w (and Why) SpaceX Will Colonize Mars

ust 16, 2015 By Tim Urban

t 3: How to Colonize Mars

are some tough "going from A to B" situations in life. Going from A) I can't believe my alarm just ff to B) Now I'm sitting at work. From A) My lease ends next month to B) Now I'm totally moved into a new apartment and all the things are even hung on the walls. From A) Oh shit wait I actually hate my wife to B) Oh good now I have a new wife and everything's good. These are all tough.

But A) I think I'd like to put 1,000,000 people on Mars to B) Now there are 1,000,000 people on Mars—that one seems extra difficult.

Elon Musk is more ambitious than you.

Since the beginning of this project, I've spoken with Musk six times, not that I'm counting, and much of that time was spent talking about how this Mars thing is actually going to happen. From the sound of it, he really just needs two things and then he'll be all set:

1) A will

2) A way

The conventional wisdom might be that this is a case of, "If there's a will, there's a way." We went to the moon over four decades ago, 15 years before anyone owned a computer, so it seems like Mars could have been perfectly doable by now—the limiting factor must be a lack of will.

But Musk believes it's the other way around. What we have is a way to go to Mars *for an astronomical amount of money.* And that's no way to colonize Mars. To Musk, what's missing is a way to go to Mars *affordably.* He calls the United States "a nation of explorers" and "the spirit of human exploration distilled," and he believes that if going to Mars were much cheaper, plenty of will would arise. But because this isn't something that's been remotely possible, no one is talking about it, and whatever will there is in people to go to Mars is totally dormant.

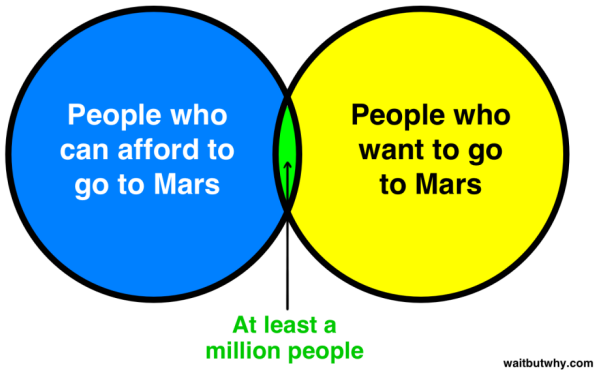
If someone told me that a penthouse apartment in Manhattan with a huge balcony had dropped in price by 95%, I'd have plenty of will to sign a lease and move in. But because the price is what it is, I'm not burning with a desire to move in—I'm not even thinking about it. The reason I'm not writing this post while sitting in a hot tub overlooking the New York skyline isn't a lack of will, it's a lack of *way.*

Musk sees the Mars situation the same way. Rather than "If there's a will, there's a way," he seems to believe it's more a case of, "If you build it, they will come."

Specifically, the model Musk has in mind is that "flights" to Mars will be funded by the passengers riding on them, the same way public transportation works on Earth—and the key will be to bring ticket prices down far enough that a million people will buy one. Or as he explained to me, in Musk-speak:

There has to be an intersection of sets of people who wish to go to Mars and people who can afford to go to Mars, and if that intersection of sets equals a number of people necessary to make Mars self-sustaining, that's the critical solution.

So kinda like:



The problem is, right now it's more like:

Since Musk thinks the will (the yellow circle) will grow accordingly when there exists a feasible *way*, Musk identifies the tiny blue circle as the critical limiting factor: the dramatically-too-high cost of space travel. And fixing that, he believes, will be the key link between A and B.

So, in 2002, Musk explored further: "I put together a team, and over a series of Saturdays I had them do a feasibility study about building rockets more efficiently. It became clear that there wasn't anything to prevent us from doing it. Rocket technology had not materially improved since the '60s—arguably it had gone backward!"[1] He was pumped.

But back to reality for a second. If you decided that revolutionizing the cost of space travel was the key to something very important, you wouldn't be like, "Great! I'm gonna do it!", you'd be like, "I don't know how to do that." To get our heads around how one might achieve such a thing, let's imagine that we're trying to do it and work backwards:

Q: How do I revolutionize the cost of space travel?

A: With decades of innovation, hundreds of trial and error launches, and thousands of super-smart people working on it. Straightforward, but icky. It's icky because:

Q: Where the hell is the money gonna come from to pay for that? If the government were interested in funding it, they'd have done it themselves already. And no charitable donor is going to put tens of billions of dollars toward funding a massive, 30+ year project that has no guarantee to work.

A: You pay for it by making your research and development operation double as a profitable space delivery service. To test your innovative new technology, you'll need to do a lot of launches. Governments and companies will pay you a ton of money to take satellites, cargo, and people up to space during those launches. Two birds with one stone.

Q: But how do I know how to launch something into space?

A: You don't. You have to spend a few years learning how to do it from scratch, and building all of the vehicles yourself, and proving that you can launch successfully before anyone will hire you as a delivery service.

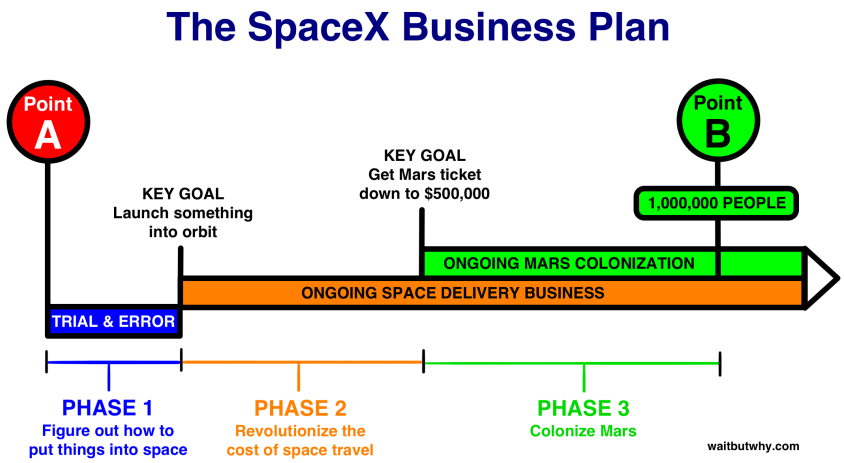
Q: But if there aren't any customers during the initial learning and development stage, who pays for that stage?

A: You, the founder.

Q: How do I get the money for that?

A: You co-found PayPal and then sell it.

So that's the logic that Musk thought through back in 2001, and it dictated SpaceX's business plan:



SpaceX has been at it for 13 years now. Let's go through what's happened so far and what still lies ahead.

Phase 1: Figure out how to put things into space

Main Character: Falcon 1

Goal: Launch something into orbit before Musk runs out of money

Phase 1 really started before SpaceX even existed, back in mid-2001 while Musk was still at PayPal. Strongly considering entering the space arena as his next move, Musk did what everyone does when they want to become a world-class rocket scientist in about a year with no schooling—he read some stuff.

He read books like this and this and this and this and basically memorized all of them. Rocket expert Jim Cantrell, who met Musk around that time and was on the failed trip to Russia with him, says "He would quote passages verbatim from these books. He became very conversant in the material."[2]

To supplement his reading, Musk asked a lot of questions of a lot of people. Cantrell, who calls Musk "by far the single smartest person that I have ever worked with," says that Musk "hired as many of my colleagues in the rocket and spacecraft business that were willing to consult with him" and that "it was as if he would suck the experience out of them."[3]

As Musk started to talk more and more seriously about making space his next big pursuit, Musk's friends were worried about him. Wouldn't you be? Imagine if your friend made a huge amount of money selling an internet business and then told you he was going to spend almost all of it trying to become the first entrepreneur to succeed at building a space launch company—because it was important that human life become multi-planetary. You wouldn't feel good about this. One of Musk's friends did his best to talk him out of the insane project by putting together a montage of rockets blowing up and forcing Musk to watch it.

But Musk is an odd duck, and he continued along unfazed.[1] After building himself a tree trunk foundation of knowledge, it was time to get other people on board. When I asked Musk about his knowledge of business, he scolded me, explaining, "I don't know what a business is. All a company is is a bunch of people together to create a product or service. There's no such thing as a business, just pursuit of a goal—a group of people pursuing a goal."

So he started assembling a group of the smartest people he could find, and SpaceX was born.

Then the core team of all-stars, which included renowned rocket engineer Tom Mueller, began to hire. Some early SpaceX hiring policies:

No assholes. Musk says that if you hate your colleagues or boss, you won't want to come to work and stay for long hours.

