Chapter 9 Ready for colleagues

Flying Machines: The Challenge of Staying Aloft

One Sunday morning in the spring of 1980, Seattle residents awoke to the blast of nearby Mount St. Helens. We knew it was coming. For weeks beforehand, seismologists had recorded the mountain's rumblings and filmed its belching steam. Onlookers were warned to stay clear. Then, suddenly, the mountain literally blew its top.

The St. Helens eruption was timid compared to the 1883 blast of Krakatoa, an island set between Java and Sumatra. During the days prior to that explosion, sailors in the area reported unusual activity. Then, in one huge paroxysm, the island blew up. Thousands died, 40-meter tsunamis inundated nearby islands, and waves rocked ships as far as South Africa. Most of the volcanic island of Krakatoa literally disappeared from the map.

Both of those volcanoes spewed boulders, gases, ash, and sundry materials high into the sky. The boulders fell quickly to earth, but the finer particles remained aloft for some time. After the Krakatoa eruption, for example, particles circled the earth multiple times before finally settling to the land below. Those airborne particles produced lingering optical effects — sunsets lasted longer and became redder. The intense red glow reportedly triggered frantic calls to fire engines to quell the supposed fires. Those optical effects persisted for several *years*.

The lingering airborne particles also changed the weather. Since suspended debris reflects sunlight, one anticipates temperature lowering. The 1815 eruption of Mt. Tambora in Indonesia led to a New England year without summer, while the particulate matter from Krakatoa reflected enough sunlight to reduce the global temperature for several years.

If you are now anticipating settling in to a chapter filled with volcano exotica, what follows may disappoint you. The rest of the chapter will deal only indirectly with volcanoes. It will consider the airborne particles that originate from volcanoes and elsewhere but will focus on *why* those particles stay aloft for as long as they do. What keeps those dense particles suspended? How can we understand their remaining in the atmosphere for several years?

We then ask a related question: can the principles that explain particle suspension also explain the suspension of larger objects? Can those principles tell us why paper airplanes, gliders, and even Frisbees manage to stay aloft for as long as they do?

Remaining Aloft from Charge

Let us return to those persisting volcano-enhanced sunsets. The conventional response to the question of long-lasting suspension involves the particles' diminutive size: finer particles experience relatively more air friction per unit mass, restricting their downward speed. Minute particles take longer to settle to the earth. This explanation may seem plausible, but can it explain *years* aloft?

By now, it will not surprise readers of this book that an alternative explanation for why such particles resist settling to earth comes from the force of charges. Small dust particles and blown sand acquire negative charge. According to wind-tunnel studies, higher wind speed creates stronger negative charge (Shinbrot and Hermann, 2008: Zheng et al., 2004). Evidence of particle charge also comes from volcanic eruptions: strategically positioned cameras have recorded intense lightning-like discharges, projecting from the erupting mass to ground (**Fig. 9.1**).

Figure 9.1. *Icelandic eruption, April 2010. Source?*

It seems natural to ask whether that negative charge bears responsibility for the long-term levitation of such particles. **Chapter X** showed that clouds stay aloft because their inherent negativity repels the earth's negativity. The same principle should apply to volcanic particles. So long as the particulate dust remains sufficiently negatively charged, the particles should remain in the atmosphere, even for years.

Similar reasoning applies to dust. Ordinary house dust comprises mainly flakes of skin and hair, both of which are denser than air. Yet house dust doesn't readily settle to the floor. A beam of sunshine coming through your bedroom window will reveal numerous dust particles dancing through the air in a seemingly random fashion. Like most proteins, skin and hair proteins bear negative charge. One wonders whether that negative charge keeps the dust particles up in the air.

Finally, consider dust storms. Called "haboob," from the Arabic for "blowing," dry dust can blanket areas in choking darkness. An Arizona dust storm in 2011 stretched for some 50 miles, the dust rising as much as 8,000 feet high http://vimeo.com/26045314.

