

## 10.12.6: HUMAN FLIGHT

Aeronautics was neither an industry nor a science. It was a miracle.

—*You (also, Igor Sikorsky)*

### WHAT IT IS

A way to fulfill the earliest dream of humanity, held in perpetuity ever since our gaze first alighted upon the majestic beauty of a bird in flight and thought, “Oh hey, that looks cool, I wanna do that now”

### BEFORE IT WAS INVENTED

You were born on the ground, and you died on the ground, and you told yourself this was fine and you were silly to ever dream of anything greater

## ORIGINALLY INVENTED

500 BCE (strapping humans to giant kites)

1250 CE (earliest sketches for lighter-than-air flight, designed to be powered by a technology not yet discovered)

1716 CE (earliest published sketches for heavier-than-air flight, designed to be powered by technology not yet discovered)

1783 CE (first lighter-than-air flight)

1874 CE (first externally powered heavier-than-air flight)

1902 CE (first self-powered heavier-than-air flight)

## PREREQUISITES

paper and fabric (or, if you have it, silk), sulfuric acid and iron (for hydrogen airships), wood (for gliders and heavier-than-air flight), engines and metal (for powered heavier-than-air flight), compasses, latitude and longitude (for navigation)

## HOW TO INVENT

A hot-air balloon is an astonishingly simple invention. Fire creates hot air, which rises. If you put a fabric bag above that hot air, it'll fill with it, and a big enough bag with small enough leaks will become buoyant enough to rise through the air. Hold on to a large enough bag—or, to save your arms from getting tired, attach a basket to the bottom that you climb into—and you will rise with it. You don't even need to seal the bag at the bottom, since the hottest air rises to the top, and the air at the bottom will be at about the same temperature and pressure as the surrounding atmosphere. You can keep it tethered to the ground for early test flights, add sand for ballast (which you can toss overboard to lighten your weight as you sink, useful for slowing your descent as the hot air in the bag escapes or cools), and eventually even bring the fire on board—which, while more dangerous, lets you increase your altitude during flight.

In other words, it turns out that to invent human flight, the dream of thousands and thousands of generations of humanity, you only need some fabric and some fire. That's it.

And it still took us until 1783 CE to figure it out.

We have made a lot of hay in this text out of how long it takes humans to invent something even after they've got all the prerequisite technologies, but this is gosh-darned *humiliating*. If you draw a line between when humans had the technological prerequisites (fire and the drop spindle needed for fabric creation) and the time when they finally took flight for the first time, that line covers almost *ten thousand years*. Hot-air balloons aren't like spaceflight or time travel, technologies that require many members of a civilization to work together to produce them. The original hot-air balloons were invented by *two bored brothers* out of a *burlap sack*.

With enough motivation, you don't even need a civilization to produce a hot-air balloon: a single individual, even in Neolithic times and without any spindles or spinning wheels, could over the course of their life collect enough plant and animal fibers and spin enough thread by hand to create a hot-air balloon. In the more than 200,000 years during which this was possible, nobody ever thought to do that. Instead flight-minded humans usually just looked at birds and tried to copy them, which typically involved making giant feather-covered artificial wings, and sometimes covering the person strapped to the wings in feathers too, just to be safe.



**CIVILIZATION PRO TIP:** Covering yourself in feathers is neither a necessary nor sufficient condition for flight, but rather is a choice that should be made for fashion purposes only.

Since taking off from land in such a contraption wouldn't work, people instead jumped from towers wearing them, assuming that was the secret to flight. At best they could hope to glide for a short distance, but these pilots usually fell straight down to either broken bones, death, or castration,\* with the lack of flight being blamed on the pilots not having a tail (852 CE, 1010 CE),

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\* As with most things involving heights, a lot depends on what you fall on and how hard you fall on it.

using chicken feathers instead of eagle feathers (1507 CE), or the wind not being strong enough to fill their coat like a sail to keep them airborne (1589 CE).<sup>\*36</sup>

In China around 500 BCE, kites were invented (you can invent them too; just spread fabric across a light framework, attach a string, and add a tail for stability). Afterward sufficiently large kites in strong enough winds were being used to lift humans, but anyone who has flown a kite and seen how easily they can crash knows how dangerous and deadly this was. Around 200 BCE the Chinese had also invented paper sky lanterns, which are in effect tiny hot-air balloons powered by a candle. However, despite this, nobody ever scaled this idea up to human-sized flight. In contrast, in 1250 CE a European actually published a book with a design for a hot-air balloon in it,<sup>†</sup> but since nobody at that time had figured out that air had weight and hot air weighed less, it was designed to be filled with “aetherial air”: a gas, to be invented in the future, that was capable of floating in the atmosphere. Put simply, in 200 BCE humanity held in one hand the knowledge that hot air rose, and by 1250 CE held in the other hand a design for a machine that could be powered by hot air, but the two ideas were never joined together until both were rediscovered in France in 1783 CE.

And these Frenchmen (the Montgolfier brothers, who named their hot-air balloon the “montgolfier,” a name still used by the French today) didn’t even know that hot air rose! Their earliest experiments were, as we said, done with a burlap sack lined with paper to help keep the air in. They initially used steam as fuel, but this tended to ruin the paper. They instead switched to woodsmoke,

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\* Yes, this was the one that resulted in castration! A near contemporary account of this can be found in a publication made by one John Hacket in 1692 CE, delightfully titled *Scrinia Reserata: A Memorial Offer'd to the Great Deservings of John Williams, D. D., Who Some Time Held the Places of Lord Keeper of the Great Seal of England, Lord Bishop of Lincoln, and Lord Archbishop of York. Containing a Series of the Most Remarkable Occurrences and Transactions of His Life, in Relation Both to Church and State, Part 4.*

† It wasn’t quite a modern hot-air balloon, but all the parts were there. The design by Franciscan friar Roger Bacon featured a single-mast sailboat held aloft by four large “balloons” (hollow copper globes), attached to the hull of the boat with rope. Remove the mast and you’ve got the equivalent of a modern invention: a basket held aloft by balloons.

believing it to be some kind of “electric steam” that released a special gas they named “Montgolfier gas” (*because of course they did*), and this gas had a special property called “levity.” Even with all these fundamental misunderstandings of what was going on, the basic idea of “capture a lighter-than-air gas in a thing, and then the thing goes up” is all that was required for that first flight.