Hire (and promote) based on raw talent, not experience. Musk has said he doesn't care that much about a grad degree, college degree, or even a high school degree—just raw talent, personality, and

passion for the SpaceX mission. I sat down with SpaceX's VP of Vehicle Engineering, Mark Juncosa, who I was surprised to learn is a casual California *bro*. He seemed like some silly dude I'd be friends with, not a leading rocket scientist. He told me he was a terrible student and on his way to being a burnout of a human when he found an affinity for working on race cars[2] at the car club where he went to college. Turns out he was a total genius at it, and after school someone introduced him to Musk, who hired him. Juncosa quickly rose up at the company and now, in his early 30s, he's in charge of one of the major departments of the company, with hundreds of far more experienced people working for him.

There seem to be lots of stories like this that reflect on SpaceX being unusually meritocratic—I met with Zach Dunn, the Senior Director of Launch Engineering, who seemed to be about 12 years old. Dunn told me he started as an intern just a few years ago. Early on, when he assumed Musk had no idea who he was, Musk surprised him by telling Dunn he thought he was a very strong engineer, which made Dunn realize that Musk is acutely aware of everyone at the company. A few years later, Dunn was put in charge of launch engineering and more than 100 employees.

Musk interviews everyone, including janitors, and does so like a weirdo. This rule held with almost no exception through the first eight years of the company's life, up to the company having 1,000 employees. According to Musk's biography, "Each employee receives a warning before going to meet with Musk. The interview, he or she is told, could last anywhere from thirty seconds to fifteen minutes. *Elon will likely keep on writing e-mails and working during the initial part of the interview and not speak much. Don't panic. That's normal. Eventually, he will turn around in his chair to face you. Even then, though, he might not make actual eye contact with you or fully acknowledge your presence. Don't panic. That's normal. In due course, he will speak to you.*"[3]

The company itself, like Tesla, is heavily vertically integrated. This means that rather than outsource most of the parts of the rocket-making process to third party suppliers, SpaceX does nearly all of the major pieces itself, maintaining ownership and control over most of the supply chain. This is highly unusual in the aerospace industry—as Ashlee Vance explains, "The factory is a temple devoted to what SpaceX sees as its major weapon in the rocket-building game, in-house manufacturing. SpaceX manufactures between 80 percent and 90 percent of its rockets, engines, electronics, and … designs its own motherboards and circuits, sensors to detect vibrations, flight computers, and solar panels." Old-fashioned industrialists, like Andrew Carnegie and Henry Ford, were all about vertical integration, as is Apple today in many ways. Most of today's companies avoid taking on the massive scope vertical integration requires, but for a quality control freak, like Musk or Jobs, it's the only way they'd have it.

On top of so many parts of the process being merged together under the SpaceX roof, they're physically enmeshed together in the building, just like at Tesla—engineers on their computers are stationed either out on the floor amidst the design and manufacturing or in all-glass offices with the assembly process visible all around them.

As the team grew and departments formed, Musk remained intimately involved in almost every process in a truly unusual way. Some bosses are called micromanagers—at Musk's companies, his level of involvement earned him the term "nanomanager."

Elon Musk Knows a Lot of Shit Blue Box

Almost every person I talked to at both Tesla and SpaceX emphasized how much of an expert Musk is at their particular field, whether that field be car batteries, car design, electric motors, rocket structures, rocket engines, rocket electronics ("avionics"), or aerospace engineering. He can do this because of a combination of his immensely thick tree trunk of fundamental understanding of physics and engineering and his genius-level ability to retain information as he learns it.

It's that insane breadth of expertise that allows Musk to maintain such an abnormally high level of control over everything that happens at his companies. About SpaceX's rockets, Musk said, "I know my rocket inside out and backward. I can tell you the heat treating temper of the skin material, where it changes, why we chose that material, the welding technique…down to the gnat's ass."[4]

I asked SpaceX's VP of Software Engineering, Jinnah Hosein, about Musk's nanomanagement. He said:

The biggest surprise for anyone first joining the company—SpaceX throws around term "nanomanager," and you're like, "Okay he likes to go down in the weeds, that's cool"—but you have no idea. For the CEO of the company, he has an incredibly deep stack—he has all that info available to him, and he can drill down on any one thing, and often does. He's making very low-level decisions and very low-level course directions for the company,

> *with high fidelity, and I can't imagine it working with anyone else at any other company. The thought of one person being a key decision point for so many things is remarkable to me—he can hold it all it in his head and recall it on demand in real time, as necessary, in order to be able to make good decisions.*

Okay so now it's mid-2002, and this crazy idea is starting to become a real thing. There's a clear mission, a team, and a force-of-nature CEO. Next step—a rocket.

Before we get into SpaceX's first rocket, let's get clear on terms:

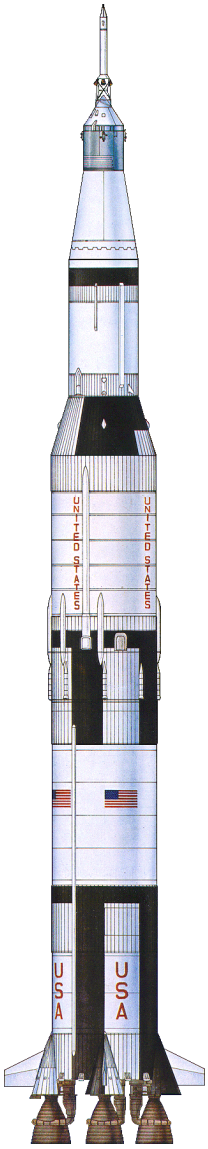
The point of almost any space launch is to take something to space. The thing you're taking is called the **payload**. A payload can be a satellite, cargo, people, a monkey[4]—anything.

In order to survive the rough trip to space, the payload is sometimes inside a protective shell called a **fairing**. Other times, the payload needs to be steered, navigated, and docked when it's out in space and maybe even be brought back to Earth. In that case, the payload is carried inside of a **spacecraft** or, if you're nine, a **spaceship**.

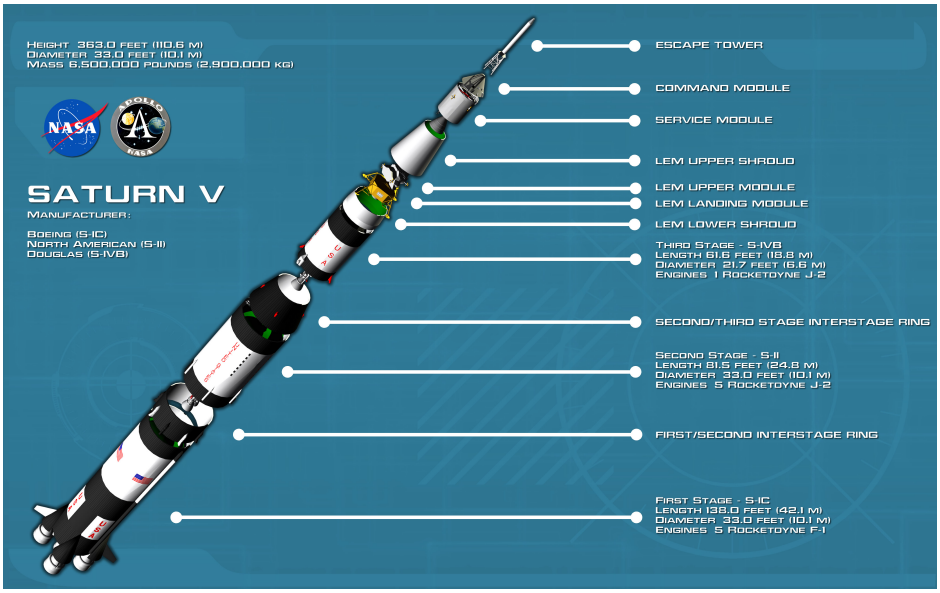
Then you have the **rocket**. The rocket is the main big thing that launches, and it has one job: to carry the payload and its container up through the atmosphere and put it into space. Most of the rocket is a big fuel tank, and at the bottom of a rocket is one or more insanely powerful, bell-shaped **engines**. These provide the immense force—or **thrust**—that it takes to lift many tons of weight up through Earth's atmosphere. Sometimes a rocket is made up of multiple smaller rockets called **stages**. Oh, and everything I just described becomes a missile if the payload is a weapon.