Electrostatic repulsion helps explain these phenomena. The airborne particles' negative charge repels the earth's negative charge. (The particles also repel one another). *Staying aloft involves nothing more than developing sufficient negative charge to repel the earth's charge*.

We will observe many manifestations of this simple principle in the remainder of this chapter and the several that follow. We will see the principle operating in practically everything that flies, from paper planes and Frisbees all the way to gliders and eagles.

Lifters and Charge

Mentioned briefly in **Chapter 7**, "lifters" represent one possible example of this kind of repulsion. When energized by high voltage, these gadgets, after an initial hesitation, lift almost mysteriously from the ground, like a magic carpet. They contain no engine of any sort — only two wires mounted circumferentially on a lightweight frame and connected flexibly to the terminals of a high-voltage supply. Somehow, the electrical activation creates demonstrable lift.

Hobbyist demonstrations of these lifters are the sad remnants of a once-active field called "electrogravitics." A book by Paul LaViolette (2008) details this field's fascinating history, which began almost a century ago and peaked during WW II. The account details developments not only by Americans but also by Germans and Russians. It cites multiple reports and patents.

However, that progress terminated abruptly. With the increasing recognition of the patents secured by the American engineer T. Townsend Brown and the ensuing developments by the US Navy (which at one time spent as much as 5 percent of its budget on electrostatic lifting machines) the field suddenly went underground. That happened in the late 1950s, apparently for security reasons. Since then, academics have largely ceased pursuing the subject, and accessible developments have come mainly from curious hobbyists.

Where those underground developments have led remains unknown to the general public, although it's widely speculated that the B2 "Stealth" bomber gains lift in part from electrogravitic forces.

Uncertainty persists regarding how lifters achieve their lift. The standard explanation posits that the lift arises from the so-called Biefield-Brown effect, which involves an ion current from one wire to the other. Whether this explanation suffices seems unclear: reports conflict on whether vacuum environments can sustain lift. The lifter built in our laboratory (**Fig. 9.2**) could rise whether the negative electrode was the lower or upper one, dashing our initial speculation that lift might arise because the negative pole was closer to the negative earth.

Following that disappointment came a more promising idea. Lifters consist of two ring-like electrodes vertically separated some distance from one another. The negative electrode emits electrons. The positive electrode might correspondingly emit protons; however, protons sit firmly embedded in atoms; therefore, the positive electrode emits nothing. Only electrons, which carry current, can be emitted from the pair of electrodes.

Figure 9.2. Our lifter rising up.

As a result of this imbalance, electrons emitted from the negative terminal should dominate. Those electrons attract to the positive terminal, effectively neutralizing its positive charge. Meanwhile, the negative terminal's endless supply of electrons ensures persisting negativity of the electrode pair. That negative charge repels the earth, irrespective of electrode-polarity orientation. Essentially, the lifter acts as a blob of negative charge. As a result, the lifter lifts from the earth.

So, obtaining lift from charge might not be all that arcane. Negative charge repels negative charge. The principle operates on particles, dust, and clouds, as well as on lifters. A small amount of charge, please recall (**Chapter 1**), can create appreciable lift.

Triboelectricity: Acquiring Charge by Air Friction

Charge can create lift, but where do those charges come from? How do charges build?

An important source of charge is friction, especially air friction. Consider the garden-variety hair dryer, which dries by blowing streams of dry air past your just-showered locks. The dryer also fluffs your hair. As each strand acquires charge from air friction, the hairs repel one another and your hair fluffs.

The familiar phenomenon of acquiring charge by passing one material over another is not limited to the use of hair dryers. Rubbing any two substances past one another will accomplish the same end: one surface will become positively charged, while the other will become negatively charged. Perhaps you've rubbed a sheet of paper on the wall: following a few vigorous strokes, the paper sticks to the wall because the two entities have acquired opposite charges. The effect lasts for a few seconds, after which the charges neutralize and the paper falls to the floor.

The study of frictionally acquired charge is an established scientific discipline, called triboelectricity. "Tribo-," from the Greek "rubbing," refers to friction. Triboelectricity deals with the theory and specifics of charge transfers that attend the rubbing of different substances on one another. The so-called triboelectric series summarizes those transfers (**Table 9.1**).

