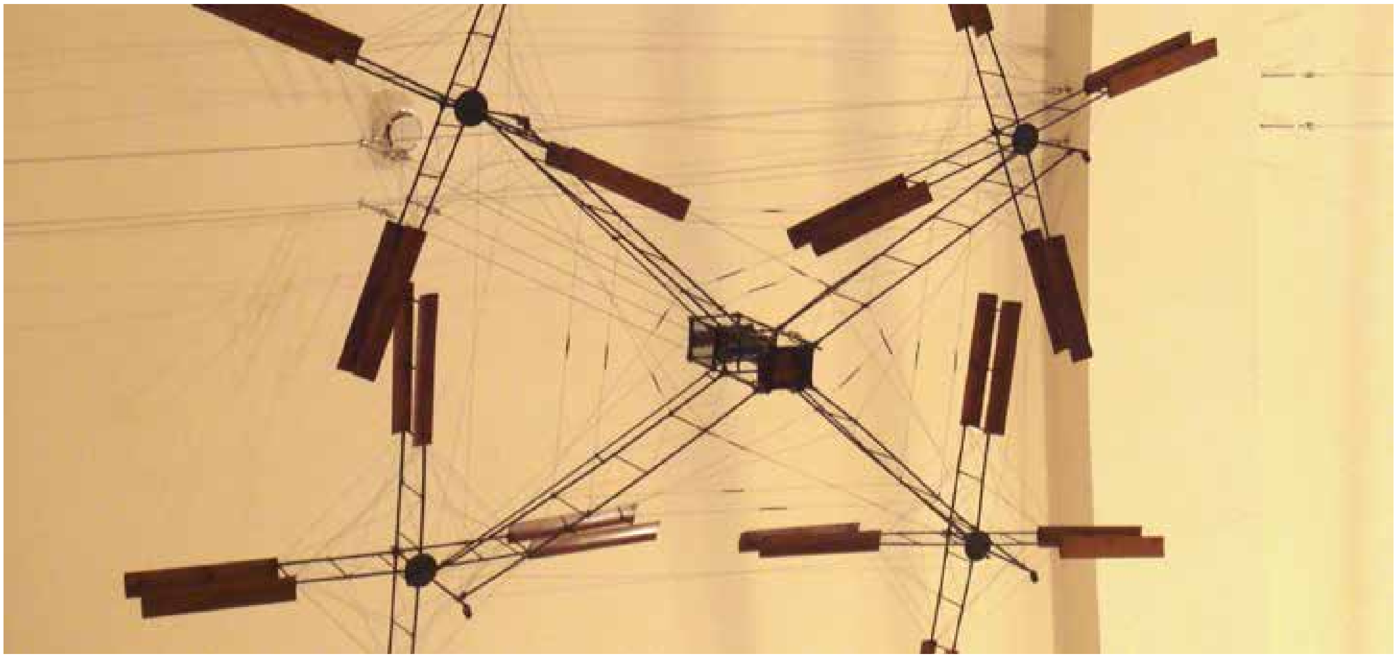
# CHAPTER 1: WHAT DRONES CAN DO AND HOW THEY CAN DO IT

### KONSTANTIN KAKAES



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The first quadcopter, built by Louis and Jacque Bréguet with Charles Richet, weighed over 1,100 pounds and got 5 feet off the ground.

On June 16, 1861, Thaddeus Lowe, a 28-year-old man from New Hampshire, hovered 500 feet over the White House, hanging in a tiny basket from a balloon of his own design. “This point of observation commands an area near fifty miles in diameter—the city with its girdle of encampments presents a superb scene,” Lowe wrote in a telegram to Abraham Lincoln, who waited far below. This was the first electronic message to be sent from the air to the ground.[1] Aerial observation has a long history; Lowe was not its first practitioner. But the point he made remains true today; aerial views command a great deal, in both senses of the word. Lincoln would support Lowe in his struggles with the military bureaucracy, which was largely uninterested in his ballooning innovations. On the night of May 4, 1862, Lowe saw the Confederates attempt to secretly retreat from Yorktown, Va., under the cover of night: “The greatest activity prevailed, which was not visible except from the balloon,” Lowe wrote.[2] Nevertheless, Lowe’s balloon corps would soon be disbanded after General George McClellan, who had been a supporter of Lowe’s, was forced out of his command following a massive retreat up the James River.

Lowe failed to fully realize his ambitions for aerial observation in part because of bureaucratic inertia, but also because of the technological limitations he faced. He could communicate with the ground only through a tethered cable; he could effectively observe only with his own eyes; he could fly only where the wind would take him. In the century and half since Lowe’s flight over the White House, military needs have been the primary driver of innovation in aerial observation techniques. In the past decade, however, a number of technologies have evolved to the point where they are small, cheap, and light enough to enable a dramatic democratization of aerial observation. Crucially, small aircraft are now capable of flying themselves and gathering information with minimal human intervention—and without a person on board. These aircraft, which range widely in size, cost, and endurance, are known as drones, unmanned aerial vehicles (UAVs), unmanned aerial systems (UAS), remotely piloted aerial vehicles (RPAVs), and remotely piloted aircraft systems (RPAS). We will use these terms interchangeably, but mostly, we will call them drones.