Finally, a **rocketship** is not a thing. A rocketship is a term to make a four-year-old excited about life—that's it.

The Apollo missions went to the moon using an enormous rocket called the Saturn V. Saturn V weighed 3,000 tons—about as much as seven Boeing 747s—and was the height of a 35-story building.[5]



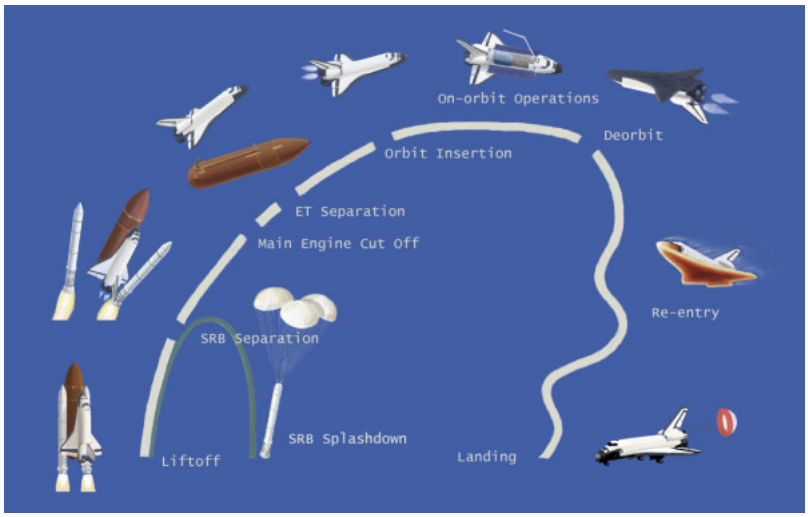
Saturn V was like one of those satisfying Russian doll sets where it keeps getting smaller and smaller. Here are all the pieces:[6]



The Space Shuttle, with a much simpler job of only ever going into Low Earth Orbit, took a totally different approach.

Instead of one big first stage rocket, the Space Shuttle used two rockets (called solid rocket boosters)[5] to do the meat of the heavy part of the ascent, and the payload—people and equipment—rode in the shuttle spacecraft, which they really made look like a stereotypical spaceship. The spacecraft provided

the rest of the boost after the rockets dropped away, using fuel from the big, for-some-reason-orange fuel tank. Normally, returning spacecraft[6] land in the ocean using parachutes, but the Space Shuttle took a more civilized approach, landing on a runway like an airplane:[7]



When SpaceX made their first rocket, they weren't trying to do the biggest, baddest thing that had ever been done. Instead, they built what was kind of their training-wheels rocket, a small, straightforward rocket Musk named **Falcon 1** (after the Millennium Falcon in *Star Wars*). It was a 70-foot-tall (21 m), two-stage rocket with one super-powerful engine at the bottom—SpaceX's own invention, the Merlin engine.[8]

Despite its modest size and capability, Falcon 1 was full of innovative new technology. The primary goal was to make it cheaper than ever before to take small payloads into space—not just because Musk sees cost-reduction as the way to get us to Mars, but because he sees it as the only aspect of space travel that currently *can* be improved in a meaningful way. He says, "Speed for a rocket is always going to be roughly the same. The convenience and comfort is going to be about the same. Reliability…there's not going to be much improvement there. So you're really left with one key parameter against which technology improvements must be judged, and that's cost."

Musk cites two reasons costs have remained so high:

1) The only companies in aerospace are huge, and huge companies are risk averse. He says, "There's a tremendous bias against taking risks. Everyone is trying to optimize their ass-covering … Even if better technology is available, they're still using legacy components, often ones that were developed in the 1960s … [many] use Russian rocket engines that were made in the '60s. I don't mean their design is from the '60s—I mean they start with engines that were literally made in the '60s and, like, packed away in Siberia somewhere."

2) Not enough vertical integration. We mentioned SpaceX's vertical integration and the full control it affords Musk over what happens at SpaceX, but Musk also believes the vertical structure is critical to keeping costs down, and he criticizes the rest of the industry for not doing so: "There's this tendency of

big aerospace companies to outsource everything … They outsource to subcontractors, and then the subcontractors outsource to sub-subcontractors, and so on. You have to go four or five layers down to find somebody actually doing something useful—actually cutting metal, shaping atoms. Every level above that tacks on profit—it's overhead to the fifth power."[9]

Without the baggage of a huge company with a long history, SpaceX was able to "design and develop [Falcon 1] from the ground up from a blank sheet of paper," says Max Vozoff, an early SpaceX employee,[10] and you can see the "blank sheet of paper" mindset in Musk's ground-up reasoning: "[I asked], What is a rocket made of? Aerospace-grade aluminum alloys, plus some titanium, copper, and carbon fiber. And then I asked, what is the value of those materials on the commodity market? It turned out that the materials cost of a rocket was around 2 percent of the typical price—which is a crazy ratio for a large mechanical product…So, I thought, we should be able to make a much cheaper rocket given those materials costs."[11]

And that's all great—but this was not a normal company with a normal budget and timeframe for development. This was a venture few sane investors would touch, and the ability for the company to exist rode largely on Elon Musk's personal bank account. By the time 2006 rolled around, Musk had decided to revolutionize the automotive industry as a side project, and with $70 million of his PayPal fortune tied up in Tesla, that left about $100 million for SpaceX. Musk said this would be enough for "three or four launches." SpaceX would have that many tries to prove it was worthy of paying customers. And since the thing paying customers would want is for SpaceX to deliver a payload of theirs into orbit, that's what SpaceX needed to do—successfully launch something into orbit to show the world that they were for real.

So the game was simple—launch a payload into orbit in three or possibly four tries, or the company was done. At the time, of the many private companies who had tried to put something into orbit (see the dearth of "operational" companies on this list), only one had ever succeeded (Orbital Sciences).

To understand why this is such a hard thing to do, we have to understand what an orbit *is.*

What is an orbit?

It's intuitive to think that the challenge of putting an object in orbit is the difficulty of getting it *up* to orbit, just like it's intuitive to think that the astronauts in the ISS are floating around because there's no gravity up in space where they are. This is a good time to stop trusting your intuition.

Let's zip back to high school for a second. Here's the equation we use to figure out the force of gravity:

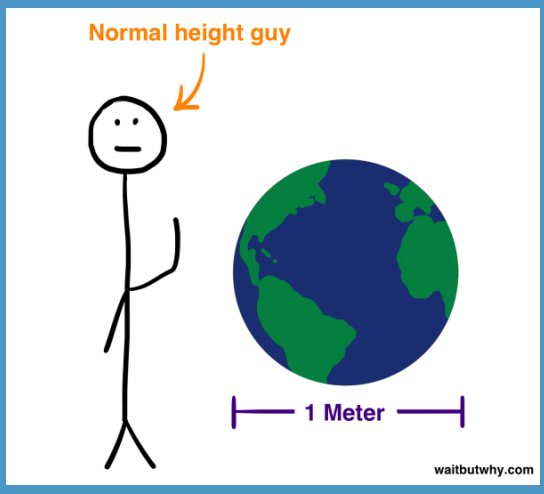
$$g = G \times \frac{m_1 m_2}{d^2}$$

G is the gravitational constant, a super-icky number we can ignore for this exercise.

m_1 and m_2 are the masses of the two objects. There are two objects because gravity isn't a one-way thing—every two objects attract each other with an equal force. In the case of you and the Earth, what you think of as your weight *is* the force of gravity between you and the Earth, a force acting equally on you and the planet.[7] And because the two mass numbers are in the numerator, it means that when they go up, the force of gravity will go up too (proportional to their product). So if I doubled your mass, your weight would double. If I left your mass the same but doubled the Earth's mass—again, your weight would double. If I doubled *both* your and the Earth's mass—your weight would *quadruple.* For our purposes in this post, we don't need to work with mass.

What we care about is the **d^2** part. *d* is the distance between the two objects—or more specifically, the distance between the *centers of mass* of the two objects. In the case of the Earth, the mass is symmetrically distributed, so the center of mass is the center of the planet. The Earth's radius is 3,959 miles (6,371 km), so when you're on the surface of the Earth, that's the number you use for *d* to determine the force of gravity you're experiencing. Because *d* is in the denominator of the equation, as *d* grows, the force of gravity decreases.

