KELLY AND ZACH WEINERSMITH

SOONISH

TEN EMERGING TECHNOLOGIES THAT'LL IMPROVE AND/OR RUIN EVERYTHING

'Hilarious, provocative, shamelessly informative'
TIM HARFORD

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Soonish

'Space elevators, gold asteroids, and fusion-powered toasters – who knew science could be so much fun? And who knew fun could be so scientific? *Soonish* is hilarious, provocative, and shamelessly informative' Tim Harford, author of *Messy* and *The Undercover Economist*

'Basically, I think this book is a masterpiece, and something I wish I'd written myself' Scott Aaronson, author of *Quantum Computing Since Democritus*

'Playful, yet deep' Dr George Church, Harvard University

'Kelly and Zach promised me a crystal ball, but what I got is both more insightful and far more entertaining than staring into a dumb glass orb. *Soonish* will make you laugh and – without you even realizing it – give you insight into the most ambitious technological feats of our time. You should read this book, sooner than soonish' Alexis Ohanian, Co-founder of Reddit

'Compelling, accessible, and wryly funny . . . Popular-science writing has rarely been so whip-smart, captivating, or hilarious (albeit occasionally terrifying)' Sarah Hunter, *Booklist*

'A fascinating look at the most provocative and promising research going on today and how it could alter the way we work and live' *Publishers Weekly*

'With good, common sense the authors turn the problems on their heads by discussing the barriers to the marvels to come . . . solid, well-thought-out, useful information on cutting-edge technology' *Kirkus Reviews*

'Custom-printed cocktails on the moon? *Soonish* shows us how the Weinersmiths just lay out, clearly and with a wry sense of humour, exactly what it might take to get us there' NPR

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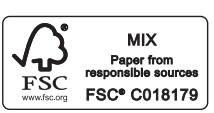

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Dedicated to our parents,

Patricia and Carl Smith

and

Phyllis and Martin Weiner,

without whom this book could never have been completed.
You fed us, cared for us when we were sick,
watched Ada when we couldn't,
and made sure we came up for air now and then.
We will always appreciate what you did to make our dream real.
This book is as much yours as ours.[1]

1. Of course, we're keeping the check to ourselves. But the sentiment is there.

CONTENTS

Soonish

1.

Introduction

Soonish. Emphasis on the Ish.

This is one of those books where we predict the future.

Fortunately, predicting the future is pretty easy. People do it all the time. Getting your prediction right is a bit harder, but honestly, does anyone really care?

There was a study in 2011 called "Are Talking Heads Blowing Hot Air,"[1] in which the predictive abilities of twenty-six pundits were assessed. Predictive powers ranged from mostly right to usually wrong.[2]

For most people, the pleasure of reading this study was the discovery that certain individuals were not *just* intolerable morons, but *statistically* intolerable morons. From our perspective as pop science writers, there was an even more exciting result: Regardless of their predictive prowess, *all these people still have jobs*. In fact, a lot of the worst predictors were the most prominent public figures.

If there really is no relationship between predictive ability and having a successful career, we've put ourselves in an excellent position. After all, those pundits were just trying to predict what will happen in the short term among a

1. By a group of public policy students at Hamilton College. It is, in fact, a small sample set. But given that it confirms our biases, we choose to believe it.
2. Fun fact: Having a degree in law correlated with being worse at prediction.

small number of squabbling political actors. They weren't trying to decide if we'll have an elevator to space in fifty years or if we'll be uploading our brains to the cloud soon,[3] or if machines will print us new livers and kidneys and hearts, or if hospitals will use tiny, swimming robots to cure diseases.

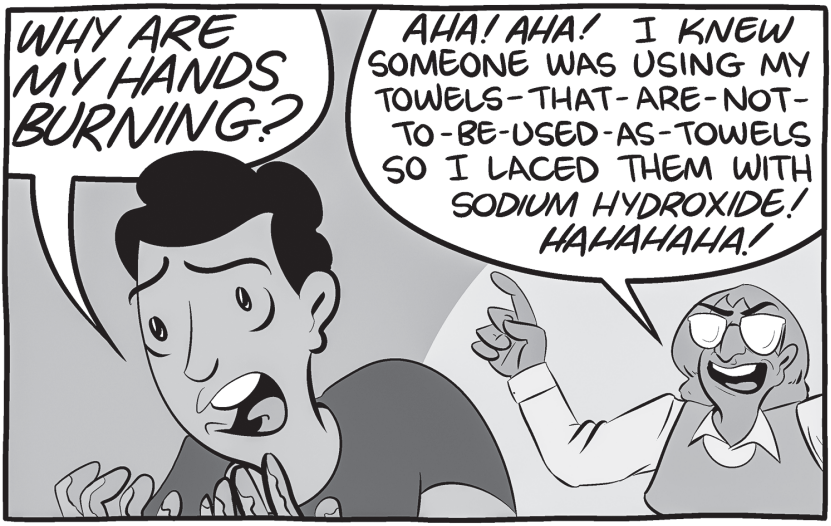
Frankly, it's really freakin' hard to tell you whether any of the technologies in this book will be realized in their fullest form in any particular time frame. New technology is not simply the slow accumulation of better and better things. The big discontinuous leaps, like the laser and the computer, often depend on unrelated developments in different fields. And even if those big discoveries are made, it's not always clear that a particular technology will find a market. Yes, time travelers from the year 1920, we have flying cars. No, nobody wants them. They're the chessboxing[4] of vehicles—amusing to see once in a while, but most of the time, you'd rather have the two parts separate.