The series shown in Table 9.1 reveals what happens when any one substance rubs against another: substances higher on the list become positively charged, while lower ones become negatively charged. Fur lies above vinyl; when rubbed on vinyl, it acquires positive charge, leaving the vinyl negative.

Table 9.1. *Triboelectric series. Substances higher on the chart become positive when rubbed on substances lower, which acquire negativity. Obtained from http://www.rfcafe.com/references/electrical/triboelectric_series.htm E: "acquire", not "aquire"*

Air is the highest substance on the chart — implying that *air blown on anything confers negativity on its recipient*.

The acquired negativity can keep objects aloft. That explains why wind gusts can blow dried autumn leaves high into the air. Wind friction can also create dust devils: the particles at the tops of those devils become so intensely charged that they produce electric fields on the order of 100,000 volts per meter (Jackson and Farrell, 2006), sustaining the devil by keeping the particles suspended high in the air. Even wind-blown sand, which is denser than dust, acquires enough charge to rise high in the atmosphere. The sandstorm's leading edge can appear as a highly charged wall rising up to 1,500 meters high <http://www.infoplease.com/ce6/weather/A0843423.html>.

These diverse examples lend credence to the concept of charge-based lifting. The charge comes from air friction. Friction, according to the triboelectric effect, builds negative charge on anything passing through the air, and that negative charge repels the earth, creating lift.

Charge Based Amusements

With some understanding of air friction, we may now ask about familiar flying objects. Why do Frisbees, boomerangs, and even kites float for as long as they do?

The modern Frisbee dates back to 1871, when William Russell Frisbie of Bridgeport, Connecticut, opened a small bakery known as the Frisbie Pie Company. Frisbie's pies gained popularity among nearby Yale University students, who began tossing around the empty pie tins. They called those tins "Frisbies." The first commercial production of these flying discs came in 1957, and became popular later, when the Wham-O Company released their trademarked "Frisbee."

Aficionados presume that the Frisbee's iconic shape must play a critical role in its persisting flotation. That is, the lift comes from the Frisbee's rounded edge, which creates a lower pressure above than below the disc, so the Frisbee floats. The spin confers angular momentum, which stabilizes the floating disc from wobble.

This interpretation gained broad acceptance until someone invented the flat Frisbee (**Fig. 9.3**). Lacking the iconic rim, the washer-like Frisbee stays aloft almost as long as the classical version. Its lack of the rounded edge purportedly necessary for creating the pressure difference implies that something other than pressure difference must explain the toy's lift.

Figure 9.3. *Two types of Frisbee — the classic one, and the flat donut.*

I suggest charge. A Frisbee will rise if it acquires enough negative charge as it passes through the air. The charge polarity should be negative (**Table 9.1**). The highest charge should reside at the Frisbee's edge because the rim's high rotational speed through the air creates the highest friction. Rotation is key: once the rotational motion slows, the Frisbee will begin losing its charge and will quickly sink — as common experience confirms.

The same principle applies to the boomerang, which also rotates through the air. Like Frisbees, boomerangs stay aloft much longer when thrown with their characteristic twirl, creating charge from air friction. Spinning-wheel discs launched from gun-like hobby devices work similarly: start those lightweight discs spinning, and they will fly like Frisbees, falling only when rotation ceases.

Charged-based educational toys have recently hit the market <http://www.teachersource.com/ElectricityAndMagnetism/Electricity/FunFlyStick.aspx>. A wand, powered by an internal moving-belt Van der Graaf generator, acquires charge. Touching or approaching certain objects with the wand confers charge on those objects, which then exhibit sundry effects, including levitation.

Finally, charge-based levitation brings to mind the subject of flying kites. Many of us remember Benjamin Franklin's kite experiments. Franklin was canny — he did not experiment during actual lightning discharge, which would probably have brought instant electrocution; his experiments took place in the charged atmosphere just prior to the storm. Modern experiments confirm Franklin's results: they show electrical discharge (corona) around the kite's edges, as well as high-voltage discharge to the earth http://cst.mos.org/sln/toe/kite.html. Clearly, kites bear charge, presumably triboelectric, and one wonders about the extent to which those charges keep the kite suspended in the air.

