keel that is used for balance, a significant portion of the hull is below the waterline and generating resistance that must be overcome. With a trimaran design, there is one main hull and two other hulls acting as balancing arms akin to Polynesian canoe designs. Only a small portion of the entire hull is below the water line because only the central hull is in the water at any given time. The other two hulls are never deep in the water. There is also no weighted keel required for balance, so the sailboat sits high in the water with a relatively small amount of her hull beneath the water. The combined effect of the small wetted surface and the superior balancing apparatus results in a world-class vessel capable of winning the America's Cup.

If there is an aspect of play to sport, the Frisbee flying disk is surely emblematic of it. Its concept is simple. It is shaped like the cross-section of an airfoil. It generates its own lift as it spins, allowing it to fly through the air. There are many variations on the flying disk but all owe their start to the time Walter Frederick Morrison was playing catch with his future wife during a Thanksgiving Day party in 1937.

They started out playing with the lid from a popcorn maker. “When flicked through the air rightside-up, the lid’s smooth top side offered little resistance to the air passing over it, while its downturned edge created a baffle slowing the air passing beneath. The result: lift.” As the game progressed, the lid got banged up and they switched to cake pans. “Stabilized by the spin imparted by a backhanded throw, the lid not only flew but also answered simple commands—depending on its angle when it left the hand, it would glide flat, curve or boomerang.” [13]

They’d switched from playing with a large popcorn can lid to an empty cake pan and were still using the cake pan for their catches one day in 1938 on a beach in Santa Monica, California. A man Morrison described as a local beach bum walked up and offered them a quarter for their cake pan. “That got the wheels turning,” Morrison told the Virginian-Pilot, “because you could buy a cake pan for 5 cent, and if people on the beach were willing to pay a quarter for it, well, there was a business.”

Morrison sold cake plans for a while before working up a design for a flying disk toy in 1948. His sketch was of an aerodynamic refinement of the metal cake pan. Shortly after Morrison envisioned his new design, a private pilot named Kenneth Arnold described nine bright objects he’d observed near Mount Rainier in Washington state. This first report of Unidentified Flying Objects began the UFO craze in the summer of 1947. Morrison was ready.

By 1948, Morrison had a plastic flying disk to demonstrate as he continued to tweak the aerodynamic properties of his invention. “A lot if it was intuitive,” said Phil Kennedy, Morrison’s coauthor of their book, “Flat Flip Flies Straight: True Origins of the Frisbee.” Because of his aviation experience, he [Morrison] knew what made a wing fly, and he applied that knowledge.[14]

In the time the Frisbee has been in existence everyone from the casual athlete to Bill Nye the Science Guy has weighed in on the forces at work in the flight of a Frisbee. The two main forces are gravity and air. Gravity is the force pushing down on the disk. Air is part of the force that generates upward lift for the Frisbee. The distance and direction of your Frisbee flight will depend upon the angle of release. The launch angle is the angle that exists as the person throwing the disk releases the disk. A Frisbee thrown at 180 degrees results in a straight throw. An angle greater than 180 degrees upon release will result in greater lift—an upward ride for the flying disk. Release at an angle of attack less than 180 degrees will lead the Frisbee to a meeting with the ground.

Lift is generated as the airflow over the top, curved surface of the spinning disk moves more quickly than the air flowing beneath the lower, less curved surface of the disk. The rim is an important component of the Frisbee because it is what helps to create the deep camber of the airfoil. In fact, without the rim, the angle of attack becomes the most important variable in the flight of the disk. Newton’s Third Law is also in play with the Frisbee as the air pushing up on the Frisbee is met by an equal and opposite force pushing back toward the ground. This force results in additional lift.

Angular momentum is also in play while the Frisbee is in motion. It provides stability and is provided by the spin. The faster the spin, the greater the stability. This stability is essential for those trying to do tricks with the Frisbee. Of course, drag is in play, as well. On a windy day there will be more drag, or resistance, making it more difficult for the Frisbee to maintain its momentum. The angle of attack is one way to overcome the forces of resistance, too.

So what generates the power in a Frisbee toss? According to Morrison, it's all in the wrist![15]

Man on Land

Today, it is commonly accepted practice for automobiles and trucks to be designed to minimize resistance and drag. This has not always been the case. The earliest instance of the purposeful use of aerodynamics in automobile design occurred in 1935. The engineers at Chrysler, with the full support of founder Walter P. Chrysler, were determined to introduce an aerodynamically sound car to the American public. The car was wind tunnel tested and, in addition to a better ride due to changes in the overall design, boasted increased fuel economy and faster running speeds.