Given that any prediction we give you is likely to be not only wrong, but stupid, we've decided to employ some strategies we learned while reading other books where the authors envision the future.

First, a few preliminary predictions:

We predict that computers will get faster. We predict screens will get higher resolution. We predict gene sequencing will get cheaper. We predict the sky will remain blue, puppies will remain cute, pie will remain tasty, cows will continue mooing, and decorative hand towels will continue to make sense only to your mom.

3. Apple iCloud if this book does well. Amazon Cloud if this book does poorly.
4. This is a real sport, which is unsurprisingly popular in Russia. You alternate rounds of chess and boxing until you lose at one of them.



We urge you to check back in a few years to grade our accuracy. Please note that we specified no time frame, so your grading options are either "correct" or "not *not* correct."

Now that we've made the first round of predictions, we're prepared to make a few more. We predict reusable rockets will lower the cost of rocket launches by 30–50% in the next twenty years. We predict it will be possible to diagnose most cancers with a blood test in the next thirty years. We predict that nano-bio-machines will cure most genetic disorders in the next fifty years.

Okay, that's a total of eleven predictions. We believe that if we get eight out of eleven, we should be considered geniuses. Oh, and if any of the first set comes true, you can write clever news articles with titles like "COUPLE WHO PREDICTED THE FUTURE OF GENE SEQUENCING SAY SPACEFARING WILL BE CHEAP IN NEAR FUTURE."

Predicting the future accurately is hard. Really hard.

New technologies are almost never the work of isolated geniuses with a neat

idea. As time goes on, this is more and more true. A given future technology may need any number of intermediate technologies to develop beforehand, and many of them may appear to be irrelevant when they are first discovered.

One recently developed device we discuss in the book is called a superconducting quantum interference device, aka a SQUID. This very sensitive device detects subtle magnetic fields in the brain, which is one way to analyze people's thought patterns without drilling holes in their skulls.

How did we get this thing?

Well, a superconductor is any material that conducts electricity without losing any electricity on the way. This is different from a regular old conductor (like a copper wire), which transmits electricity pretty well, but loses some en route.

We have superconductors because about two hundred years ago, Michael Faraday was making some glassware and accidentally turned a gas into a liquid by trapping it under pressure in a glass tube. There wasn't TV back then, so a bunch of Victorians got really excited about the idea of liquefying gasses.

As it turns out, it's easier to liquefy gasses by getting them really cold rather than getting them really pressurized. This insight led scientists to develop advanced refrigeration technology, which allowed them to liquefy stubbornly gassy elements, like hydrogen and helium. And once you have liquid hydrogen or helium, you can use them to cool down just about anything you like.

Helium, for example, is at about -450 degrees Fahrenheit when in liquid form. If you pour it onto just about anything, the liquid helium turns into a gas and takes heat away with it, until the thing you're cooling is also about -450 degrees.[5]

Eventually scientists wondered about what happens to conductors when you

5. To understand why, think of it like pouring cold water on a hot pan. The pan transfers a bunch of its heat to the water and thus cools down. You can cool it down faster by pouring off the water and getting new cold water. That cold water is something like 50 degrees Fahrenheit, so you can keep cooling the pan until it gets down to 50 degrees Fahrenheit. After that, the water is the same temperature as the pan, so the heat can't just go from one thing to another. It'd be sort of like trying to dry off with a towel that's just as wet as you are. You can't get dryer without a dryer towel, and you can't get colder without a colder cooling liquid.

get them *really* cold. Conductors tend to get better at what they do as they cool down. In simple terms, this is because conductors are sort of like pipes for electrons, but they're not perfect. In a copper wire, for example, the copper atoms get in the way of electron motion.