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Gyroscopes, Bicycle Wheels, and Eric Lathwaite

Comprising little more than a wheel rotating in the horizontal plane around a vertical post, the gyroscope somehow manages to maintain a stable orientation. As long as the wheel rotates, the post remains vertical, and that verticality makes gyroscopes useful for knowing which way is up.

Charge may be responsible for the gyroscope's vaunted stability. Spinning rapidly through the air, the rotating wheel acquires substantial negative charge. That negative charge repels the negative charge of the earth. Should the wheel slightly tilt, its downward edge will repel the earth more strongly than its upper edge because of its diminished distance from the earth's negative charge. That stronger repulsion rights the wheel, maintaining the gyroscope's stability.

The charge mechanism implies that the gyroscope will be easier to lift when the wheel is turning than when it's not: the assist comes from the repulsion between the spinning wheel's negative charge and the earth's negative charge.

The prominent British electrical engineering professor Eric Lathwaite once stunned the otherwise dour Faraday Society by demonstrating exactly that: a heavy wheel mounted on a pole was a struggle to lift; however, when the wheel was made to rotate, anyone could lift it. A video (https://www.youtube.com/watch?v=JRPC7a_AcQ - https://www.youtube.com/watch?v=JRPC7a_AcQ) captures that feat, which seemed so radical to the audience that Faraday Society members abstained from their otherwise routine practice of publishing those presentations. Apparent levitation was simply too extreme.

A similar principle may apply to bicycles. Oddly, nobody's sure why fast-moving bicycles remain stable, whereas slowly moving or stalled ones will falter to one side or the other.

A bicycle's fast-rotating tires should acquire substantial negative charge. Any tilt increases the tire's repulsion from the earth, thereby edging the top of the tire back toward verticality. The higher the speed, the more the charge and hence the higher the stability. Thus, fast-moving bicycles don't fall over.

Flying Machines

Continuing on the theme of electrostatic lift, we next focus on gliders, the engineless man-made birds of the sky (**Fig. 9.4**). Commonly towed by powered planes or fast-moving cars and then released to fly independently, these quiet aircraft create endless joy for enthusiasts and some challenge for those trying to understand the principles. How might sailplanes remain aloft without the benefit of engine power? I think you can guess at the conclusion I'll draw.

Figure 9.4. A modern glider. *from: http://inflight.squarespace.com/featured/2011/3/14/the-secret-lives-of-gliders.html -- Hollister soaring center.*

First, some background. According to the prevailing view, gliders gain lift from rising air. Experienced pilots know four likely sources: (i) rows of cumulus clouds, beneath which warmer air appears to rise (thermals); (ii) areas where air masses converge, forcing air upward; (iii) sharply rising cliffs, against which strong winds have no choice but to rise; and (iv) regions where strong winds blow over mountains, forming so-called mountain waves.

No doubt air can rise (**Chapter X –** weather). However, the criteria that pilots use to infer rising air can mislead. If the glider rises, then it is presumed that the air around it must be rising, for what else could lift the glider? Rising air has seemed a no-brainer.

However, a subtle problem plagues the rising-air scenario: upward airflow at one location implies an equal downward airflow elsewhere; otherwise, we'd quickly lose our atmosphere. Downflows must accompany upflows. Those downflows could wreak havoc — if the upward flows can lift the plane, then the downward flows would surely drive the plane downward. Imagine the fate of the hapless pilot inadvertently meandering into sinking air. Opportunities for downflow encounters surely exist — sailplanes have flown as far as 2000 km at a stretch http://www.stuff.co.nz/travel/themes/adventure/68515467/soaring-over-the-south-island . Since sailplanes rarely crash, updrafts seem unable to explain the full story of lift. Some other force must help keep gliders aloft.