To illustrate all this, I'm going to shrink the Earth down to about one 13-millionth of its size, so that it's exactly one meter in diameter:



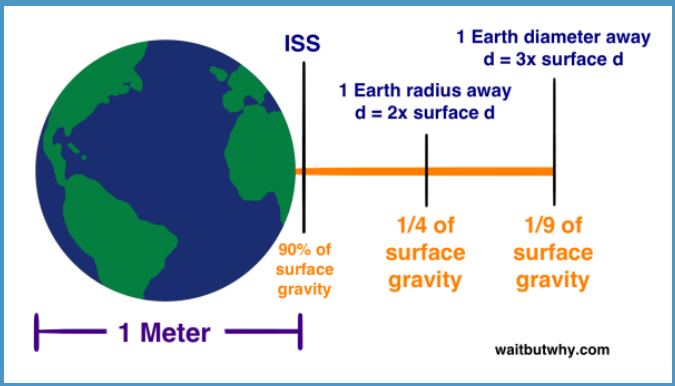
If we double *d* by moving an Earth radius away from the surface (half a meter), d^2 goes up by 4x, so the force of gravity, and your weight, would be a quarter of what they are on the surface. If you moved to a full meter away—where you could fit a full Earth between you and the Earth—*d* has now tripled and your gravity is 1/9 of what it is on Earth. [8]

And where does the ISS fall in all of this?

It's between 205 and 255 miles away, which on our meter globe is about 2-3 cm, or a little over an *inch* from the surface. If a ping pong ball were stuck to the globe, the ISS (and a lot of satellites) would run into it. (While we're here, the commonly-recognized altitude where "space" starts is the Kármán line, 62 mi (100 km) up, which on our globe starts 7.8 mm above the surface—about the width of a pencil. And an airplane flies at .84 mm off the surface, about the height of a grain of sand.)

So what does that mean about gravity in Low Earth Orbit, in a place like the ISS?

Well if we take the mid-point of the average altitude of the ISS (230 mi), we find that being at that height adds only 5.8% to the normal *d* on Earth's surface, which only brings surface gravity down by about 10%.



So ISS astronauts should barely feel the gravity difference. And yet, they're floating.

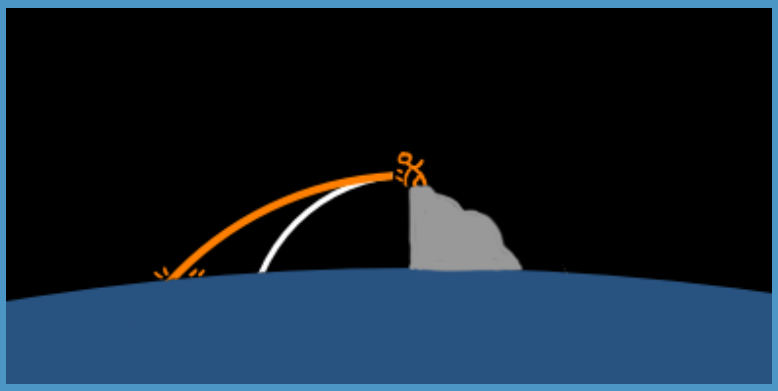
The reason is they're in free fall.

I once had a chance to fly in a little plane with a pilot who didn't give a shit, so he brought the plane up to 4,000 feet and then quickly dropped to 2,000 feet. Before the drop, he handed me a pen and told me to rest it on my open palm. During the drop, the 8% of me not in bed-shitting survival mode saw the pen hover in front of me and gently float over to the side before abruptly dropping into my lap when we leveled off again at 2,000 feet. This is what's happening inside the ISS at all times.

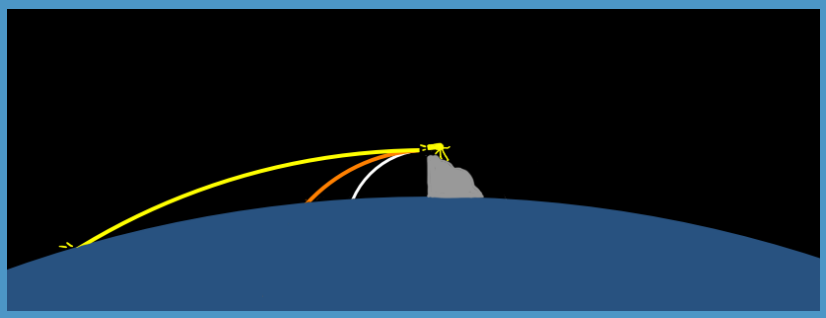
Here's why: picture you're standing on a cliff on a planet smaller and smoother than the Earth and with no atmosphere—and you throw a baseball as hard as you can.

It would go something like this:

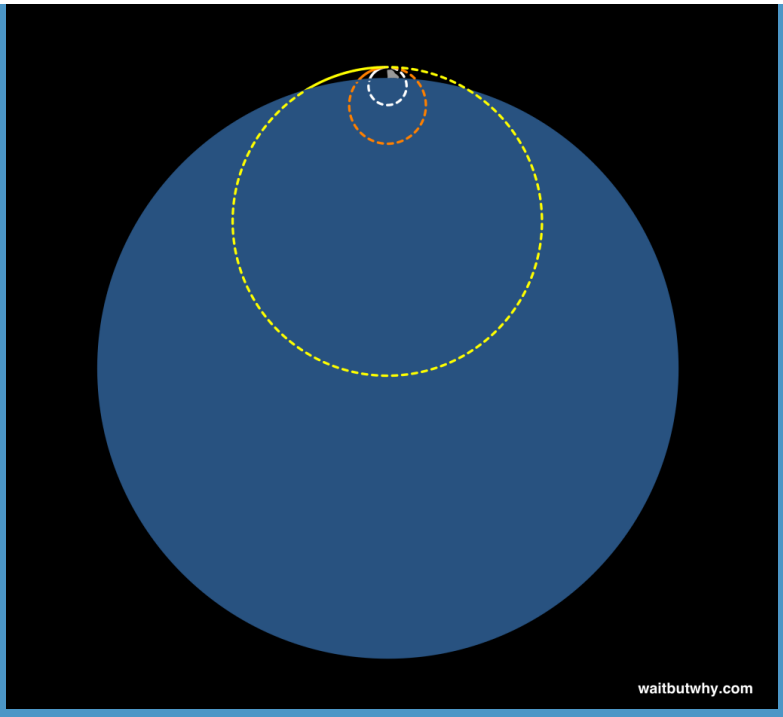
Now what if a major league pitcher gave it a try. It might look like this:



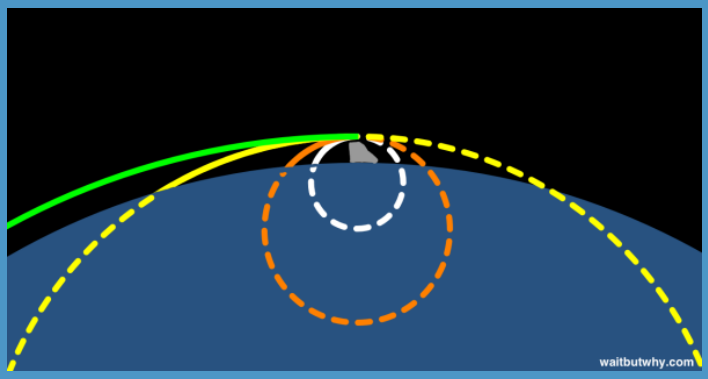
And what if you fired the ball out of a cannon? It would go even further.