What we call "heat" is really just rapid wobbling at an atomic level. When you heat (aka wobble) atoms in copper wire, they are more likely to block electrons from moving downstream, in the same way it's harder to get down the street if the guy in front of you keeps changing lanes over and over. At the level of atoms, wobbling (aka heat) means the electrons are more likely to bump into the copper atoms, increasing the wobble still more. This is why your laptop charger gets really hot after you use it for a while.

When you put that liquid helium on the conductor, the wobble energy in the copper atoms is transferred to the helium atoms, which then fly away. Now your copper atoms are less wobbly and your electrons experience a lot less resistance. The colder they get, the easier it is for electrons to flow.

Back then there was a debate about what would happen when you got toward *zero* wobble. Some thought conductance would cease because at that temperature motion should be impossible, even for electrons. Some thought conductance would get very good, but nothing special would happen.

So researchers started to pour their ultracold gasses onto metal elements. It turned out, bizarrely, that some metals became *perfect* conductors (aka superconductors) when they reached a certain very low temperature. If you kept the metal cold enough to superconduct, you could put electric current in a loop, and it would just keep looping forever. This may sound like a cute science fun fact, but it leads to all sorts of weirdness! That looping current would generate a magnetic field. And that means you could turn these cold metals into permanent magnets, whose magnetic strength was determined by how much current you added.

Later, in the 1960s, a guy named Brian Josephson (who got a Nobel Prize, but now spends his days defending magic nonsense like cold fusion and "water memory" at Cambridge) discovered an arrangement of superconductors that al-

lows you to detect tiny variations in magnetic fields. This device, called a Josephson junction, eventually allowed for the development of the SQUID.

Now then. Consider this: If someone came to you two hundred years ago and asked how we might build a device to scan people's brain patterns, would your immediate response be, "Well, first we need to trap some gas in a glass tube"?

We suspect not. In fact, even the last big technical step—the Josephson junction, which again was discovered by a man who thinks it's possible that *water remembers what you put in it*—was considered theoretically impossible when it was first proposed. Its behavior was explained later, using a theoretical framework developed long after Michael Faraday was dead.

The contingent nature of technological development is why we don't have a lunar base, even though we thought we would by now, but we do have pocket-sized supercomputers, which few people saw coming.[6]

The same difficulty holds for all the technologies in this book: Whether we can build an elevator to space may depend on how good chemists get at arranging carbon atoms into little straws. Whether we can make matter that assumes any shape we tell it to may depend on how well we understand termite behavior. Whether we can build medical nanobots may depend on how well we understand origami. Or maybe none of that stuff will end up mattering in the end. There is nothing about history that necessarily had to be as it was.

We now know that the ancient Greeks could create complex gear systems, but never constructed an advanced clock. The ancient Alexandrians had a rudimentary steam engine but never designed a train. The ancient Egyptians invented the folding stool four thousand years ago, but never built an IKEA.

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6. This sort of thing sometimes causes people undue distress, as in the recent *MIT Technology Review* cover, featuring moonwalker Buzz Aldrin with the headline "YOU PROMISED ME MARS COLONIES. INSTEAD I GOT FACEBOOK." But, in fairness, a Mars colony would cost a few trillion dollars, while Facebook is free. And, it's worth noting that the choice of Facebook is a bit crafty. Imagine if they'd picked Wikipedia: "YOU PROMISED ME MARS COLONIES, AND ALL I GOT WAS ALL OF HUMAN KNOWLEDGE INDEXED AND AVAILABLE TO EVERYONE ON EARTH FOR FREE."

All this is to say—we don't know when any of this stuff is going to happen.

So why write this book? Because there are *amazing things* happening all over the place every day, all the time, and most people aren't aware of them. There are also people who become cynical because they thought we'd have fusion power or weekend trips to Venus by now. This disappointment is not always due to scientists who overpromise the future; often books like this one omit the economic and technical challenges that stand between us and the future as depicted in fiction.

We don't know why these challenges are so often left out of books. Would the story of Apollo 11 be better if getting to the moon were easy? To our way of thinking, part of what makes the idea of a brain-computer interface so exciting is that right now we have almost no clue how to decode thoughts. There is an unlimited frontier of questions to be asked, discoveries to be made, glory to be won, and heroes to be garlanded.

We picked out ten different emerging fields to explore with you, and we ordered them roughly from large to small, moving from outer space, to giant experimental power plants, to new ways to build things and experience the world, to the human body, finally all the way down to your brain. No offense.

Our guiding principle for each of these chapters was this: If you were sitting at a bar, and someone asked you, "Hey, what's the deal on nuclear fusion power," what would be the best answer possible? We were told we don't know what bars are like, *but the point is* that each chapter will tell you what the technology is, where it is right this second, the challenges to its realization, the ways it might make everything terrible, and the ways it might make things wonderful.