There is no one element that makes a drone possible. Nor is there a clear dividing line between drones and manned aircraft. Automation has become increasingly important in manned aircraft. Drones require human intervention. Some planes are “optionally piloted.” Nevertheless, drones constitute what W. Brian Arthur, in his book *The Nature of Technology*, called a new technological domain.[3] Domains, Arthur wrote:

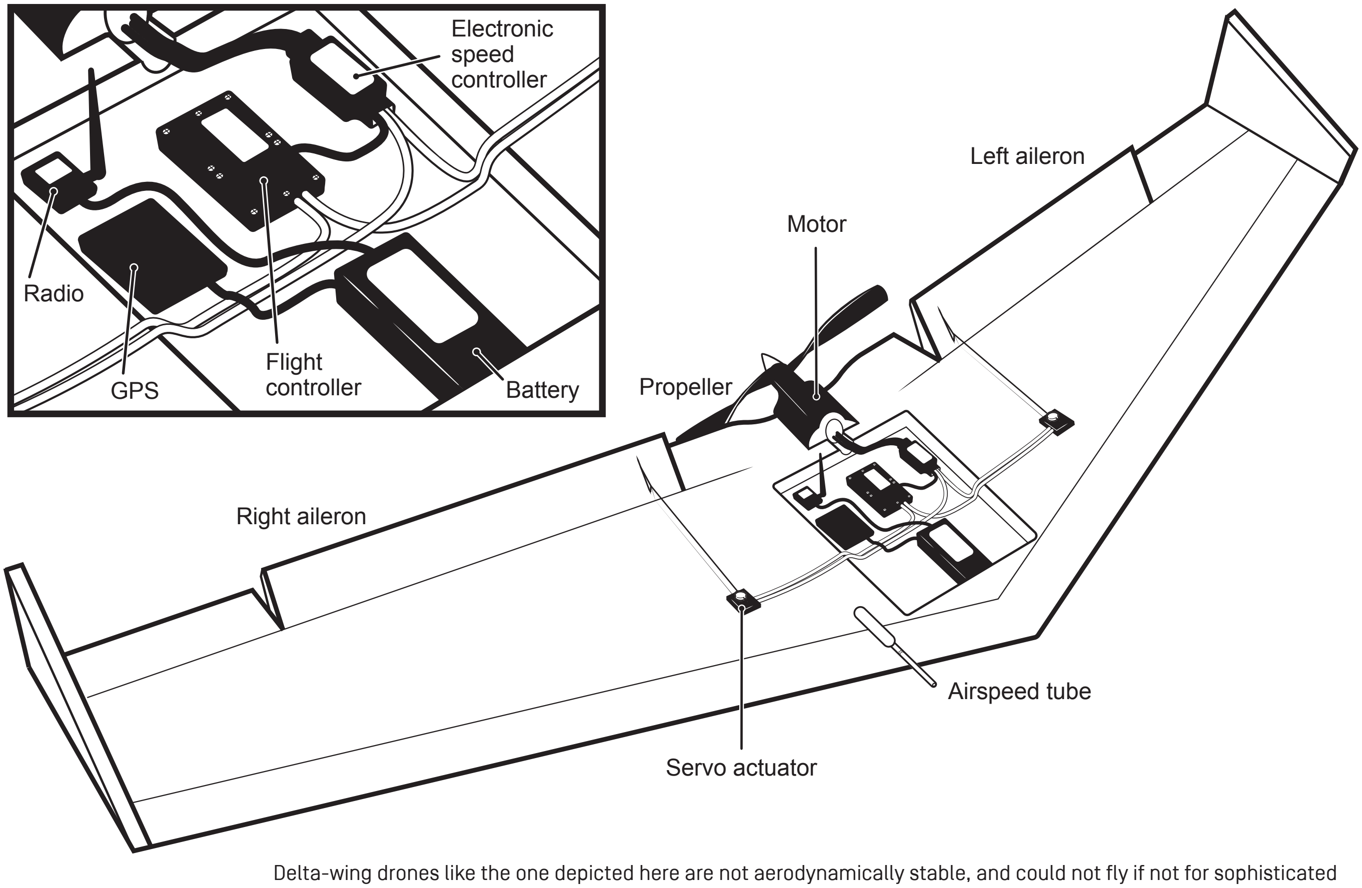
> are more than the sum of their individual technologies. They are coherent wholes, families of devices, methods, and practices, whose coming into being and development have a character that differs from that of individual technologies. They are not invented; they emerge, crystallizing around a set of phenomena or a novel enabling technology, and building organically from these. They develop not on a time scale measured in years, but on one measured in decades.

As a new technological domain emerges, Arthur explained, “different industries, businesses, and organizations encounter the new technology and reconfigure themselves. … A new version of the economy slowly comes into being.”

This short book is about some of these reconfigurations insofar as they affect the nexus of humanitarian work and development, with particular attention to the role drones can play in enunciating, and thus protecting, property rights. It does not consider the use of drones for offensive military purposes, or for law enforcement or counterterrorism purposes. It also does not discuss purely commercial ventures such as the use of drones to film scenes in Hollywood or to inspect oil pipelines or bridges. These are all worthy subjects, but beyond the scope of the present work. These boundaries are not hard and fast; militaries and police forces are normally involved in disaster response, which is discussed in Chapter 6. The U.N. peacekeeping force in the Democratic Republic of the Congo, discussed in Chapter 10, is indisputably a military force, but one whose intervention is fundamentally motivated by the protection of civilians. This work also does not much discuss the use of drones for delivery of physical goods. This is potentially an important application, particularly in parts of the world lacking good surface transportation infrastructure. However, it is one whose technological maturity is somewhat farther off. This book focuses on examples of work using drones in the recent past—surveying land in Albania, Guyana, and Indonesia, or responding to disasters like the 2015 earthquakes in Nepal—and considers how similar work can be done in the immediate future using today’s drone technology.