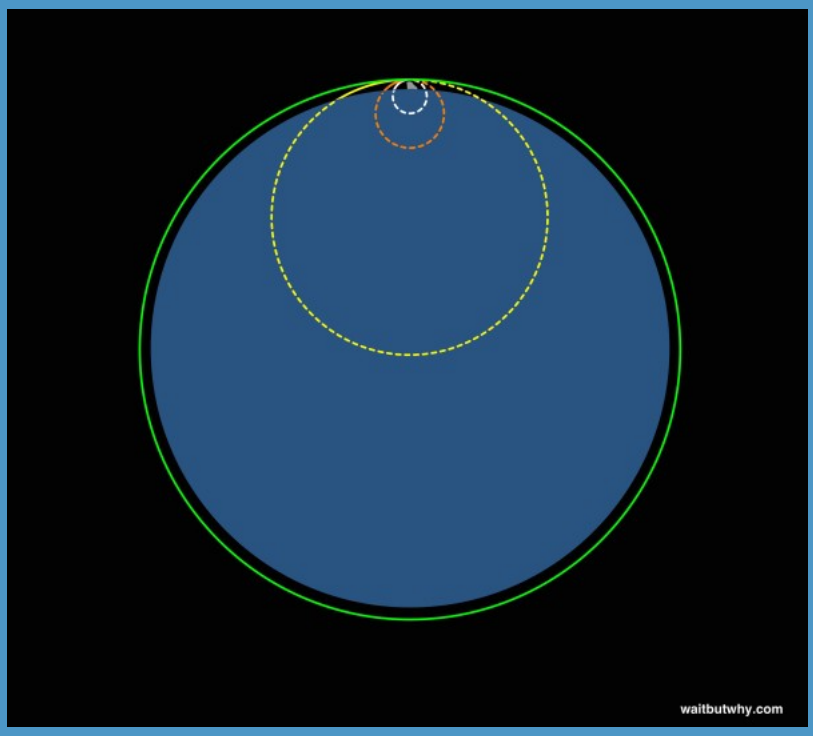
Before each of these balls hits the ground, they fly in a curved path. If the planet's surface didn't get in the way, those paths would continue as long ellipses. To keep things simple, let's just match each path up with a circle whose curve lines up with it ball's trajectory pretty well:



Now let's get a much more powerful cannon, and it does this:



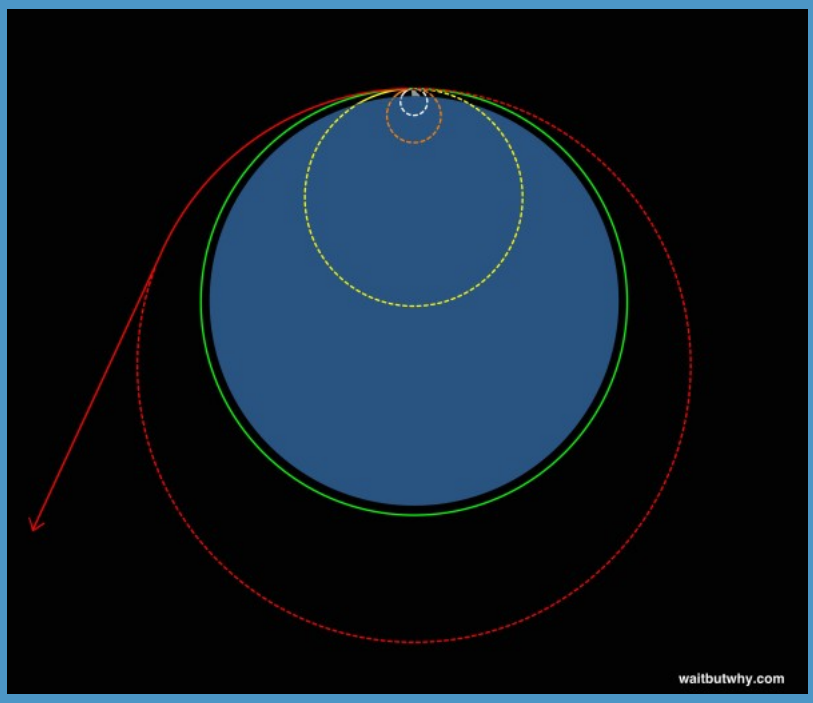
Seems normal, but notice that the arc's curve is matching the shape of the planet. So what ends up happening is this:



The ball would circle the planet and run into the back of the cannon. And if nothing were there to block it, the ball would continue "falling" forever, never able to land. Because the ball's path's curve, and corresponding circle, match up exactly with the curvature of the planet, the planet keeps falling away from the ball as the ball tries to fall down to the ground. You've put the ball in orbit.

If you had a perfectly smooth planet of any size, and it had no atmosphere at all, you could in theory put something into orbit right above the ground. But because the Earth has a thick atmosphere (and an uneven surface with mountains), no matter how hard you fired a ball near the surface, the atmosphere would slow it down, making its path's curvature tighter and tighter until it fell out of orbit and hit the ground. That's why everything we put in orbit is high up, where the atmosphere is so thin it doesn't slow the object down. And without any force of friction to interfere, Newton's Law of Inertia kicks in and it'll circle the planet forever. [9]

In order to fall into orbit around the Earth, an object has to be moving *unbelievably* fast. But not *too* fast. Why? Because then the curve is *too* broad, the corresponding circle is bigger than the planet, and this happens:



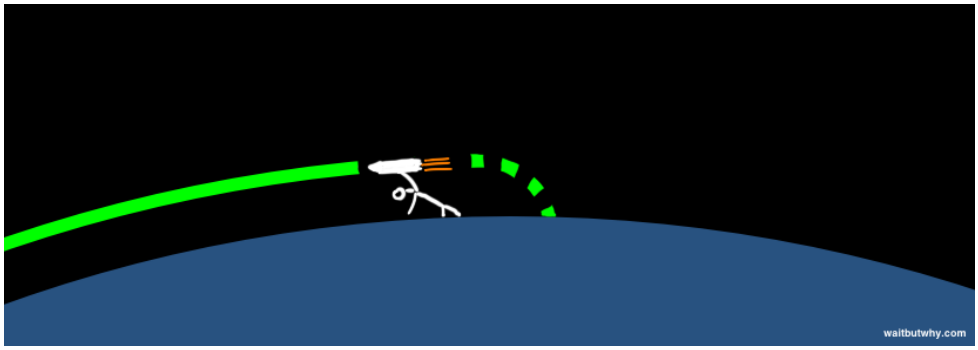
That's why people talk about something reaching "orbital velocity" to stay in orbit, and "escape velocity" to escape from the Earth's gravity well and head out into space. Escape velocity just means the arc the path makes is broader than the curvature of the planet.

So what's orbital velocity at about a 230 mi altitude where the ISS is? 17,150 mph (27,600 km/h). Or 4.76 mi / 7.66 km per *second*. That's the goldilocks speed that will keep an object in orbit at that height.

To get a feel for how fast that is, if you threw a ball at that speed from the beach into the ocean, it would zing out and over the horizon, out of sight, in about a half a second. At that speed, the ISS circles the Earth every 90 minutes (and yet, because velocity is relative, the astronauts in the ISS don't feel like they're moving at all, the same way you don't on an airplane).

Back to SpaceX. Given the blue box above, it makes sense that SpaceX's challenge was to essentially "throw" a payload up into orbit. People think a rocket launch goes *up*, but really it's throwing something really hard *sideways*, which is why a rocket's trajectory looks like this: [12]

It's like our examples above, and the rocket is acting like the hand of a giant who's throwing the payload:



Except in the real world, instead of an arm and a hand, a rocket company has to throw the payload with a seven-story high, 40-ton [10] metal tower that explodes away from the Earth, and it'll need to ping a delicate machine out at *just* the right altitude, at *just* the right speed.

To make things even harder, the "throw" starts off in the sea-level atmosphere, which is both molasses-thick and full of moving parts (i.e. weather). It's like trying to throw a ball with precision with your hand starting under a few feet of flowing water. SpaceX's head of vehicle engineering, Mark Juncosa, described the challenge of guiding a rocket up through the atmosphere: "The rocket is like a wet noodle and you're trying to push it to space. It's flopping around like hell. You can't even figure out where it's going by measuring the trajectory of any one point on the rocket—you have to measure a few points."

And with such large forces in play—the weight of the rocket, the speeds, the thick atmosphere—even a tiny equipment malfunction can immediately destroy the mission. The problem is, you can't reliably test exactly how the equipment will hold up until it actually launches.

SpaceX learned all of this the hard way.

2006: First launch—failure

2007: Second launch—failure

2008: Third launch—failure

Bad times.

The failures were caused by tiny things. Specifically, a corroded nut not holding up under the pressure, liquid in the rocket sloshing around more than expected, and the first stage engines shutting down a few seconds too late during stage separation. You can get everything 99.9% right, and the last .1% will explode the rocket in a catastrophic failure. Space is hard.

Every rocket-launching government or company—each and every one—has failures. It's part of the gig. Normally, you take a deep breath, roll up your sleeves, figure out what went wrong, and move on to the next launch. But SpaceX had special circumstances—the company had money for "three or four launches," and after three failures, the only launch they had left was the Or Four one. It was scheduled for less than two months after the third launch failed. And this was the last chance.

A friend of Musk, Adeo Ressi, describes it like this: "Everything hinged on that launch … If it works, epic success. If it fails — if one thing goes differently and it fails — epic failure. No in between. No partial credit. He'd had three failures already. It would have been over. We're talking Harvard Business School case study — rich guy who goes into the rocket business and loses it all."[13][11]

But on September 28, 2008, SpaceX set off the fourth launch—and *nailed* it.[12] They put a dummy payload into orbit without a hitch, becoming only the second privately-funded company ever to do so.