To us, scientific progress isn't just exciting because it does new things for us. Knowing how damn hard it would be to mine an asteroid or build a house with a robot swarm makes those things *more* interesting. And it means that when these things finally *do* happen[7] you'll understand exactly how exciting it is.

You'll also understand a bit about the strange detours and blind alleys science and technology take. At the end of most chapters, we provide a nota bene on some nugget of weirdness (or grossness or awesomeness) we unearthed. Sometimes these sections are directly related to their chapters, and sometimes they're just weird, weird things we bumped into while doing our research. Like, really weird. Like, octopus-made-of-cornbread weird.

For all these chapters, we had to read a lot of technical books and papers and we had to talk to a lot of mildly crazy people. Some were crazier than others, and generally they were our favorites. The one unifying experience in all our

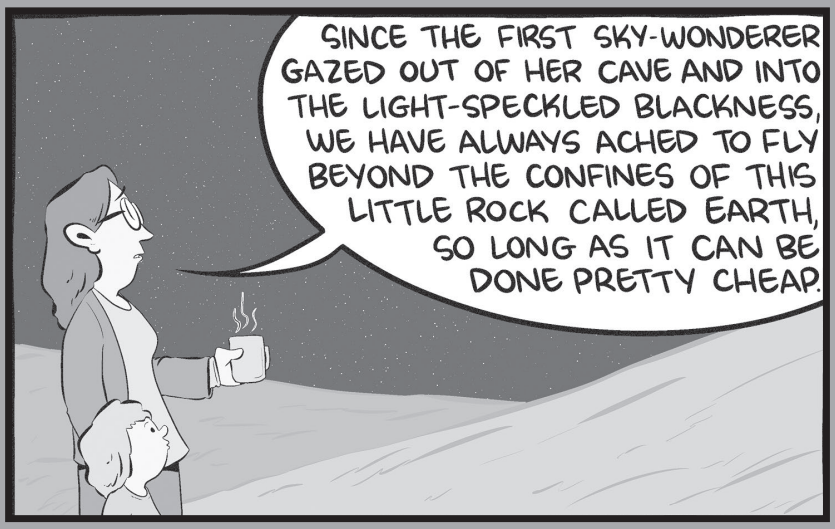
7. Even as we wrote this book, two technologies in it took a major leap. We had to amend our cheap access to space chapter after SpaceX repeatedly landed booster stages of its Falcon 9 rocket, and we had to amend our augmented reality chapter because people will not stop talking about Pokémon GO.

research was that on every single topic all of our preconceptions were crushed. In every case, as we researched we discovered that we not only hadn't understood the technology itself, but we hadn't understood what was holding it back. Often what seemed complicated was easy, but what seemed easy was complicated.

New technologies are beautiful things, but just like with Michelangelo's *Pietà* or Rodin's *Le Penseur,* it's usually an unholy pain in the ass to make them. We want you not just to understand what a technology is, but to understand why the future so stubbornly resists our best efforts.

Kelly and Zach Weinersmith
Weinersmith Manor, September 2016

P.S. We also want you to know about this one experiment in which undergrads were forced to breathe through one nostril, then take exams. It's kinda relevant. We promise.



SECTION 1

The Universe, Soonish

2.

Cheap Access to Space

The Final Frontier Is Too Damn Expensive

Up, up the long, delirious, burning blue
I've topped the wind-swept heights with easy grace.
Where never lark, or even eagle flew—
And, while with silent, lifting mind I've trod
The high untrespassed sanctity of space,
—Put out my hand, and touched the face of God.

• John Gillespie Magee, Jr., "High Flight," 1941

One thing you'll immediately notice about this poem is that he never once talks about price. This is the kind of glaring technical omission often made in poetry, so we're adding one more couplet:

And when I asked what space was priced,
I turned around, 'cause HOLY CHRIST!

Right this second, it runs you about $10,000 to send a pound to space.[1] That's about $2,500 per cheeseburger.

1. This number actually varies a lot, and depends on things like the country from which you're flying, the company you go with, where you're going, and the size of the space vehicle that is transporting the stuff. We're using $10,000 per pound as a ballpark figure throughout the book. Adding or subtracting $9,000 from that figure encompasses all estimates we've encountered while researching this topic.

This is why human beings have only been to the moon's surface half a dozen times, and it's why our moon vehicles were paper thin in places. The fact that in 2017 we have a space travel paradigm that would've disappointed all the hopes of 1969 is not due to a lack of engineering or scientific genius. It's because the cost of the way we get to space has remained stubbornly high. If we could dramatically reduce the cost, we would have better space science, better communication systems, access to off-planet resources, better ability to control our climate, and best of all, the solar system would open up for exploration and settlement.