The reconfiguration that drones are catalyzing is an ongoing process. This primer presents some views about how it *ought* to take place, as well as concrete guidance about how to use a drone effectively.

Much of this primer is devoted to drones as mapmaking devices; it is perhaps the most important transformative use of drones today. Drones are very good at making maps far more cheaply than the techniques they are replacing. Drones now far outnumber manned aircraft—but it is the very small drones, like DJI’s Phantom, that account for the vast majority of unmanned aircraft. These small drones are good at taking pictures, and computer image-processing



Delta-wing drones like the one depicted here are not aerodynamically stable, and could not fly if not for sophisticated electronics. The wing is usually made of foam. Some fixed-wing drones resemble traditional model aircraft, with a fuselage, wings, and a tail, and are more stable.

Illustration ©Valerie Altounian

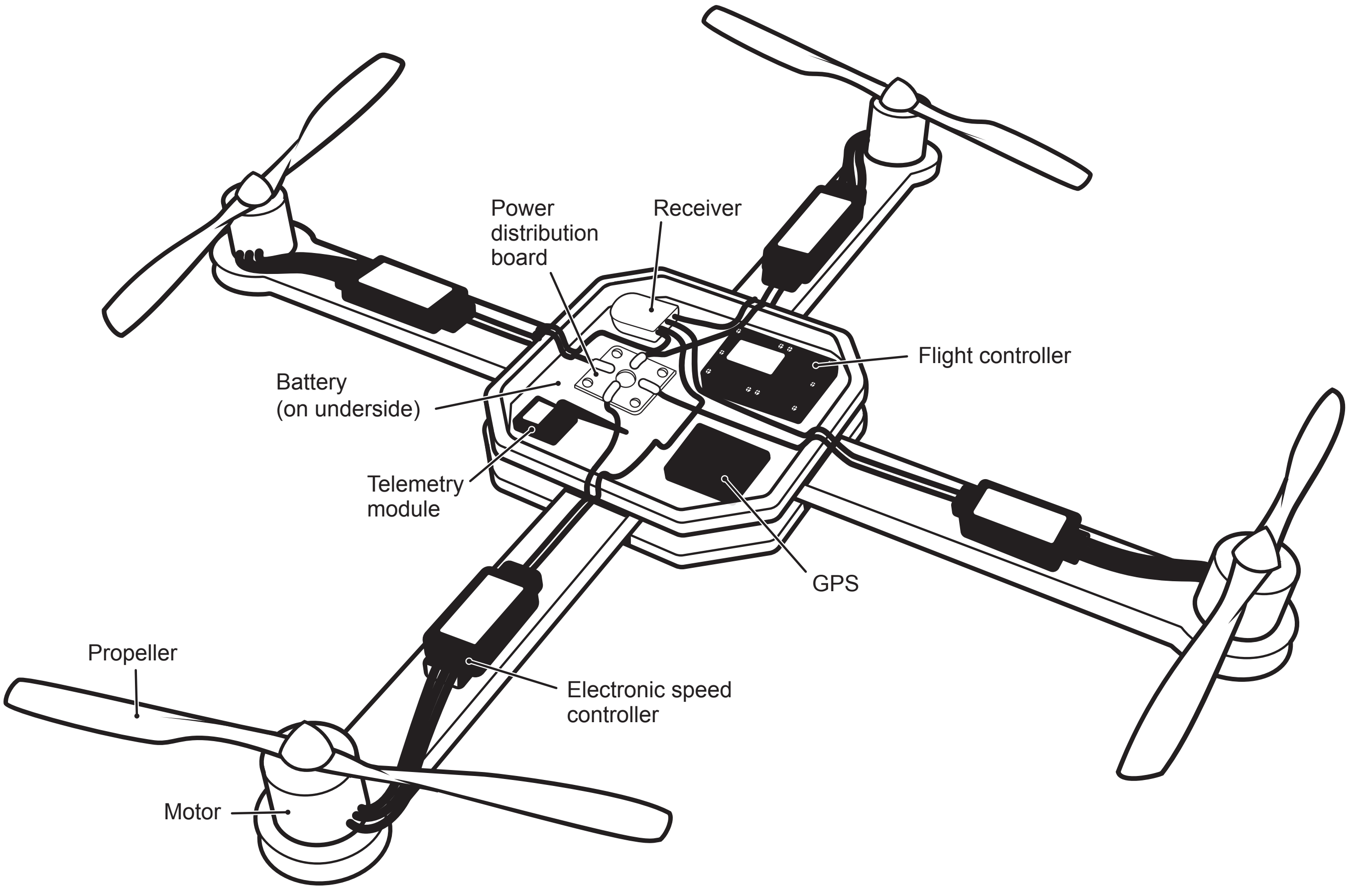
software is good at processing those pictures into maps. As Denis Wood puts it, “Maps are engines that convert social energy to social work. … Maps convert energy to work by linking things in space.”[4]

A recurring theme in this book is that a drone—be it a small quadcopter that can fit comfortably on a cafeteria tray or a half-ton Selex Falco—is useful only insofar as it is part of a larger technological and social system. As Arthur explains, “A device seems to be a piece of hardware and not at all like a process. But this is just appearance.”[5] This primer points to the importance of social processes surrounding drones; when sufficient thought is not given to those processes, even well-intentioned and well-resourced efforts can fail in their promise.