Testing a scale model automobile in a wind tunnel was a direct result of the work done in model basins by Froude and Taylor in the design of ships. By observing the behavior of air flow around automobile models with slight changes in design components, the design could be perfected in far less time and at a significant reduction in cost. The wind tunnel tests were an accepted method of design because of Froude's groundbreaking work with scale ship models. They were also possible because da Vinci had long ago theorized that it was not necessary to move an object to observe the effect of the wind on that object. It was possible to have the wind move past the object and record the results. The outcome would be identical.

Chrysler used the wind tunnel tests to learn that by putting the headlights flush with the grill, making the bumpers flush with the car, and having the nose of the car project slightly before the upsweep of the hood and windshield, the Airstream lines decreased resistance. In fact, "air resistance at maximum speed was reduced 44 percent and fuel economy was increased 57 percent at 80 mph. At moderate speeds the fuel economy advantage was in the area of 25 to 35 percent. Less horsepower was needed to move the car through the air, so the engine ran slower and less frictional wear resulted."[16] Despite the fact this decrease in resistance translated into greater fuel economy and the attainment of faster road speeds, the American public was not ready for the huge departure from traditional automobile designs (Fig. 2.12). They did not flock to buy the Airstream or DeSoto and ultimately, despite the improvements in performance and Chrysler's adamant defense of their designs, the company was forced to abandon these models. Today the Chrysler Airstream is recognized as an innovative design.

Man in Water

Man hasn't only looked to the skies for inspiration. Many have looked instead to the oceans. They've studied the movement of fish to see what economies man could incorporate to benefit us in our own activities. One area of intense focus on fluid dynamic principles has come from participants in the sport of elite competitive swimming.

Fig. 2.12 The Chrysler Airflow was ahead of its time. It achieved a 44 % reduction in air resistance at maximum speed and a 57 % increase in fuel economy at 80 mph

Fish are perfectly adapted to their aquatic environment. Their bodies are sleek; no bumps or lumps jut out at irregular intervals. Everything about them is designed to reduce resistance. A swimmer is subject to the same fluid dynamic forces as any other creature making its way through the water. In fact, "there are four primary types of drag that contribute to total body drag: (1) skin friction drag which is a tangential force resulting from shear stresses in the water sliding by the body, (2) pressure drag which is a perpendicular force on the body associated with the pressure of the surrounding fluid, (3) wave drag that occurs when a swimmer moves on or near the water surface, and (4) induced drag that is associated with water deflection off hydrofoil surfaces… "[17] For a swimmer going for the gold in an Olympic event, no source of resistance is too small to consider. They seek a state of minimum resistance.

"There are several ways in which a swimmer tries to overcome drag. One is to use a stroke technique that makes his body stay as high on the water as possible. The more of his body that's out of the water, the less the water can hold it back. Another way is to make sure that his hands knife into the water as he reaches forward for the next stroke instead of inadvertently pushing forward, which is like stepping on a brake."[18]

Anything that reduces resistance is eagerly adopted. "There's only so much training a swimmer can do to make themselves stronger and improve their technique. That's why they look for ways to reduce drag that are 'free,' i.e., take no extra effort."[19] Bathing caps, shaven heads, shaven legs and arms on male and female swimmers—it's all done on a routine basis. Same thing with timing breaths to minimize disruption of the water surface and swimming beneath the water at the optimal depth for the optimal (allowed time) to mitigate the effects of surface disruption on performance—both matters of common practice.

Fig. 2.13 Speedo LZR Racer swimsuit image. The LZR Racer Suit changes the shape of the racers body. *Source*: Retrieved from http://www.nasa.gov/topics/technology/features/2008-0214-swimsuit.html

Since anything that will reduce the *boundary layer* and lessen *drag* is entertained as a possibility, it's not surprising that the current trend is toward long, one-piece racing suits that reduce resistance. These suits give the swimmer more in common with a fish or someone wearing a wing suit than a simple bathing suit possibly could. At the 2008 Summer Olympics in Beijing, swimmers wore a new type of swimsuit. It not only lessened resistance because of the sleek material that allowed someone wearing it to glide through the water with minimal drag, but also minimized resistance by forcing the body into an uncomfortable but aerodynamic configuration.