To understand why it's currently so expensive to get stuff up to space, you need to understand what you're looking at when you see a rocket.

A rocket is essentially a tube of explosive propellant with a liiiittle bit of cargo on top. For a typical mission going to Low Earth Orbit (LEO; about 300 miles high, and where most launches go), by mass you're looking at 80% fuel, 16% the rocket itself, and 4% cargo (4% is actually on the high end, and if you're going farther out, it gets closer to 1 or 2%).

But when you look at cost, things are inverted. The propellant is a negligible component of price—it's gonna run you a mere few hundred thousand dollars. So most of the cost is taken up by the rocket itself, which is almost always discarded after use.

In sum, launching rockets is really expensive and most of the space onboard is taken up by propellant. This leaves two ways we can try to drastically lower the cost to make space access cheap:

1. Recover the launch vehicle.
2. Use less propellant.

Vehicle recovery suddenly became a reality in 2015, which we'll get into in the section on reusable rockets. But the basic idea is pretty simple—you can save money if you don't junk your vehicle after one use.

Using less propellant is a little trickier, even though propellant is 80% of a spacecraft's starting mass. To understand why, consider a situation where you

have to drive from Russia to South Africa and back again. You're offered two ways to get your fuel:

1. Gas up at stations along the way.
2. Take all the fuel you'll need for the whole trip and drag it along with you.

Of course, you'd rather use option 1. But consider why, in particular.

A car is just a machine that converts fuel into forward motion. If your car is really heavy, it takes more fuel to get a certain amount of forward motion. If you gas up regularly, most of your weight is the car and not the fuel. This means the fuel the engine is using right this second is supplying forward motion mostly to the vehicle (and you, and your luggage) and not to the fuel in the tank.

In the case of option 2, you're dragging an enormous tanker. The weight of fuel is probably far, far higher than the weight of the car itself. Especially at the beginning, you're using most of the energy derived from the fuel just to move the fuel itself. So *most of the fuel's energy goes to moving other fuel.*

The result? The total amount of fuel you need is far higher in case 2 than in case 1. Your little caravan, just like all space rockets, is mostly made of fuel, not of vehicle or cargo.

Unfortunately, it's a little hard to build gas stations for rockets. So without a major change, we're stuck in scenario 2 when it comes to space travel.

All of this sets up some very tantalizing math. If you could make the launch vehicle recoverable, you could potentially eliminate 90% of the cost of space launch. Or, if you could use just three quarters as much fuel, you'd be able to fit six times as much cargo,[2] instantly dividing the cost per pound by six.

The hard thing here is that you're fighting fundamental physics. The cheapest orbit available is LEO. People often think that "orbit" means there's no gravity. This is incorrect. In fact, the International Space Station (which is in

2. Fuel is 80%. Three quarters of that is 60%. That frees up 20%. But cargo originally only took up 4%. So you have increased from 4% cargo to 24% cargo!

LEO right now) is usually around 250 miles high and experiences about 90% of the gravity you experience on Earth. So why do the astronauts float around like there's no gravity? Because they are going really, really, really fast. About 5 miles per *second*. Although they are pulled toward the Earth all the time, they always "miss" it.

Think of it like this: Imagine you fire a cannonball from the top of a tower. If you fire it softly, the ball will go a little ways then fall to the ground. If you fire it incredibly fast, it will just fly off into space. But between falling right down and going off into space, there are a lot of intermediate regimes. For a given height, there is some speed that is slow enough that it can't leave Earth, but fast enough that you'll never plop to the ground. If you were riding that cannonball, you'd be falling, because gravity is tugging you down. At the same time, because you're going so fast, you'd be able to see Earth's curve. As you move from a point on the globe in a straight line, Earth curves down and away from you, increasing your distance from the surface. At this particular speed, you have two balanced effects: Gravity wants you down low, but your speed keeps you up high. So you just keep going around and around and around. You "orbit."

Even though LEO is the cheapest orbit to achieve, it's still pretty expensive to get there. Getting a big hunk of metal to 5 miles per second is not an easy task. If we ever want spaceships that look like the ones in movies instead of giant tin cans wrapped in foil, we're going to need a cheaper way.

Where Are We Now?

Method 1: Reusable Rockets

Reusable rockets are the best bet for cheaper spaceflight in the short term. They are traditional rockets, but rather than falling into the ocean as they do now, they fall to Earth and land after they finish the mission. This doesn't fix the problem that the rocket only holds 4% cargo, but it potentially drives the cost way down.