Nevertheless, it’s worth examining the drones as devices to understand their limitations and possibilities. What are the technologies that make them possible and what are the limits of those technologies? Why do drones look the way they do? How do they, as devices, compete with other similar devices—most importantly, satellites—in doing the work they do?

Since the advent of powered flight at the beginning of the 20th century, inventors, from the Wright brothers themselves onward, have wrestled with the challenge of controlling an airplane without a person on board. In 1907, Louis and Jacques Bréguet, brothers from a family of clockmakers, built the first quadcopter, the Gyroplane No. 1, with the help of Charles Richet, who would receive the 1913 Nobel Prize in Physiology or Medicine. “The Bréguet-Richet quadrotor consisted of four long girders made of welded steel tubes and arranged in the form of a horizontal cross, looking somewhat like an assemblage of ladders. Each rotor consisted of four light, fabric-covered biplane type blades, giving a total of 32 separate lifting surfaces. The rotors were placed at each of the four corners of the cross.”[6] As J. Gordon Leishman explains, “Diagonally opposite pairs of rotors rotated in opposite directions, thereby canceling torque reaction on the airframe.” This was the first implementation of the same principle used in small quadcopters today. The Bréguet-Richet quadcopter weighed over 1,100 pounds; the pilot sat in the middle below a 40 horsepower engine. The quadcopter flew in August 1907. It got about 5 feet off the ground.

Gyroplane No. 1 was limited not by power, but by stability. Though in principle the opposite spin of the propellers would cancel out one another and allow the aircraft to rise straight up into the air, in practice small imbalances in the force generated by each propeller meant that for the aircraft to fly, it would have to be able to detect these imbalances and correct them. Devices for achieving stability were easier to implement in fixed-wing aircraft. In 1909, Elmer



Multirotor UAVs are laid out in a variety of different ways. This image displays one possible configuration.

## MODEL P

No drone better represents the industry's turn toward inexpensive and accessible drones than DJI's line of Phantom UAVs. They are common first drones, but are capable enough to belie their toy-like appearance. As of 2015, DJI sells three series of the Phantom: the new 2015 Phantom 3 series, the Phantom 2 series first released in 2014, and the Phantom 1 series first released in early 2013. Models are differentiated within each series by their cameras and control systems.

As of this writing, unlike the Phantom 2 and Phantom 2 Vison+, the newly-released Phantom 3 does not yet have an established track record.* Furthermore, it has two serious drawbacks for mapping and fieldwork more generally. Neither its camera nor its gimbal can be removed or changed. Furthermore, it has no support for waypoint navigation.†

The Phantoms use proprietary lithium-polymer batteries to power their rotors, cameras, and gimbal systems. DJI claims the quadcopters can achieve a maximum flight time of 25 minutes; however, users report actual flight times of around 12 to 15 minutes. While this may sound paltry, it is adequate for mapping small areas and other photography needs, with copious use of expensive $149 spare batteries.

The Phantom 2 Vision+ is favored by hobby users and casual drone pilots for its plug-and-play functionality. It uses a camera of DJI's own design to shoot video and still photography. The camera, the angle of the camera, and some flight features, such as creating navigation waypoints and tracking battery life and altitude, can be controlled remotely with the DJI Vision app on Apple and Android mobile devices. Things get more complex but also considerably more customizable with the Phantom 2, which ships without a camera, waypoint navigation abilities, or a gimbal. If it is to be used to make maps, the owner must separately purchase a gimbal and a camera. A popular combination is the H3-3D gimbal and the GoPro Hero line of cameras. Some Phantom users doing mapping projects prefer to use small, lightweight point-and-shoot cameras instead, which prevent the bothersome "fish-eye" effect of both DJI's Phantom Vision+ and Vision cameras and the GoPro line. Some point-and-shoot cameras, such as the Canon S100, are also equipped with GPS-logging abilities, making it easier to georeference aerial maps.

Using a point-and-shoot camera with the Phantom 2 requires some technical ability, as the camera must either be controlled remotely or be programmed to take pictures at intervals, which is only possible with some camera models. Furthermore, off-the-shelf gimbals for the Phantom 2 that accommodate these point-and-shoot cameras are not available, so users have to hack together their own solutions, though ample advice on how to do this is available online.

Though the Phantom 2 cannot fly autonomously between waypoints out of the box, it can do so with the purchase of an additional DJI datalink system. The Phantoms are all reasonably rugged, although the plastic "arms" of the drone's body have been known to snap off after hard crashes. In a crash, the gimbal and the camera are much more likely to be seriously damaged than the drone itself. The Phantom 3 and Phantom Vision+ models are less durable in this respect, since the gimbals and cameras are integrated into the body. Phantoms are not waterproof.‡ Flight shouldn't be attempted in rain or heavy winds. The Phantom is reasonably portable with the propellers removed and can be comfortably and successfully transported in a large backpack. Many users purchase foam-lined hard cases to take the Phantom across international borders.

Sometimes Phantoms "fly away." The pilot loses control of the drone—an expensive and potentially dangerous mishap. While this may sound intimidating, the problem doesn't seem pervasive. DJI has corrected the firmware problems thought to be at the root of some recent crashes. Safety-minded pilots (and those with limited budgets for replacements) should ensure the Phantom 2's internal compass is always calibrated prior to flight, reducing the risk of an expensive miscommunication.