Little consideration has been given to the possible role of charge. Gliding through the air should build plenty of negative charge, and negative charge produces lift, which can be substantial (Chapter 1). If gliders gain lift from charge, then pilots need not face the harrowing prospect of a sinking-air disaster.

Understanding these lift principles can lead to improved aircraft design. Since charge magnitude depends on the surface area exposed to the air, increasing that area should create more charge and more lift. Adding grid-like fenestrations to wings may seem exotic, but I'm told that Boeing engineers have tried exactly that, with some gains in performance. Perhaps fenestrations may one day appear on gliders as well.

Similar lift mechanisms may apply to paper airplanes (**Fig. 9.5**). Paper planes first appeared around 500 BCE in ancient China, when the manufacturing of paper became widespread; they also appeared in Japan in conjunction with the art of paper folding (origami). The Wright brothers also flew paper planes. Credited with building the first successful powered aircraft, the Wrights used paper planes extensively to test their designs in wind-tunnel experiments. Paper planes have a venerable history.

Figure 9.5. *Common paper airplane.*

Paper-plane flight begins when someone imparts forward thrust. The plane then soars. Most paper planes soar for limited distances, others surprisingly far — the current distance record being just shy of 70 meters. The obvious question: what keeps paper planes aloft for so long? Rising air would certainly seem unlikely here.

Nor does the Bernoulli mechanism elucidate matters. That standard explanation for lift relies on shape difference between the wing's upper and lower surfaces — curved above and flat on bottom. That difference supposedly creates lower pressure above than below, conferring lift. It is tempting to invoke Bernoulli except for one inconvenient fact: paper-plane wings typically have flat tops and bottoms. They lack the classic curvature responsible for creating Bernoulli's lift. Some other mechanism must keep paper planes aloft, and if neither Bernoulli's principle nor rising air makes sense of this phenomenon, we must search for something else.

We come again to charge. According to our triboelectric table, a sheet of paper passing through air should acquire negative charge, and that charge can confer lift. The lift should vanish once the plane slows, and that's typically when the plane falls to the ground.

Hence, negative charge could easily keep both paper planes and gliders aloft. So long as those planes keep moving, they should sustain charge and keep afloat.

Forward Thrust

While negative charge may solve the problem of lift, it skirts the issue of forward motion. Gliders do not simply hover; they advance continuously, even as they rise. What drives those vehicles forward?

I posit that two forces drive them. We will first consider inertia. The same force that keeps planets moving (**Chapter X**) can also keep glider planes moving. Recall the scenario: Moving bodies compress the positive charges ahead. Those relatively dense charges pull on the moving bodies, while the relatively uncharged void in the bodies' wakes reduces any retarding force. The unbalanced forces ahead of and behind the objects keeps them going in the same direction they had been moving. That inertial principle applies to moving objects of any kind, including aircraft. By this principle, forward-moving gliders keep traveling forward.

Another force, also based on charge but perhaps less obvious, requires some explanation. Let me begin with a classic example from physics: a dielectric (insulating) rod suspended in an electric field (**Fig. 9.6**).

The figure shows two capacitors, i.e., parallel plates separated by an insulating material (in this case, a dielectric rod). One capacitor envelops the tip of the rod, the other the shaft. Each capacitor generates an electric field because of the separated charges (much like the atmospheric electric field). The field created by the capacitor on the right induces equal and opposite charges along the length of the rod, resulting in equal upward and downward forces; the rod remains suspended midway between the plates.

The left-hand capacitor does much the same. However, the partial insertion of the shaft between that capacitor's plates creates an additional effect: since much of the capacitor's charge lies to the left of the rod, those charges will create a leftward pull; the tip of the rod will be drawn leftward.