There are a few difficulties with this approach, though. You have to keep extra propellant onboard for the landing phase, which lowers efficiency. You want to carry the smallest amount of extra propellant possible, but this makes the landing phase very hard.

A very serious issue is that nobody yet knows what it'll cost to refurbish a used rocket. This thing has gone to space, man. You can't just put a spit shine on it and put it back on the launchpad.

The U.S. Space Shuttle, which was designed to be a reusable launch vehicle, ended up being more costly than a regular rocket precisely because refurbishing was so expensive. There's an ongoing argument over whose fault this was—the engineers, Congress, the Air Force, a risk-averse public, and more—but the bottom line is that the program was largely done in by the cost of getting the Shuttle launch ready again after a flight. This is why, when lots of people were sad about the Shuttle retiring, a lot of space nerds were glad to see it go.

But there is reason to hope that a better reusable launch vehicle can be created. As we were writing this chapter, SpaceX became the first company to successfully put cargo into space, then land part of its rocket.[3]

If it really can bring the price down, this may prove to be the biggest development in space travel in a generation. As we were watching a launch, a reader

3. Actual rockets have several sections called "stages." Once you use up a stage, it's deadweight that's slowing you down. So you dump it. SpaceX recovered the first booster stage, which is the largest.

of ours tweeted that although he had witnessed the moon landing as a young boy, he found the reusable rocket even more exciting. It sounds crazy, but he's got a point—the moon landing was certainly the greater technical feat, but it was done at a cost that more or less guaranteed it couldn't become commonplace. Exactly how much the cost can be dropped is a matter of debate. Elon Musk apparently claimed he could eventually get the cost down by a factor of 100. In the more near term, SpaceX's president Gwynne Shotwell said their current Falcon 9 should be able to offer a 30% discount. But even if reusable rockets only mean a small price drop now, they may yet represent a path to greater future savings. The road to Mars may be paved with small discounts.

Method 2: Air-Breathing Rockets and Spaceplanes

Airplanes already go really high. Can't we just have them go a bit higher so they get to space?

No. Why would you even ask that? Jesus.

If you want to put a satellite in orbit, the hard part is not going really high. The hard part is going really fast. That takes a lot of propellant. But using a spaceplane might allow a serious reduction. To understand why, you have to understand what propellant is.

If you refer to propellant as "fuel," a NASA engineer will beat you with a TI-83.[4] Propellant is actually a combination of two things: fuel and oxidizer. When you want a combustion reaction, you need three things: fuel, oxidizer, and energy. For example, when you light a campfire, the fuel is wood, the oxidizer is (you guessed it) oxygen, and the energy is a lit match.

In a rocket, you carry both fuel and oxidizer inside the ship. The actual ratio of oxidizer to fuel varies by rocket and mission, but generally speaking the *majority* of the propellant's mass is oxidizer. The oxidizer is often just liquid oxygen.[5] Why carry all that liquid oxygen when the rocket is literally surrounded by oxygen for much of its trip?

The short version is that we're keeping it simple. A rocket is a brute force way to get to space. You put everything you need in a big tube and blast your way skyward. With an airplane, you might be able to improve your efficiency by getting your oxidizer from the air rather than carrying it with you, but you're adding a lot more complexity to an already complicated machine.

The big problem for a spaceplane is that you need multiple types of engines to handle all the different speeds and conditions you encounter en route to space. Here's why:

Most airplanes today use a turbofan engine. They're a bit complicated, but the basic mechanism is simple. Fans suck air into a chamber. The air is compressed, so you have a lot of oxygen (your oxidizer!) in a small space. Fuel is injected and ignited. The result is hot compressed air that you channel out the back as you suck in more air. Now, you've got high-pressure air behind the

4. We asked Twitter what a rocket engineer is most likely to use to beat someone to death, and the most frequent suggestions were a TI-83, a TI-89, a TI-30X, a slide rule, or just a reasonably good laptop with MATLAB installed.

5. Delightfully abbreviated as "LOX."

engine and comparatively low pressure in front of the engine. So you go forward.

Turbofans start having trouble when you get toward the speed of sound, at about 767 miles per hour,[6] also known as Mach 1. At the speed of sound, the air can't get around the plane as fast as it builds up. This creates problems if your front intake is a fan.

One solution to getting over this hump is what's called an afterburner. An afterburner takes leftover oxygen at the back of your turbofan, throws more fuel at it, and ignites it. In short, you make a little ongoing fuel explosion at the back of your plane. By this means you can get toward Mach 1.5, though not terribly efficiently. But once you're at Mach 1.5, you can use a different type of engine called a ramjet.