Matt Merrifield of the Nature Conservancy, a research and advocacy group, used the Phantom 2 Vision+ to count migratory bird populations on Staten Island, a protected area in California's Bay Delta. To Merrifield, the Phantom's utility goes beyond collecting data on migratory birds: aerial footage helps the public understand what the Nature Conservancy's work truly entails. "It becomes immediately apparent what we're doing—instead of a long document, it's an extremely powerful visualization tool. [The benefits are] hard to quantify."

While alternatives exist, the Phantom family of drones is the world's most widely used in the under-$1,000 category for good reason. Considering the Phantom's low price, ease of use, and integration with mobile devices, it's a hard system to beat in its class and a compelling choice for new drone pilots on a budget.

—Faine Greenwood

Vicki Burton via Wikimedia Commons

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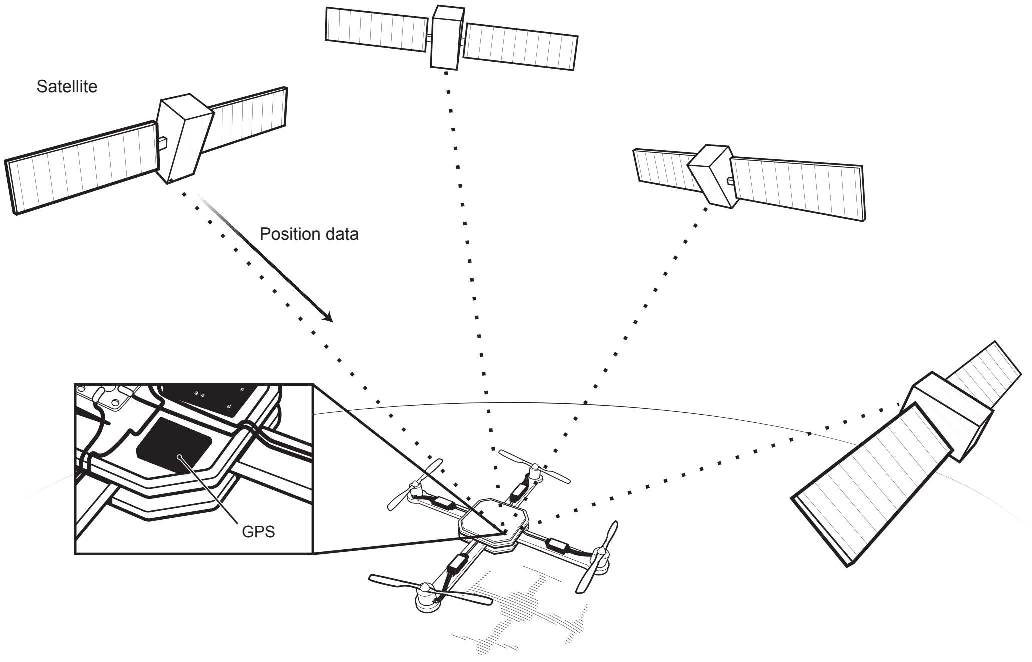
* The Phantom 2 Vision is not often used due to its diminished range of communication and its lower-quality gimbal, which often produces poorly stabilized footage.

† DJI is developing a software development kit (SDK) and is inviting others to create new features—but as of this writing, the waypoint problem hasn't been addressed.

‡ As a number of epic crash videos on YouTube demonstrate. See: http://makezine.com/magazine/drowned-drones-when-a-multicopter-hits-the-water/.

Sperry, an American inventor, began developing a gyroscope that would enable him to develop the Hewitt-Sperry Automatic Airplane, one of the first drones, a few years later. “Although Sperry’s intent was to improve the safety of flight by providing a pilot with vertigo or disorientation a mechanical sense of wings level, in doing so he also solved a key technical impediment to unmanned flight: stabilized flight in the absence of a pilot’s inputs. But his 30-lb gyrostabilizer, besides being excessively heavy, performed poorly when it encountered the three dimensions of flight.”[7] Before World War I ended, Sperry would develop a working unmanned aircraft, though interest in them would fade after the war.[8]



Global Positioning System (GPS) receivers work by inferring their position from timing data sent by a constellation of satellites. At least 4 signals are needed to do so.

Illustration ©Valerie Altounian

In place of Sperry’s 30-pound gyrostabilizers, today’s drones have autopilots that contain gyroscopes, accelerometers, magnetometers, and barometers, at a total weight of less than a tenth of a pound.[9] For a drone to fly successfully, these sensors must replicate what a pilot used to be able to do—what Wolfgang Langewiesche, in his book *Stick and Rudder*, described: “The pilot needs this sense of buoyancy also when climbing out of a tight airport. … His life depends on his ability to sense ‘lift’ or the loss of it; most accidents happen only because the pilot’s sensing of his buoyancy failed him, and he stalled or spun.”[10] Though the difficulty of duplicating this pilot’s instinct in hardware and software is hidden from the end user who purchases a drone at Radio Shack, it is worth underlining the intricacy of the engineering challenges involved. Obviously, a crash of a drone does not imply loss of life; however, if drones were constantly crashing,* they would be unable to achieve what they set out to do.