Speedo recognized that the human body is not tapered and sleek as an aquatic animal. They recognized that, "any time a muscle or loose section of skin bulges or shifts, it's going to block the smooth flow of water and impede the swimmer's forward motion." They designed the LZR Racer with the help of NASA. Because the human body has "momentary bulges of skin, fat, and muscle" when in motion, the Speedo LZR Racer is a full body-length swimsuit that "consists of a series of carefully shaped panels that push, squeeze, and compress the entire body into a more streamlined shape than the one he or she [the swimmer] started with." (Fig. 2.13).

"The LZR Suit holds all those bits tightly in place and stops them from sticking out into the water and increasing drag. A the same time, it changes the overall shape of the swimmer's body into a more streamlined configuration."[23] This aerodynamic perfection does not come easy. "The suit is so tight it takes half an hour—literally—to put on properly. Once it's in place, all that squeezing makes breathing more difficult, and it's so uncomfortable that the first thing wearers do when they get out of the pool is start tearing it off."[24]

Wearing this suit didn't just make the swimmer look more compact. It in fact made the swimmer's body more compact, reducing all possible sources of drag in the process. Speedo boasts that it requires 5 percent less effort to go the same speed when wearing the suit. So what was the effect of reducing resistance and changing the shape of the swimmer's body? Olympic swimmers wearing the suits attained the fastest times in the history of the Games. "When I hit the water, I feel like a rocket," says Michael Phelps, Olympic champion and one of the greatest swimmers in the history of the sport.

But how much was due to the LZR Racer and much can be attributed to the extraordinary measures taken in the creation of the pool? To further increase the speed of the pool, every technological innovation possible was used in creating the pool with the goal to reduce waves and the effect of those waves on the swimmers as they participated in their events. The desired outcome was what is commonly referred to as "fast water." The depth of the pool, the number of lanes, the gutter system, and the temperature of the water were all part of this effort, as was calculating the exact depth versus width of the pool to allow the maximum dissipation of disruption in the smallest amount of time. When the pool was complete, it was the epitome of a swimming environment designed to allow the peak performance of every athlete.

"In general, body drag for a swimmer moving on or near the water surface is 4–5 times higher than the level of drag encountered by the submerged swimmer moving at the same speed (Hertel 1966). Much of this increase in drag at the water surface is due to energy wasted in the formation waves."[25] Fish and marine mammals overcome this problem by swimming deep enough to avoid the effect of these waves. Olympic swimming rules restrict the distance over which a swimmer can proceed in this way.

As a result, "swimmers generate waves as they churn down the lane, not just at the water's surface but below it as well. These waves travel rapidly down to the bottom of the pool and then bounce, in the same way that a sound wave echoes off a wall. The returning wave creates turbulence that slows the racers down. The deeper the pool, the more these waves will be dampened on the way down and up, resulting in a smoother and therefore faster ride for the swimmer. Modern competition pools have a uniform depth of seven to nine feet."[26] The pool at the Beijing Olympics is 10 feet deep, 1.3 meters deeper than most Olympic pools. This is the optimal depth for a pool because it minimizes the effects of turbulence caused by the activity of the swimmers, yet is not so deep that their sense of vision is lost.

"Waves travel sideways, too, affecting swimmers in adjacent lanes. One way to ameliorate this effect is to make the lanes wider" but "even more important than the lane lines are the gutters at each end and along the sides of the pool."[27]

"In some high-end pools, such as the one at Beijing, there is an extra lane on each side, which remains unoccupied during a race. Its only function is to give lateral waves a chance to dissipate as they bounce."[28]

The Beijing pool also employed perforated gutters on both sides to absorb the lateral waves. The net effect, along with the temperature of the water—set at a point where it was comfortable for the swimmers yet reduced the viscosity of the water, was to create the fastest water yet at an Olympic swimming venue. Between the optimal conditions in the pool and the use of the Speedo LZR Racer swim suit, 25 world records were broken over the course of the Beijing Olympics. All of the improvements in conditions were "free." They required no extra training on the part of the athletes in the same way that shaving their heads or dolphin swimming upon initial entry to the pool brings improved performance.