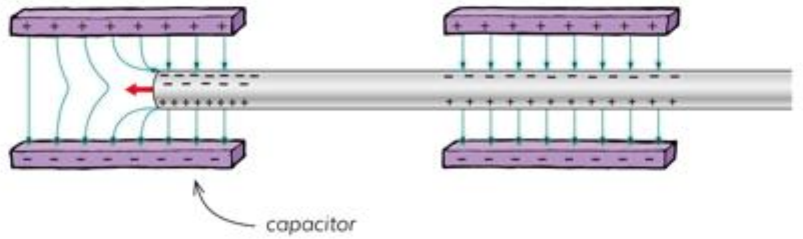

Figure 9.6. Dielectric rod suspended within the plates of two capacitors. Right hand capacitor induces charges on the rod, resulting in lateral forces that balance one another. Left hand capacitor draws the rod's charges toward the tip, creating an attraction that pulls the rod into the capacitor's field.

An equivalent description of this force is that the electric field bends toward the tip, as the figure shows; it has both vertical and horizontal components. The horizontal component creates a lateral force that pulls the rod farther into the capacitor — exactly as deduced in the paragraph above.

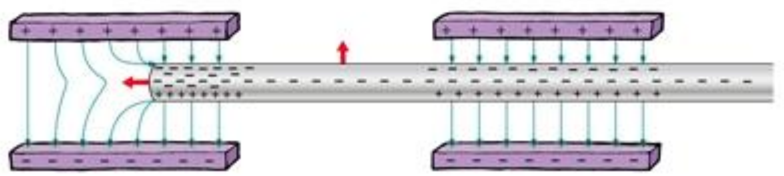

Figure 9.7. Similar to Figure 9.6, except that the rod contains net negative charge.

Next, consider the same scenario but suppose that the rod bears a net negative charge, as might a wing (**Fig. 9.7**). The result is similar to that of **Figure 9.6**, except that the rod's negativity creates a net upward force because the positive plate pulls the rod upward while the negative plate also pushes it upward. That creates lift. The lateral force, on the other hand, remains similar to that of **Figure 9.6**, possibly intensified because of the higher concentration of negativity at the rod's tip. Thus, negatively charged bodies can experience both upward and lateral forces, so long as the scenario is asymmetric.

Asymmetry arises naturally in wing-shaped devices such as those found on airplanes. **Figure 9.8** shows an example. Most of the negative charge will develop at the front edge of the wing, where the wind hits the wing directly. As the front edge acquires negative charge, the passing air acquires an equal and opposite positive charge, with the expected distribution shown in the figure. The front has the highest negativity. The rear may also acquire some negativity; however, the positively charged backward-streaming air weakens that.

The moving wing situation in **Figure 9.8** therefore resembles the tip of the rod in **Figure 9.7**. The earth's electric field replaces the capacitor's electric field. The field lines in front of the leading edge will bend toward the wing, as in **Figure 9.8**. So the wing will advance.

A paradoxical expectation of this second model, as well as the inertial model, is that forward motion can occur even *against* the wind. Wind ordinarily generates frictional drag, which produces a backward-directed force; wings should move rearward. However, these two models anticipate forward motion. Provided that the wind generates enough negative charge to overcome the drag force, the plane should move *into* the wind.

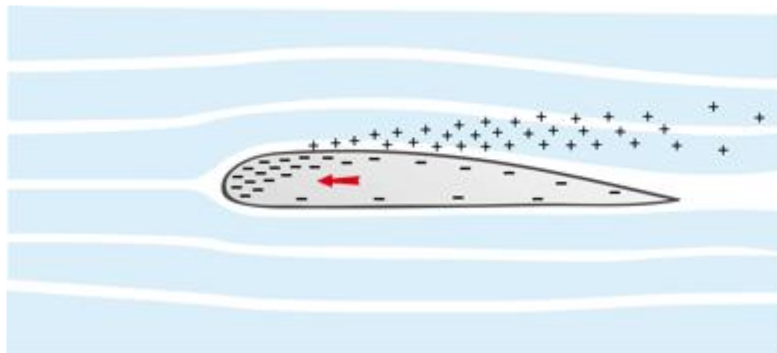

Figure 9.8. *High-velocity air passing over the wing's front edge builds negative charge. Meanwhile, the air acquires positive charge, neutralizing the wing's rear edge.*

In sum, we have a good rationale for understanding how simple flying machines fly. Charge-based mechanisms can account for the lift as well as the forward motion.