A ramjet is an incredibly simple machine, but it's not necessarily easy to make. Basically, you have a turbofan engine minus all moving parts, including the fan. You don't need a fan to compress the air because your high speed is doing it for you. You fly fast, and air crams into a chamber where it slows down as you add fuel and ignite. The downside here is that because speed itself is your compressor, you can't *start* with a ramjet. You can only use a ramjet once you're going about 1100 miles per hour. So, for example, on an SR-71 spy plane, you have a turbofan that changes its shape to behave like a ramjet once you get to the right speed.

Once you get really, really fast (but still not fast enough to stay in LEO), you need a supersonic ramjet, or "scramjet." A scramjet is an even simpler machine that is even harder to build. Basically, supersonic air comes in and, along with fuel, gets ignited directly, without ever slowing it down. You can do this because the oxygen is coming so fast, there's enough to get a combustion reaction going without compression. But it's not easy to, so to speak, light a candle in supersonic wind. Scramjets are still experimental, but after about 4500 miles per hour[7] they become the most efficient way to go. In theory, they can take you all the way up to Mach 25, which is orbital speed. There have been a number of

6. This number can change a bit, as the speed of sound depends on things like temperature and elevation.
7. That's Tokyo to London in about two hours, if you don't count the acceleration time.

scramjet programs, most of them military, and all have met with only limited success. None of them have yet come anywhere near orbital velocity.

An ideal spaceplane should be able to make use of all these engine types in sequence to get to space. Once in space, where there is no available oxygen, you will probably switch over to a traditional rocket propellant method. But by using oxygen from the air instead of an onboard tank, you can cut down fuel use enough that you might be able to carry ten times more cargo.

Oh, and since it's a plane, it can just land afterward. If this can be done repeatedly, without too much damage, you've solved the vehicle loss problem *and* the fuel efficiency problem.

The hard part is that all these machines have to work under extreme conditions. The conditions a scramjet is optimized for are *so extreme* that they're expensive just to simulate down here on Earth.

A British firm called Reaction Engines is working on a vehicle called Skylon, which uses an engine called SABRE, for Synergetic Air-Breathing Rocket Engine. We're guessing they came up with the "ABRE" part quickly, then spent a few days deciding on an *S*. In short, it's a rocket, but it takes in ambient oxygen as part of its thrust reaction. Their engine is designed to efficiently switch from a turbofan to a ramjet to a rocket. Presumably they aren't doing a scramjet phase because, well, nobody really knows how to *do* the scramjet phase.

It's an expensive, complicated endeavor, but they do have substantial funding from the European Space Agency[8] and the British government. If things go well, they hope to field one of these advanced planes in the next decade.

For all the downsides of rockets, they have the virtue of simplicity. An old-fashioned rocket works just fine in low speed or high speed, in thick atmosphere, thin atmosphere, and no atmosphere. So, hey, how about we try something even more old-fashioned?

8. In case you're wondering, Brexit shouldn't interfere with this program. The European Space Agency works closely with the European Union, but it already has non–European Union members (Norway and Switzerland) and is not controlled by the European Union.

Method 3: Giant Giant Giant Enormous Mega-Superguns

One way to save on rocket fuel is not to use any. Earlier we discussed how rockets are encumbered by the need to use propellant to accelerate propellant. What if instead of running a relatively slow controlled burn all the way to space, we had one giant boom down here on the ground? Sure, you have to use a lot of explosives overall, but none of those explosions are used to lift more explosives. This should save a lot of overall energy.

Mind you, it won't be cheap. It's a cannon that would probably be thousands of feet long, with a barrel on the order of 10 feet in diameter, packed with literally tons of explosives. But there are advantages: no discarded parts, no using fuel to carry fuel, and pretty much every bit of each shot actually goes to space.

It's not quite as crazy as it sounds, and there have been at least two well-funded government projects to explore this method, one of which we discuss in the nota bene for this chapter. But there are two major drawbacks:

First, every time you fire, you have to create an enormous explosion. So if you want to use this thing repeatedly without too much expense, you need some kind of chamber that can withstand several tons of explosive material being detonated regularly.

Second, getting shot out of a cannon isn't very fun. Well actually, if you were shot out of a space cannon, it wouldn't be fun or not fun. You'd just be splatted.

It's not the speed that kills you. It's the acceleration—the *change* in speed.