It's interesting to note that the same concerns with dissipation of waves were expressed by the early designers of model basins for scale model testing. William Froude and David Taylor each took elaborate measures to ensure that the depth of the water would reduce the bounce back of turbulence from the model runs. Gutter systems were put in place on the sides of the basins to hasten the dispersion of lateral movement. These early fluid dynamicists sought to eliminate any forms of turbulence in their venues with their designs; today's swimmers seek to do the same with the design of their venues. The prize for their efforts is a model basin or pool that permits the best possible performance of the model or swimmer because of the active steps taken to reduce the resistance created by the test or event itself.

It stands to reason that if man will pursue perfection in the form they take while moving directly through the water, they'll want to utilize a design for peak performance when moving through the water in a craft. This has been precisely the case with the development of the submarine. From the earliest days of testing and innovation of the first truly practical and modern submarines at the start of the twentieth century, consideration of ways in which to minimize resistance have been of primary importance.

Submarines are essentially stealth craft. They make their way, unnoticed beneath the waves. If a submarine is "noisy," it will be easy to detect. If it is capable of running "quietly" it can enter areas at will without drawing attention. The same factors that make a submarine noisy are the things that reduce its hydrodynamic efficiency. These factors include anything that increases resistance or turbulence at the boundary layer. They also include cavitation or bubbles around the propeller action that disrupt the water at the prop. A submarine that can flow with a sound footprint similar to that of a shark is one that is making the best use of its propulsive power: It is running with maximum efficiency.

Since a submarine moves through the water in a manner similar to the manner in which a bird makes its way through the sky, the four forces of flight are at play in the design of these craft. The shape is important because it influences the body drag of the vessel. Streamlines are in effect for a submarine, just as they are for any craft moving through a fluid. Bernoulli's principle is also in play. This will influence the amount of lift the sub can generate.

Skin friction is another consideration. The more attention paid to the laminar and turbulent flows around the vessel, the better. This attention will result in an optimal length to go with the optimal shape, resulting in increased quite and efficiency. Appendages must also be designed for least resistance. By carefully studying the effects of hydrodynamic forces on submarine designs in model basins and in full-sized craft, submarine design has resulted in vessels that are not only efficient but also nearly silent.

Conclusion

From the time of the ancient Greeks to the time of the first submariners, humans have set their sights on moving through the air like a bird and the oceans like a fish. The result has not been the unencumbered movement enjoyed by these animals in nature, but it has been sufficient to bring humans eye to eye with the objects of their fascination in their own environment.

Notes

1. Fuller, J. (1998–2012). "How Stuff Works." *Top 10 Bungled Attempts at One-Person Flight*. 2012, from http://science.howstuffworks.com/transport/flight/classic/ten-bungled-flight-attempt3.htm.
2. Henderson, C. L. (2008). *Birds in flight : the art and science of how birds fly*. Minneapolis, MN, Voyageur Press.
3. Ibid.
4. Ibid.
5. "Birdman."
6. Brenkus, J. (2010). *The perfection point*. New York, NYEnfield, Harper ; Publishers Group UK distributor.
7. Ibid.
8. Ibid.
9. Adair, R. K. (1994). *The physics of baseball*. New York, HarperPerennial.
10. Ibid.
11. Brenkus, J. (2010). *The perfection point*. New York, NY Enfield, Harper ; Publishers Group UK distributor.
12. Ibid.
13. Swift, E. (2007). the man with the original plan. *The Virginian-Pilot*, Landmark Communications Inc.
14. Ibid.
15. Ibid.
16. Butler, D. Adventures in Airflow: Part II. *Cars & Parts*: 8.
17. Perrin, W. F., B. G. Würsig, et al. (2009). *Encyclopedia of marine mammals*. San Diego, Academic Press.
18. Brenkus, J. (2010). *The perfection point*. New York, NY Enfield, Harper; Publishers Group UK distributor.
19. Ibid.
20. Ibid.

21. Ibid.
22. Ibid.
23. Ibid.
24. Ibid.
25. Perrin, W. F., B. G. Würsig, et al. (2009). *Encyclopedia of marine mammals*. San Diego, Academic Press.
26. Brenkus, J. (2010). *The perfection point*. New York, NY Enfield, Harper; Publishers Group UK distributor.
27. Ibid.
28. Ibid.

Springer
http://www.springer.com/978-1-4614-4595-1

Modeling Ships and Space Craft
The Science and Art of Mastering the Oceans and Sky
Hagler, G.
2013, XIV, 249 p. 112 illus., 11 illus. in color., Softcover
ISBN: 978-1-4614-4595-1