Powered Flight

While hobbyists may revel in the excitement of engineless flight, most airplanes run on fuel. Engines create thrust. Thrust moves the plane forward, overwhelming any drag forces. The lift, according to conventional thinking, comes from Bernoulli's principle, the relatively higher pressure beneath the wing pushing upward. These fuel-energized forces can supposedly take us from Seattle to Chicago.

I alluded earlier to some concerns about the Bernoulli lift mechanism. According to that mechanism, lift arises from the wing's classical airfoil shape: The longer front-to-back path length on the top versus the shorter span on bottom. That path difference creates the reduced pressure above that brings lift. However, that mechanism cannot provide a consistent explanation: Some planes can fly upside down. A dramatic example: http://www.dailymail.co.uk/news/article-1265891/Hold-think-youre-going-Skydiver-grabs-gliders-tail-fin-fly-2-100-metres-100mph.html. Also, model airplanes and paper airplanes can fly with flat wings — and so did the original planes flown by the Wright brothers.

Beginning in the 1950s, wing designs have progressively diverged from the classic aerodynamic cross-section to so-called supercritical designs that are flatter on top

(**Fig. 9.9)**. Modern examples can be seen just by looking at wings at your nearest airport. Classic airfoil shapes are hard to find.

Looking at hobby-plane designs reinforces concern about the Bernoulli mechanism. Many hobby planes are made of Styrofoam covered with fabric. They can be flown as gliders or fitted with small motors for powered flight. The wings of those foam models come with diverse cross-sections, ranging from classical to symmetrical, the latter having identical curvatures on top and bottom (http://www.flyingfoam.com/Airfoil-Help.html). If gliders with symmetrical wing cross-sections can fly perfectly well, then what does that say about Bernoulli-based lift as a general principle?

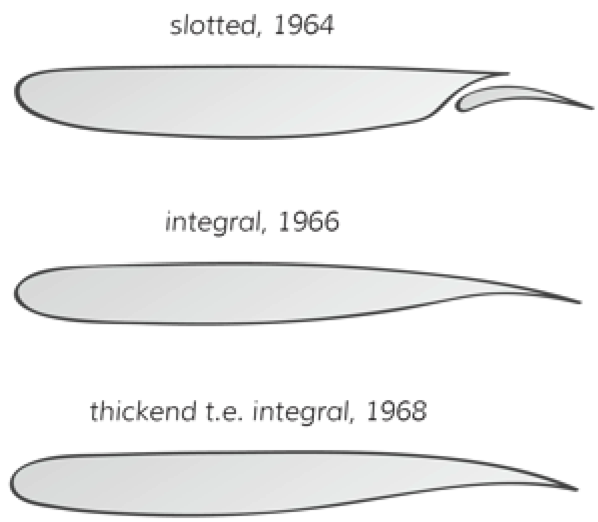

Figure 9.9. *Cross sections of three supercritical wing cross sections. Redrawn from a company flyer: http://www.centennialofflight.gov/essay/Evolution_of_Technology/supercritical/Tech12G1*.htm

I thought I was alone in questioning Mr. Bernoulli but soon discovered many people questioning not only the applicability of his principle for explaining lift, but also the validity of the principle itself. Two relevant examples: a book with the colorful title *Stop Abusing Bernoulli: How Airplanes Really Fly (Craig, 1997)*, and an experimental demonstration that a fundamental assumption of the Bernoulli mechanism is invalid: http://www.telegraph.co.uk/science/science-news/9035708/Cambridge-scientist-debunks-flying-myth.html.

If Bernoulli's principle fails to explain lift, then something else must. Recognizing the limitations of the Bernoulli principle, some have argued for an alternative involving wing tilt — the so-called "angle-of-attack" mechanism. Surely you've stuck your hand out of the window of a fast-moving car; your hand drags backward, but with judicious tilt it also pushes upward. Planes could theoretically use this same mechanism for gaining lift. However, that maneuver incurs major drag, which demands additional fuel to maintain the same speed. Since airlines will do practically anything to avoid extra fuel costs, one wonders about the extent to which this principle gets used. For gliders, that mechanism is obviously inapplicable — where is the fuel for counteracting the drag? The gliders would quickly stall.