The finer and tighter the weave of your fabric, the better it will hold air, and silk (see Section 10.8.4) works great. The direction a hot-air balloon travels in is of course up to the winds, but by adding engines to your balloon you’ll get directional control, and with that you’ve invented the airship! But can you do even better?

You absolutely can. While the hot air you’ve been using rises because it’s lighter than regular air, it’s far from the lightest gas there is. And you want lighter gases, because the lighter the gas, the less fuel you need to get airborne, the more you can lift, and the farther you can travel. An obvious improvement here would be to eschew heated air entirely and fill your balloons with *the lightest gas in the entire universe* instead. So let’s do that!

The lightest gas in the universe is hydrogen, and Appendix C.11 shows how you can use electricity to extract it from brine. But if you need a lot of it—and you will, if you’re building airships—you’ll probably want to use cheaper methods. You could run steam over red-hot iron, which will break up the steam into hydrogen (as a gas) and oxygen (which will helpfully form iron oxide on the iron), but this requires a lot of iron. An easier solution is to do as early amateur aviators in our timeline did and rely on the fact that dilute sulfuric acid reacts with iron to produce hydrogen gas.\* Dilute sulfuric acid by (slowly) adding it to 3½ times its weight in water, put iron filings in a barrel, and pour your diluted acid on top of the iron filings in a 2:1 ratio by weight—meaning 2kg of acid gets poured on top of 1kg of iron. This will react to give you your hydrogen! You can then pass it through a second barrel filled with slaked lime (which you can make in Appendix C.4) to remove any acid carried over with the gas, which

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\* Sulfuric acid actually reacts with lots of metals, including aluminum, zinc, manganese, magnesium, and nickel. But you’ll probably use iron, since that’s likely to be the easiest metal to find.

you'll want to do because otherwise the gas you're producing could eat through your balloon: historically, rarely a good thing. The sulfuric acid will exhaust itself before the iron does, so you can drain out the used-up acid from the first barrel and refill it with more until there's no more iron left to react. Your hydrogen production apparatus will look like this:

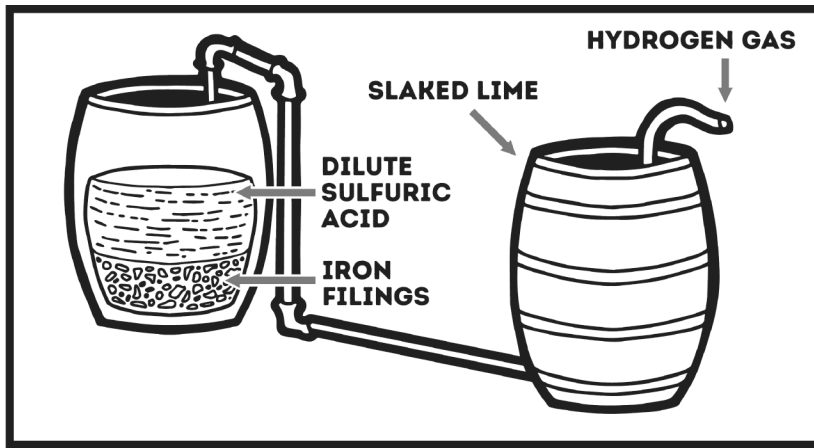


Figure 46: An apparatus for the production of hydrogen.

Around 400kg of iron and 800kg of acid will produce about 140 cubic meters of hydrogen, and 10 cubic meters of hydrogen is enough to lift around 10.7kg, depending on the day's air pressure, temperature, and humidity.

Now before you rush out to start mixing sulfuric acid and iron together, keep in mind: hydrogen is an extremely flammable, *violently explosive* gas. The world was horribly reminded of this on May 6, 1937 CE, when a hydrogen-filled aircraft named *Hindenburg* burst into flames and fell to the ground while attempting to dock with a mooring mast in a disaster so ghastly that it ended the entire era of hydrogen airship travel. The culprit was a single spark of static electricity.<sup>37</sup>

At this point, you may be thinking, "Wow, why didn't they just use helium instead, that's definitely what I would've used." And yes, while helium doesn't explode, react, and *is* the next-lightest gas—with about 88 percent of the lift-

ing power of hydrogen—it is much, much harder to come by. The only natural source of helium on Earth is produced through the (extremely slow) radioactive decay of heavy elements like uranium. And even when that happens, any helium that isn't trapped deep underground escapes into the atmosphere, where it's so light that it eventually ends up *lost in space*. Helium is an almost entirely non-renewable resource.\* So if you want inexpensive and efficient lighter-than-air flight, your only option in the short term is to use hydrogen and be very, very, very, very careful.

There is, however, one more alternative: inducing things *heavier* than air to fly.

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\* In the 1960s CE the United States actually started stockpiling helium underground as part of a National Helium Reserve, and by 1995 CE a billion cubic meters of gas were being stored. However in the next year, the government decided to begin phasing out the reserve to save money, selling the stored gases to industry. There are a few ways to produce helium without relying on natural reserves: hydrogen fusion, proton bombardment of lithium in a particle accelerator, or through lunar mining missions, but these are all, it's fair to say, *slightly* more expensive alternatives.