Falcon 1 was also the most cost-efficient rocket ever to launch—priced at $7.9 million, it cost less than a third of the best US alternative at the time.

NASA took notice. The successful fourth launch was enough evidence for them that SpaceX was worth trusting, and at the end of 2008, NASA called Musk and told him they wanted to offer SpaceX a $1.6 billion contract to make 12 deliveries for them to the ISS.

Musk's money had done its job. SpaceX had customers now and a long future ahead.

Phase 2: Revolutionize the cost of space travel →

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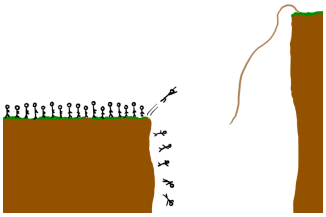

Why Cryonics Makes Sense

maria juchkov • 23 days ago

Absolutely love the series! But I have a few questions...

If Mars is to be the Plan B for Earth, why send people back to Earth? And when the time does come that

If Mars is to be the Plan B for Earth, why send people back to Earth? And when the time does come that Earth will become uninhabitable will SpaceX & Mars be able to cope with a mass exodus?

And further more, does Elon have any plans for what type of economic system will be on Mars? After all, what's the point colonising Mars, only to live unsustainability & trash it too...

Reply • Share ›

stephenshenfield • 2 months ago

The author neglects the medical effects of switching between different gravity environments. Even with well-designed exercise routines, astronauts who spend any length of time in space suffer serious physical disabilities on return to earth. Among other things, this will deter people from returning to each after even a couple of years on Mars (plus 6--12 months in space).

Another problem is the selection of colonists by ability to pay initially very high fares rather than by possession of needed skills, good physical and mental health, age, etc. If selection is based on criteria such as these most of those selected will not be able to afford the fare, so a lot of money will have to be raised from wealthy people who will not themselves be able to go to Mars.

The technical aspects of development of extraterrestrial colonies are outlined, but there is hardly any discussion of political and economic systems. The assumption seems to be that these will resemble those on earth, which is likely to be impracticable, especially at the early stages, and would also be undesirable, seeing what a mess these systems have made of earth. If two or more space powers set up their own colonies on the same planet what will the relations between them be?

Reply • Share ›

Summer of Love (bob) • 5 months ago

Tim, I'm afraid Musk sold you a load of manure on Mars. It is unlivable for humans and always will be. Reference the failure of the earthdome projects and you'll quickly realize domed cities don't work even on Earth, muc

1 Reply • Share ›

2ndGenSunRoad • 5 months ago

We on Earth are not in Energy paradise to sustain life on other planet, but actually in Energy prison;

"No device can generate energy in excess of the total energy put into constructing it".

https://the-fifth-law.com/p...

1 Reply • Share ›

GregWA • 6 months ago

"measuring contest"...have you actually read the history of Nazism or Communism? They weren't measuring anything...they were and are evil totalitarians hell bent on killing those who disagreed or would not submit (like radical Islam). And if you think this level of evil is restricted to modern times, read some more history. Musk and his family colonizing Mars as a modern day Ark story would not result in evil being excluded. I like science and I like science fiction, speculation, the rest, but please keep religion and politics out of it. Scientists, myself included, are typically no more qualified to expound on these things than anyone else. So I offer this post in that spirit: just one guy's opinion based on a little knowledge and much less wisdom.

p.s., Americans weren't horrified by the Soviets larger penis (first satellite/human in orbit), they were horrified that the Soviets could now deliver nuclear weapons to America, with no warning or protection possible. Did you miss that bit of history or does that just boil down to a "penis measuring contest" for you? Sorry for the attitude, but I'm an old guy losing patience with how little people have learned from all of humanities mistakes.

2 Reply • Share ›

The_Unknown • 8 months ago

What about the reduced gravity on Mars? It's 38% of the gravity on earth if I recall correctly. Research has shown that microgravity in the ISS has a detrimental effect on muscle mass and bone density and even on organ function. Sure the first two can probably be solved by exercise but the organ function can't. And even if there's a big difference between almost no gravity and 38% of earth's gravity, there's no telling what the effect of long term (years or decades) exposure to this reduced gravity will be on human organs.

Reading these series of posts I do believe in the colonization of Mars but this reduced gravity has gotten me wondering about the long term feasibility of all this.

1 Reply • Share ›

Ante Renic • 9 months ago

Tim, take note. Your "what is an orbit" blue box gets several things wrong.

1) You said ponds have no high and low tides due to their lower mass than that of oceans. Their mass is completely irrelevant as acceleration is always the same, regardless of mass. Ponds don't experience high tides because there is no water that comes over from the back of the planet. Similarly there's no low tides because the water has no route to take to the other side of the planet.

2) The trajectory of a ball being fired at too high a speed would not look like that. It's not like it would circle for a bit and then start moving straight through space. The Earth is still acting on it, regardless of distance. As it moves further away, the curvature of the trajectory will become lower and lower, but it will always curve

a little bit, it will certainly never become straight, not in the manner depicted, anyway.

3) Thrown objects would only fly in a circle if the source of gravity was in the center of the circle. This means that the trajectory of thrown objects isn't a circle even before they hit the ground. If the ground was a straight line (which it is if we zoom in enough, as in most physics problems) and gravity acted exactly downwards all the time, the trajectory would be a parabola (no air resistance). If the direction of gravity changed such that it's always perpendicular to the velocity, the trajectory would be a circle, as I've explained above. If the gravity, however, does change direction but is not always perpendicular to the trajectory, as is the actual, realistic (and drawn) case here, the trajectory would be something between a parabola and a circle.
Note that trajectories can also be ellipses; in fact, a circle is mathematically merely a special case of an ellipse (just as a square is a special case of a rectangle).

For the third note you can just add a blue square thing which says that the trajectory isn't exactly circular, but whatever.

Also note: Tesla started with 30 million, not 70 million. Elon's share of Paypal's sale was 130 million, so 100 went to SpaceX.

Reply • Share ›

Ralph Fischer • 9 months ago

Main reason for bad wind and temerature on Venus is the fact that it got almost no rotation.

In order to colonize Venus i assume first it needs to be hit by some pretty big Asteroid to start a rotation.

Might even need a mass close to the moon.

2 Reply • Share ›

Ralph Fischer • 9 months ago

I think you got that one wrong: "Humans have never experienced a mass extinction event, and if one happened, there's a reasonable chance it would end the human race"

Humans faced black death and that took quite a bite into population.
Not to mention that we WITNESS a mass extinction event right now while reading. It is caused by many many humans totally ignorant to the fact that their actions are about to kill loads of liveforms, including bees. High chance that the mass extinction event for humans is just waiting for new years day.

Reply • Share ›

Nicole Song ↗ Ralph Fischer • 9 months ago

Right, but the bubonic plague only killed about a third of Europe's population. It didn't even spread to any other continents. I'd say we're fine, it was not a huge event in humanity, unless you're strongly Euro-centric.

3 Reply • Share ›

Brandon • a year ago

I'm wondering whether the Martian calendar will start at year 0 from the day the first human set foot on the planet. That would be so huge. Finally not a religious calendar, but a true scientific calendar celebrating every 669 martian days the moment the first humans set foot on the planet.

5 Reply • Share ›

Hans Nelson • a year ago

Have you seen the "Economics of Airline Class" video by Wendover Productions on YouTube? I just happened to have seen this the other day, and it seems like it would be an interesting idea to toy with on the Mars Colonial Transporter. Thoughts?

Reply • Share ›

Michele • a year ago

How much space debris was added when the United States shit on the world's collective face in 1985 by destroying a satellite in orbit, and again in 2008?

4 ▲ | ▼ • Reply • Share ›

Isabella Pintor • a year ago

great article it took me an hour to read it but.. it was worth it

1 ▲ | ▼ • Reply • Share ›

Nicolas Stabilini • a year ago

I'm really concerned about horoscope... how would astrologyts get an astro-chart for a human born in Mars? (btw: I think horoscope is big big ball of bullshit)

▲ | ▼ • Reply • Share ›

ImmortalWind • a year ago

Hey Tim, I was researching a little bit about Voyager's destination and it's actually NOT heading to Proxima Centauri as you seem to imply (unwillingly) in the Voyager section above. You might want to change this sentence.