The earlier-outlined charge-based explanation for lift can also apply to powered flight. It requires neither the classic airfoil shape nor wing tilt. Achieving lift only needs charge to develop on the wing, which happens naturally as the aircraft's wings and nose pass through the air.

The development of charges on planes is no mere conjecture. A six-year study by the US Army and Navy showed that aircraft generated fields of 2,000 volts per meter while flying through ordinary city haze and up to 45,000 volts per meter — practically enough for coronal discharge — while flying through dry crystalline snow (Gunn, 1948). No wonder that airlines take special measures to dissipate that charge in order to prevent fuel-tank explosion.

Actual coronal discharges often occur around a plane's forward regions. That includes the windshield as well as the wing-fuselage joints. Suffering the highest triboelectric wind shear, those frontal regions will develop the highest charge, explaining the consequent discharges.

This high frontal charge also explains the familiar picture of jet planes lifting in front during takeoff (**Fig. 9.10**). Frontal lift seems paradoxical because the aircraft's front is heavier than the rear — the stationary plane always rests on its front landing gear. Oddly, that heavier section lifts first.

Pilots explain this anomaly in terms of the rear elevator flaps: on takeoff, they are adjusted to generate a downward force at the rear, thereby lifting the front. However, the anomaly can occur even in jets parked on the tarmac. When stiff winds hit windward-facing jets, their fronts may lift, even though they are heaviest (http://www.dailymail.co.uk/news/article-2150253/Unbelievable-video-shows-strong-winds-lift-parked-jumbo-jet-air.html) Understanding that the nose and leading edges of the wings experience the highest charge, and therefore the most lift, may help resolve the paradox.

If planes and earth both bear enough negative charge, then lift is inevitable. In this context, I was not surprised to find a patent application dealing with aerodynamic effects arising from wing triboelectricity: USPTO Application #20070246611: "Triboelectric treatment of wing and blade surfaces to reduce wake and bvi/hss noise." Others have started to recognize charge-based effects.

The lingering question — the 800-pound gorilla sitting in the room: how much lift can charges actually generate? Is it sufficient? Theoretical models can certainly address that question; however, multiple assumptions will necessarily plague any such model, leaving any attempt to test the adequacy of the proposed lift mechanism subject to question. One can merely say that charges exert unexpectedly strong forces. Recall **Chapter 1**: one second's worth of electrons flowing through a lightbulb filament could lift 5,000 jumbo jets.

With that quantitative measure, you'd think that lifting a single jumbo jet ought to be as easy as rolling off a log.

Figure 9.10. *Planes lift from the front, despite its heavier weight. The development of frontal charge may explain the familiar phenomenon.*

Summary

Fine particles remain suspended in the air for long periods of time. Volcanic dust can stay aloft for years, while dust fluffs can remain lodged on ceilings practically forever. According to conventional thinking, those substances should descend to the earth, since their densities exceed that of air. Those substances might remain aloft because their negative charges repel the earth's negative charge.

While many substances naturally bear negative charge, the laws of triboelectricity imply that all substances can acquire substantially more of that charge by passing through the air. Any moving substance will become negatively charged. Toys such as Frisbees and boomerangs should acquire substantial negativity as they twirl rapidly through the air. That negativity may explain their longer-than-expected flight durations.

The same triboelectric principle may apply to paper airplanes, gliders, and even powered planes. As they pass through the air, those objects must acquire negative charge. Their characteristic shapes allow them to exploit that negative charge to achieve lift and forward propulsion.

Forward motion and lift dominate the next chapter, where we consider the flight of birds and flying insects. We will examine the adequacy of conventional explanations, and then consider whether the principles developed in this chapter may also apply in natural flight.

Please comment on this chapter's main weaknesses. If those weaknesses are less than fatal, then what might be done to repair them?

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