Most drones use a variety of sensors to accomplish what is called “state estimation.” They use microelectromechanical (MEMS) chips to measure acceleration and rotation. Some carry lightweight onboard echolocation systems to measure the distance to the ground; some also carry barometers to measure air pressure. Some carry heat sensors called thermopiles, which can see the horizon. Some have magnetometers to measure the Earth’s magnetic field, and most contain GPS (global positioning system) sensors. GPS is needed because the MEMS sensors used in low-cost UAVs are not very accurate: “When operating as a standalone navigator, these sensors produce positioning errors on the order of several hundreds meter per minute.”[11] GPS, on the other hand, cannot update its position often enough and has its own fluctuations, so combining both sources of data is necessary. GPS relies on precisely measuring how long it takes radio signals to get from distant satellites to the GPS receiver. Because light travels so quickly, an error of just 10 billionths of a second in measuring that time of flight results in a positioning error of about 10 feet.[12] Maintaining stability without GPS input is an active area of research for both commercial drone manufacturers and academic aeronautical engineers. For instance, the DJI Inspire drone has some capability of doing this, but users report that it does not work as well as advertised.[13]

We will not go into great detail here on the functioning of autopilots. (The best succinct explanation can be found in “Fundamentals of Small Unmanned Aircraft Flight.”)[14] However, it is worth emphasizing how difficult a computational task is being accomplished under the hood , as it were, of drones. “The equations of motion for a [drone] are a fairly complicated set of 12 nonlinear, coupled, first-order, ordinary differential equations. … Because of their complexity, designing controllers based on them is difficult,” as one textbook on drone design explains.[15] For a drone to fly, this sensor data must be reconciled; this is normally done using something called an extended Kalman filter, which takes into account not only sensor data, but also a physics-based model of how the given state of a drone affects its future states. (For instance, if a drone is moving forward at 60 miles per hour, or a mile per minute, in a minute it should have traveled one mile. So if your GPS measurement says it has only traveled only half a mile, your position measurement is likely off. The extended Kalman filter is a mathematical technique for reconciling inertial measurements of acceleration with GPS and other data sources. In practice, the time steps are

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* Drones crash substantially more often than manned aircraft, but not so often as to make them impracticable, as was the case in, say, the 1920s.

on the order of fractions of a second, rather than a minute.) Techniques like this smooth out the volatility of sensor data.

In general, autopilots operate at two levels. A low-level loop maintains stability, while a higher-level autopilot, if engaged, follows a predetermined path from one GPS waypoint to another.[16] That higher-level autopilot may also include systems for detecting and avoiding obstacles; such systems are only now becoming available for consumer drones and are limited in functionality.[17]

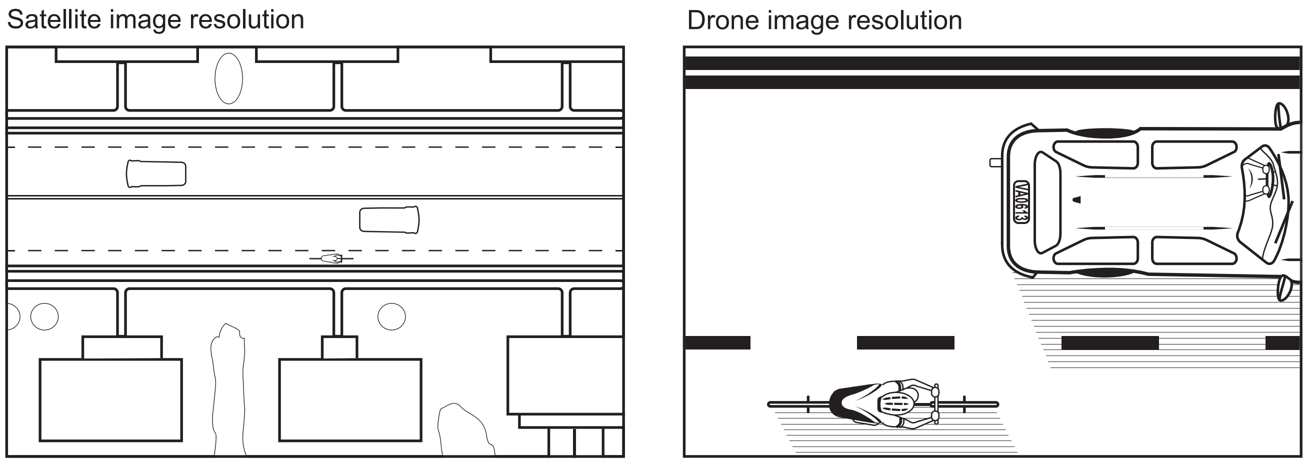
From a practical perspective, the would-be drone operator faces two major high-level choices: to use a fixed-wing or multi-rotor aircraft, and to buy a commercial system or build a "DIY" drone using commercial components. Open-source DIY solutions (of which the most popular are the ArduPlane fixed-wing http://plane.ardupilot.com/ and ArduCopter multi-rotor http://copter.ardupilot.com/) can be put together for a fraction of the cost of their commercial counterparts—from two to 10 times cheaper, depending on how exactly one counts costs and capabilities.

The choice between fixed-wing and multi-rotor UAVs is in part dictated by the exigencies of the market. The DJI Phantom is a low-cost, easy-to-use multi-rotor. No analogous fixed-wing model currently exists. Low-priced model airplanes like the Bixler require some skill to fly and assemble. It is surely only a matter of time until a drone company starts selling a Phantom-like fixed-wing. For the moment, though, novices seeking ease of use are pushed toward multi-rotors—not because they are necessarily more suited for a particular task, but because cheap and easy-to-use models are more widely available.