3 ▲ | ▼ • Reply • Share ›

Blaine • a year ago

One thing I haven't yet seen anyone address is how the 38% Earth-gravity on Mars will affect humans that live there for long periods of time. Would a Martian-born-and-raised person who traveled to Earth be weak and unable to walk (or walk with great difficulty, bearing three times their normal weight) under the influence of the heavier gravity? If their muscles had only experienced the lighter gravity of Mars, wouldn't living on Earth be incredibly difficult for them? I feel like Martians would be at a physical disadvantage if they ever left their home planet. Am I wrong here?

8 ▲ | ▼ • Reply • Share ›

Michael Pang ➚ Blaine • a year ago

Yes I'd imagine that to be the case - although they're genetically the same so it's nothing a few months of working out shouldn't be able to fix.

▲ | ▼ • Reply • Share ›

IamGrimalkin ➚ Blaine • a year ago

How 38% gravity will affect humans is unknown, because no-one has ever been in 38% gravity for long periods. However, research in the ISS and other space stations does give an idea of what zero gravity is like. Bone density and muscle mass does increase after long periods in zero-g, but it is possible to mitigate that by using the right exercise machines for 2 hours a day (if I remember correctly).

▲ | ▼ • Reply • Share ›

Drabes ➚ IamGrimalkin • a month ago

I think you mean muscle mass and bone density decrease...

▲ | ▼ • Reply • Share ›

IamGrimalkin ➚ Drabes • a month ago

Yes, I did mean that, thanks for the correction.

▲ | ▼ • Reply • Share ›

Babette • a year ago

You said : "The spacecraft provided the rest of the boost after the rockets dropped away, using fuel from the big, for-some-reason-orange fuel tank."
At first they wanted to paint it white, until they found out that it saved 3000 kilo's not to. That's the reason why the thing was orange. Funny I remembered that detail but pleased to fill you in :-)

5 ▲ | ▼ • Reply • Share ›

iykcvth • a year ago

good article ;)

▲ | ▼ • Reply • Share ›

guest • 2 years ago

The article talks about a lot of awful people in positions of power who weren't using space technology for positive things like Musk wants to, but for "measuring contests" like America vs. the Soviet Union, and other destructive military applications that continue the international measuring contest and line the pockets of politicians like Mr. Shelby. Now the US only wants to improve their space tech because another measuring contest is on the horizon -- and it's with some very scary people who are mixing mythology in with their measuring contest.

The Middle East is a mess enough to begin with, but now we've got Iran to deal with, firing off rockets for their moon god? As if that wasn't bad enough, there's the perpetual Iran-Saudi (Shia-Sunni) divide in Islam, vs. the Jewish government in Israel and whatever's left of millennialist Christianity in the United States government (not millennials as in teenagers with smartphones, but a sect of Christianity that believes in

ushering in the Revelation through a massive, population-culling war in the Holy Land).

Imagine a sequel to the US-Soviet space race that boils down to a holy war, using cutting-edge technology to fulfill the prophecies of Bronze Age storybooks. 100 million people already died as a result of the global US vs communist "measuring contest." 100 million more died before that because Adolf, Tojo and Benito had a measuring contest with Franklin, Winston and Josef. On the micro level, a young man, the nephew of a local legislator, was brutally murdered in Chicago over the weekend because of a "measuring contest" over who had the better pair of sneakers. People have been assaulting each other over having the opposing US presidential candidate's bumper sticker on their car. This is what you call intelligent life?

Why the $#&% does Elon want to save a species of $%&#-flinging monkeys who are hard-wired to pursue these immature, but globally destructive, "measuring contests," whether in the name of money or ego or the claims of their gods? Why doesn't he focus on making the Martian mission a real-life Noah's ark instead? Just him and his family taking the animals and plants on a trip to get away from the god-botherers and their "measuring contests."

Reply • Share ›

Ed Jagger guest • a year ago

It's because Elon Musk is a very astute businessman. The radiation and low gravity environment will not allow long-term human survival on Mars, even with an artificial atmosphere, hydroponics, underground shelters. Human physiology and development did not evolve to exist in such an environment. Musk secretly knows this. It's the reason there are no plans for practice colonies on the Moon (which is much nearer). I agree that his modernised space-freighter system will make him more money than God - and he is doing a very good job of advertising Space X using this 'Mars mission to save humanity' But I'm afraid in the end it boils down to profit and share-holders, like everything else.

Reply • Share ›

Steve Ed Jagger • a year ago

Read more about Musk. This is an easy story to tell about him, but it's not supported by evidence. The evidence is very good that he is actually hell-bent on colonizing Mars.

Also, the radiation concern, while nonzero, is way overblown. Here's some info:
https://www.reddit.com/r/sp...

1 Reply • Share ›

Jonas Friedmann Steve • a year ago

You are hopefully right. There is a German physicist named Harald Lesch who says it makes no sense to colonize the mars. He says more or less it is not possible to create an atmosphere because the Mars has no magnetic field. We are not able to increase the mass. And solar winds will shave off any atmosphere we could build up. And even if it would be possible to create a stable atmosphere, the two moons Phobos and Deimos will rub at the atmosphere. Following they lose their energy and crash into the Mars. Than everything is destroyed again and for 100 thousand years no living will be possible again. What do you think?

Reply • Share ›

Steve Jonas Friedmann • a year ago

Well, it's always about the quantitative facts. It took Mars (hundreds of?) millions of years to lose its atmosphere; if we come up with any way to terraform it within thousands or tens of thousands of years, that method will easily be able to keep up with the solar winds.

As for Phobos and Deimos, I haven't heard of that. They're pretty small as far as moons go -- 6 and 10 km radii -- so their impact wouldn't destroy everything for 100,000 years. Could be a problem, but a civilization able to terraform a planet should have some ideas about that -- e.g. blowing them into smaller chunks to make the impact far less severe.

However, in any case, what matters for whether or not people go colonize Mars isn't what will happen in the end, but what they believe will happen. If people believe that colonizing Mars isn't a doomed venture, and want to do it, then they'll do it, right or wrong.

Reply • Share ›

inservo Steve • a year ago

you definitely need to work on your perspective. There are much much much more non-US citizens on planet earth and maybe (hard to imagine for the standard US dickhead, I know) some have political systems that are maybe not perfect but at least do soemhow work.

If you want to throw your country in the trashcan, do us all a favour and go on but do not take everyone else with you.

Reply • Share ›

Steve inservo • a year ago

Was this supposed to be a reply to me? I don't see the connection.

2 • Reply • Share ›

Hayley Mac • 2 years ago

Is anybody else up for moving to Mars for four years to escape the Trump presidency? We can clean up the mess when we're back in 2020.

2 • Reply • Share ›

guest ↗ Hayley Mac • 2 years ago

Stop bringing politics into this. Your type is exactly the kind of tribalism that's makes the Squeegle alien or whatever his name is root for humanity's imminent demise. All I pointed out above is that there are people who stab each other over sneakers and start world wars over "measuring contests" like the article talked about, and that maybe Musk is trying to back up junk data that belongs in the recycle bin. He should focus on saving polar bears and elephants, instead of "Never Trump" or "Never Hillary" monkeys who fling poo at each other because their guy is better.

1 • Reply • Share ›

Hayley Mac ↗ guest • 2 years ago

That comment was meant in light-hearted jest. I assure you I have no intention of moving to Mars.

Ironically I've just watched the latest episode of South Park and it appears Cartman has had the same idea.

1 • Reply • Share ›

Yian Huang • 2 years ago

Why aren't they colonising the Moon first or simultaneously, as a proof of concept and/or to get people excited?

• Reply • Share ›

Dan Apted ↗ Yian Huang • 2 years ago

Your question is very appropriate. Colonization of LEO is the first step, Colonization of Geosynchronous orbit is the second step. Colonization of L1 and L2 orbit is 3rd step. Lunar colonization is 4th step and industrial mining/colonization of the asteroid belt is 5th step and colonization of LMO (Low Mars Orbit) is the 6th and final step before we invade Mars. Just figuring out where to land on Mars as a first step in the invasion is a decades long study and decision making process that should be left to the people living in LMO. They will be the ones who supply the products and knowledge about living and operating so far from home to the souls who descend to the surface.