When you go up in an elevator, you feel as if you're getting squashed. That's a slight acceleration. By comparison, on a roller coaster, you may feel as much as five times more acceleration. With training, humans can endure about ten or twenty times the elevator without passing out. Much beyond that and you might die. Why? Well, when you accelerate in a car, notice how the water in a cup rushes back and stays back until you stop accelerating. Imagine the cup is your

body and the water is your blood. Oh, and instead of 0 to 60 in 10 seconds, you're going from 0 to 17,000.[9]

For an explosion-based space cannon, you're talking around 5,000 to 10,000 times the elevator. Nothing squishy is going to space in a cannon, including squishy little you.

This may not be as bad as it seems. You could still send "hardened" payloads, like specially designed electronics. You could also send all sorts of raw material—metals, plastics, fuel, water, beef jerky. In fact, one idea is to have a sort of orbiting gas station that just receives fuel payloads from a gun.

By itself, a space gun is not a great route to space exploration. But if you coupled a space gun with an orbiting factory in space, we might be in business. The idea here would be to fire raw materials up to your orbiting factory, build gigantic spacecraft at the factory, and then take off from the factory to go explore space. For annoyingly delicate payloads, like humans, you'd still need a wussier form of launch, like rockets. But on a big space mission that's already in space, most of what you're toting is metal, plastic, and supplies for the delicate meatbags within. All these things can be "ruggedized" and shot to orbit.

Another option is to have a gun that speeds up slowly enough that the cargo experiences a more human-friendly level of acceleration.

For instance, you could have a sequence of explosions, spreading the acceleration over time. The downside is that you're taking an expensive and difficult system and making it more expensive and more difficult. Now you've got dozens of explosions instead of one, which means a longer barrel and a lot more potential for error.

Another option is to have an electromagnetic railgun. Basically, you start with a magnetically levitated train. These "MagLev" trains float on a magnetic field, which is important because with conventional rail, beyond a certain velocity you'll start bending and even melting the tracks. You put this vehicle and its

9. So why don't you die when you accelerate in the car? You're not accelerating fast enough for a long enough time. Plus, your body is a lot closer to a sponge than an open cup. Your circulatory system resists the change in speed just fine. If the acceleration were higher and sustained, you'd be a lot more like the cup. Of course, you can also die from sudden rapid speed changes, also known as "car crashes."

track in an airless tube that is about 100 miles long. Then you keep using powerful magnetic fields to boost its speed. It's basically explosive speed boosts without the boom. The upside is the method is a lot cleaner and easier to reuse. The downside is the necessary materials—specifically the ultralong evacuated tube and train system—would be much more expensive.

But this too has a problem: Even if you spread the acceleration out over time, the projectile at some point must exit the tube, going from an airless environment into the atmosphere at hypervelocity.

To understand what happens when the projectile exits the tube, consider this: Moving through air is the same as having air move past you. It's air particles thwacking against your body. The most extreme winds on Earth happen in tornados, and the fastest winds recorded are around 300 miles per hour. If you want to reach orbit at the right velocity, you need to be fifty to a hundred times faster than that as you fire out of the cannon.

At that speed, the air is fighting you so hard that it will literally ignite. So not only have you got a lot of air drag, you also have an explosion. Not great for cargo.

One way around this problem is to build the tunnel structure so high that the cargo doesn't leave the tube until it's in the thin upper atmosphere. The atmosphere gets less dense very rapidly once you get around 25 miles up. The issue with this approach is that we don't know how to build anything that stands 25 miles tall. The tallest structure humans have ever made is about half a mile from bottom to top,[10] and it's a skyscraper, not a launch track. Even if we knew how to build it, it would cost an insane amount of money.

But people are still trying to make gun methods work, and there are a couple variants on this concept, including two of the best-named ideas in this chapter: the "Slingatron" and the "rocket sled."

The Slingatron is a railgun on a spiral track. We talked to Jason Derleth from NASA Innovative Advanced Concepts (NIAC), which is a sort of asylum for people with really crazy space ideas that just might work. He told us, "The

10. The Burj Khalifa, in Dubai.

Slingatron is unfortunately highly unlikely to work. I really like it. I think that it's a brilliant idea, but what ends up happening is you have to put it at the top of Mount Everest for it to have even a chance, because it's fighting air resistance the entire time."

The rocket sled is basically another railgun, but instead of accelerating the projectile, it's accelerating a sled that carries a rocket. The sled goes really fast, getting you up to high speed into the thinner part of the atmosphere. Once you're up high, you start up the rocket. The extra speed and height get you a serious fuel savings. *Plus,* you've got a rocket sled.

All these methods could potentially be combined with a ramjet/scramjet system. Remember, those work once you're fast, and are necessarily designed to handle extreme conditions. But, as with all hybrid systems, you're developing something even more complicated and perhaps only getting a bit more efficiency.

Which leads us to this other concept we learned about from Mr. Derleth.