The trade-off between fixed-wing and multi-rotor drones is, obviously enough, one between endurance and maneuverability. There is also a trade-off in safety; fixed-wing drones can be very lightweight. A foam body or delta-wing craft can carry a small camera and still fly for over an hour. Fixed-wing drones are, all else being equal, safer than multi-rotors—if one loses power, it will likely glide to the ground instead of crashing abruptly. Fixed-wing drones are generally faster; though they can fly in small circles, they cannot hover, and cannot easily move vertically. Smaller fixed-wing drones can take off and land in fairly confined spaces, but not so confined as multi-rotors. Several hybrid models that have features of both types of drone are in development, though none as of yet has succeeded in the marketplace—the transition between vertical and horizontal flight is technically difficult.

The DJI Phantom, the world's most popular drone, has four propellers. This quadcopter design is quite common. It is, however, less efficient than a traditional helicopter design. "Single-rotor RC helicopters commonly have higher thrust-to-weight ratio, reduced drag, stiffer rotors, and more aggressive head mixing. As such, they can generally achieve greater agility."[18] The advantage of quadcopter (and other multi-rotor) drones is their mechanical simplicity. In a traditional helicopter, the angle that each blade has with the rotating hub at the center, called the pitch, must change in order to provide stability and maneuverability, a process called actuation. This complexity is, from a distance, hidden, but it makes helicopters difficult to build and maintain. On the other hand, in a quadcopter, each blade is set at a fixed angle, and stability and maneuverability come from varying the speed of each rotor individually, which is made possible by the sophisticated electronics in drones. In fact, adding rotors further reduces efficiency and therefore flight time. It does, however, make it possible to carry a heavier weight and allows for redundancy—the aircraft can keep flying even if one rotor goes out.

Octorotors like the DJI Spreading Wings S1000 tend to have limited endurance. The greater number of rotors (which are, like those in most quadcopters, not actuated)[19] provides a degree of redundancy in case one motor fails and allows the drone to carry more weight (up to 11 kilograms total takeoff weight,[20] of which nearly 7 kg can be payload). But because of the high energy demands of eight rotors, the S1000 can fly for only a maximum of 15 minutes, per DJI's


Satellite image resolution

Drone image resolution

Illustration ©Valerie Altounian

Pictures taken by simple drones flying at typical altitudes show details as small as 1cm. The highest resolution commercially-available satellite imagery has 30cm resolution.

## MAPPER'S DELIGHT

The black-and-yellow SenseFly eBee looks like an unremarkable flying-wing UAV, with a 38-inch wingspan and a body constructed from foam.[*] It is propelled by an electric pusher-propeller driven by a 160-watt brushless dc motor. The propeller is secured to the wing with a rubber band to allow it to bend with the wind. If the foam body breaks, which is quite possible, SenseFly will send another one.

It can afford to. The eBee costs $25,000.[†] This is not because of its airframe, but because of the software and hardware it comes with. The eBee weighs just under a kilogram and has a cruise speed of about 40 kilometers per hour. Its light weight makes it inherently safe and easy to travel with. However, the eBee is prone to being blown off course in heavy winds.

But its central appeal is that it flies itself. Most fixed-wing UAVs require the user to develop at least some piloting skill. However, the eBee has been developed as a fully autonomous system. To begin a mission, the user has simply to shake the eBee until the motor starts and then fling it into the air. The eBee will begin circling a previously set point to gain altitude and will then carry out its preprogrammed mission.

The eBee can even land itself with a reasonable degree of accuracy: it is able to detect how far it is from the ground when it comes in for a landing, and if users have defined a landing path ahead of time, it can make its way into narrow spaces. The eBee ships with proprietary software for both mission planning and post-flight image processing and photogrammetry. SenseFly's software can create a low-quality orthomosaic preview of aerial data that the eBee has just collected while still in the field. After processing the images for hours, users can also "fly through" 3-D point clouds the eBee generates.

The main downside of all this indisputable convenience? Price. The SenseFly eBee is expensive for a "foamie" fixed-wing mapping UAV. Technologically savvy researchers can build comparably capable systems for an order of magnitude less money.[‡] Such models evade another issue with the eBee. It is a "black box" system, not amenable to being modified or tweaked. Nevertheless, the eBee's ease of use and reliability make its popularity easy to understand. —FAINE GREENWOOD

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[*] "eBee senseFly," senseFly, https://www.sensefly.com/drones/ebee.html

[†] Baptiste Tripard, interview with the author, June 22, 2015.

[‡] See, for instance, the Unicorn (http://unicornwings.stores.yahoo.net/) or Zagi (http://www.zagi.com/zagi-rc-electric-wings).

specifications.[21] By contrast, DJI says its smaller quadrotor Phantom 2 can fly for 25 minutes.[22]

These 300 grams, in the case of a Phantom, must be divvied up parsimoniously. Assuming one is using the drone as an image-gathering device, it must carry, aside from a camera, a gimbal that can both point and stabilize the camera. Mapping drones can get away with simpler gimbals, but if you want to surveil a particular location with a video camera, for instance, the gimbal must be able to compensate for the drone's motion. This adds weight and complexity.