• Reply • Share ›

Amit Vikram ↗ Dan Apted • a year ago

Because Mars is more hospitable than moon. Mars' gravity is 38% of Eath's gravity while moon's gravity is nearly 16.7% of that of Earth's. So humans can get use to Mars' gravity much easily. Also there is cosmic radiation. Mars has an atmosphere although relatively thinner than that of Earth, it shields off some cosmic ray particles and humans can build their habitats underground for extra protection. While moon has no atmosphere whatsoever. So underground habitats would also not protect from radiation effectively at moon. Also there is possibility to terraform Mars. The main reason Mars and moon don't have a thick atmosphere like earth is because Earh has it's own magnetic field which protects atmosphere from charged particles of solar wind, while Mars and moon don't. Mars didn't had any protection from solar winds which stripped apart it's atmosphere. Mars has Dry ice (frozen CO2) sheets in it's poles and if we nuke them, it will release that CO2 in atmosphere and hence thickening it's atmosphere in which plants can grow, increased atmospheric pressure will prevent water from boil off at low temperatured and hence liquid water would be able to sustain on it's surface and the green house effect will warm up the mars a bit which is currently very cold. The solar wind will again strip that atmosphere, but it is a very slow process and therefore we would have millions of years to get a solution for that problem.

• Reply • Share ›

David Sabo ↗ Dan Apted • 2 years ago

Musk intends to skip all that and go straight to Mars. His reasons are very appropriate - i.e., the intermediary steps aren't really necessary, and the Moon isn't all that well-suited to colonization in the near term. Tim's article lays this all out reasonably well.

To Yian's question more directly, colonizing the Moon has a different set of challenges - but most importantly, for Elon, it's aiming too low (literally and figuratively). The moon also is not as well suited to long-term survival of a self-sustaining colony and cannot be terraformed the way Mars can. So the proof-of-concept idea really would be proving we can build greenhouses on the Moon, but it's not the same.

That all said, if it gets cheap enough under SpaceX's leadership to toss stuff up into space, I am sure people will want to do cool things with the moon, too!

1 • Reply • Share ›

IamGrimalkin ↗ David Sabo • a year ago

What do you mean that the moon can't be terraformed the way mars can? If you mean adding a breathable atmosphere that won't set on fire, the moon has a smaller surface area than mars so will probably need less buffer gas, and if you are launching it as nitrogen from earth you won't need as much delta-v to get it there. So in some sense it might be easier.

Reply • Share ›

Deven Kale ↗ IamGrimalkin • a year ago

The moon is too small. It's gravity isn't strong enough to support an atmosphere thick enough or dense enough to be breathable by humans.

Reply • Share ›

IamGrimalkin ↗ Deven Kale • a year ago

Yes it is. The atmosphere would eventually be lost to space without a magnetosphere, of course, but it isn't that much lighter than Titan, and that has an atmosphere thicker than the Earths.

Reply • Share ›

Deven Kale ↗ IamGrimalkin • a year ago

The mass of the moon is 54.63% of the mass of Titan. That's similar to saying $546,000 isn't that much less than $1,000,000. It's a huge difference.

The atmosphere on Titan is as dense as it is because of what that atmosphere is made of. In fact, Titan's atmosphere is not only thicker than Earth's it's also denser at 1.5 bars even though Titan is far less massive. Although this could partially be explained by being protected by Saturn and having a weaker Solar Wind as well.

Your question was about having an Earth-like atmosphere though, and I'm no physicist so I can't do the calculations myself but I trust the experts I've read/heard who say that you can't get a sustainable Earth-like atmosphere on the moon more than a dozen or so feet thick, and it would be nowhere near dense enough to be breathable.

Reply • Share ›

IamGrimalkin ↗ Deven Kale • a year ago

Just run the numbers and it turns out you're right, the moon can't have an atmosphere even for relatively short periods. You're right, Titan's higher mass can make a difference when you have an edge case like the moon, as can its higher density and lower temperature.

Reply • Share ›

IamGrimalkin ↗ Deven Kale • a year ago

Yes, you can't get a sustainable atmosphere on the moon. You can't get a sustainable atmosphere on Mars, either. The point is, it can take long enough to leak out for you to live there in the meantime, and you can help hold it there with an artificial magnetic field.

Reply • Share ›

Dan Apted ↗ David Sabo • 2 years ago

I understand his desire and share it, but he(read we) need to pay for it and we need people to be prepared for the trip and the stay. By putting up the aforementioned first steps we have the funding for the other steps. A LEO vacation or stunt or lark is far fetched as is a honeymoon on the moon. But I can rationalize how some people might be able to pay for it if the SpaceX re-usability model becomes reality. Furthermore I can envision how Hilton, or Amazon, or Trump might even fund a hotel or at least a bed and breakfast in LEO or even on the Moon. The profits from it and the taxi service to get you there are literally sky high. If they are as big as I can imagine then so is a convention center in LEO or at L1 or L2. With enough demand then we must mine asteroids or other objects to harvest the least expensive building materials if you want to attract the most visitors. That gets us the materials to go to LMO and with that distance orbiting farms and more harvesting of materials from asteroids. Then there is the money, the infrastructure and the people trained to work and live in space to actually invade Mars. You can't go to Mars and sustain a colony without knowledge and money. The first steps get us there. Attempting to skip those steps is attractive folly.

Reply • Share ›

ameba#23234 MdR • 2 years ago

I noticed a mistake or just can't find any source on that venus has any oxygen in upper or lower atmosphere.

" Randomly, at the top of Venus's clouds is a layer where the temperature and pressure are similar to those on Earth, and because oxygen and nitrogen both rise in Venus's dense atmosphere (like helium does on Earth), the air in that layer might actually be close to breathable."

Reply • Share ›

jmac ameba#23234 MdR • 2 years ago

Try this:

http://onlinelibrary.wiley....

Reply • Share ›

Mario • 2 years ago

"In the last few thousand years, humans invented the concept of being “inside,” and now almost all people think of home as somewhere indoors—maybe in the future, a giant, artificial space habitat that has mountains and rivers and trees and millions of people will be the equivalent of the invention of “inside” as it applies to an entire world" That was beautiful! I just started singing "imagine" in my head

Reply • Share ›

Hendu71 • 2 years ago

I wonder which one is technically most difficult: "Fixing" climate change, building a colony on mars, or building a Star-Wars-like floating "Cloud City" on Venus?

Reply • Share ›

Michael Pang Hendu71 • a year ago

IMO they're easiest to hardest in the order you gave, but the first two mostly depend on peoples' collective will.

Reply • Share ›

Nobody • 2 years ago

Anybody knows what the hell did just happen at Florida? Or more like, what will it cause?

Reply • Share ›

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Nadeem Adnan

The possibility depends is to enable individuals from different lands in the world to be the primary candidates to the another wave of people that will be selected to go to Mars. As reported by http://www.theboringstate.com. Even people from a nation such as Egypt, Pakistan, Saudi Arabia, have heavily shown affair and they really like to go The Red Planet. A very interesting text can be read here :
http://www.theboringstate.com/.../hello-houston-problem...

Like · Reply · 1 · 43w

Caleb Mayo

thanks for this and for rocking out in general. in case you go around updating things, the radiation shield idea seems real enough now to merit a mention under blue-green mars. many smarties note, given the missing martian magnetosphere, that cosmic and solar radiation will slowly strip away whatever atmosphere we whip up, so it seems there's some place in the convo for a note about making that evap not happen. NASA image here includes fun words magnetosheath, magnetotail and magnetopause:
https://www.popularmechanics.com/.../magnetic-shield.../

as exciting: looks like by blocking radiation we can probably start some of that sweet, sweet melting. seems relevant and likely. apologies if you already heard this stuff and thought about putting it in the piece and i'm now just one more voice telling you to spend time on something other than whatever should be your main project right now kinda like how i'm out here posting on a comment section instead of generating content oh dear god--

Like · Reply · 12w

Michelle Oblack Smith

great news say no to small penis i introduce you to DR SANTY JATTO herbal mixture cream …DR SANTY JATTO penis enlargement herbal cream and herbal remedies in Africa.This is the only Male Penis Enlargement Cream has been used by men around the world supplement that has been PROVEN to-enlarge your penis – safely, quickly, and importantly – PERMANENTLY.Full SANTY JATTO Penis Enlargement Cream when used will Increase in penis length by 1-10 inches Increase in penis width by 20%helps in preventing Premature Ejaculation.Achieved longer, rock hard erections All gains in penis length and width are 1... See More

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Mohammed Saud

How small is your penis exactly? I need to know... for research purposes only

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