If a mission requires a drone with a longer endurance or larger payload capacity, the cost rises very quickly. Low-cost drones, which can fly for roughly an hour in the case of fixed-wings or 20 minutes in the case of multi-rotors and carry a small camera, can be had for about $1,000. However, if one wants to implement persistent surveillance, say, in a conflict zone, costs rise very quickly. At some point, solar power might allow for low-cost, lightweight drones that can stay in the air for long periods and thus, though they travel slowly, survey large areas. Algorithms for autonomy are also likely to improve substantially in the coming decade, perhaps allowing for landing, refueling (or recharging), and takeoff to happen without human intervention. The capabilities of sensors (discussed in more detail in Chapter 4) will also improve, allowing a drone of comparable payload capacity to gather higher-quality data, or data of a different kind. For instance, both hyperspectral cameras, which can use detailed measurements of the wavelengths of reflected light to infer what kind of vegetation is present, and LIDAR (light detection and ranging) systems, which use lasers to measure distance, are growing cheaper and lighter. At present, the gap in capabilities between a small drone and a large one is profound. The importance of this gap will diminish with time, but for now it is substantial.

To take the comparison of cheap to expensive drones to its extreme, the most capable image-gathering drones are satellites, which are effectively very high-altitude drones. WorldView-3, a modern reconnaissance satellite operated by DigitalGlobe, cost $650 million to build and launch.[23] However, the cost comparison between drones and satellites is not so straightforward. A humanitarian customer can buy imagery, at 30-centimeter resolution, from DigitalGlobe for $250 to $300[24] for a 25 square kilometer image (ie one whose sides each measure 5 km). Whether this is cheaper or more expensive than using a drone obviously depends on how extensively a drone is used, and therefore amortized. Other relevant questions include cloud cover. In the tropics, cloud cover obscures about 40 percent of Landsat images, which capture large areas; the figure will be higher for higher-resolution DigitalGlobe images.[25] Additionally, cloud cover can introduce systemic errors: "Cloud cover can be very misleading because it might obscure only a very small (and thus presumably irrelevant) percentage of the total land area, but even this small amount of ambiguity can have large effects on the forest loss estimates."[26] Although small drones will never be able to cover as large an area as, say, Landsat can, they can be used in combination with satellite imagery to improve estimates of things like deforestation.

Additionally, as is discussed in Chapter 2, the fact that drone images can be made in collaboration with a local community, while satellite images cannot, is important. The higher resolution (1-2 cm instead of 30 cm) obtainable from drone imagery is not always technically necessary; however, it can make it far easier for non-specialists to interpret imagery, an important consideration as drone technology is democratized. As Josh Lyons, who works with both satellite and drone imagery at Human Rights Watch, says, "Drone imagery shows you a picture of a house and every single thing is far more readily identifiable to an untrained eye." This difference matters not only to untrained observers, but also to seasoned ones.

Of drone imagery Lyons gathered in Haiti, he says , "What was quite profound, what I realized as I started to process the imagery: I took this. This was my imagery. I haven't just bought it from some big American company. ... What became immediately clear was the development capability. Everywhere kids would follow and watch; kids wanted to know about the battery and the camera." Though the price of satellite imagery is declining rapidly, Lyons points out that satellites will not ever have this social effect. The lower resolution of satellite imagery, though useful for many purposes, "systematically underestimated the damage" by a factor of almost two after the 2010 earthquake in Port-au-Prince, Lyons says. "UAV imagery," he says, "wouldn't have been perfect, but nothing ever will."

Additionally, he says, the real analytic benefit of drone imagery over satellite imagery "is not the spatial resolution. It's the temporal resolution"—that is, capturing timely images. There are, today, "five satellites taking images of the same area in Damascus at 8:45 in the morning." (This is a better time for commercial satellite imagery providers because clouds are statistically less likely.) However, because drones can be sent up at specific times more easily than satellites, they have the capacity to capture "smoking-gun evidence" of human rights violations, Lyons says. Such evidence might elude satellites that arrive too late to help determine the who and why of, say, a destroyed village, but can verify only that the village has been destroyed.

As drones become more common, another limiting factor in their utility may be sheer data overload. Digital memory is cheap, and it is easier to gather data than to analyze it. The temptation to indiscriminately gather data is a risky one, as discussed in Chapter 2. In some cases, it makes sense to gather more data than human intervention can effectively analyze, and to use computer vision algorithms to parse it, as discussed in Chapter 7.

It is a mistake to think of government regulation as a force from the outside, hampering the capabilities of a technology such as drones. Drones—like manned aircraft and cars—are part of a network. The best car is of little use without good roads; air traffic control systems enable airplanes to fly without crashing into one another. Vast increases in the number of drones will require both new, smart regulation and new technological systems for managing drones' interactions with one another. Not all of the privacy quandaries that drones give rise to can be addressed by regulation, but many can. More on these issues is found in Chapter 3.

Drones will, in certain respects, be a transformative technology. It is difficult to imagine a future for aerial surveying by manned aircraft, for instance. In other respects, drones will be a useful tool on the margins. This is a consequence both of their evolving technical capabilities and of political decisions about how they ought to be employed. As Arthur wrote, "We should not accept technology that deadens us; nor should we always equate what is possible with what is desirable."[27] §

# ENDNOTES

1 Richard Holmes, *Falling Upwards: How We Took to the Air* (New York: Vintage, 2014), 127; Robert V. Bruce, *Lincoln and the Tools of War* (Champaign, IL: University of Illinois Press, 1989), 86.

2 Holmes, *Falling Upwards: How We Took to the Air*, 139.

3 W. Brian Arthur, *The Nature of Technology: What it is and How it Evolves* (New York: Simon and Schuster, 2009), 145.

4 Denis Wood, *Rethinking the Power of Maps* (New York: Guilford Press, 2010).

5 Arthur, *The Nature of Technology: What It Is and How It Evolves*, 30.

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