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Elon Musk: *Making Humans a Multi-Planetary Species*

SpaceX CEO and Lead Designer Elon Musk will provide an update to his technical presentation from IAC 2016 regarding the long-term technical challenges that need to be solved to support the creation of a permanent, self-sustaining human presence on Mars.'

Moderator: Jean-Yves Le Gall, President, International Astronautical Federation (IAF), France

Speaker: Elon Musk, CEO and Founder, SpaceX, United States

Jean-Yves Le Gall:

[00:00] It's a pleasure for me as president of the International Astronautical Federation to welcome all you today to the concluding session of the global networking forum for this IAC 2017, which has been a huge success . In particular, I wanted to thank Premier Weatherill, Minister Hamilton-Smith, and Lord Mayor Haese for their support and presence.

[00:25] Now let me please introduce our distinguished speaker for today. Elon Musk is founder, CEO, and Lead Designer of SpaceX. Elon founded SpaceX in 2002 with the goal of revolutionizing space technology and ultimately enabling humans to become a multi-planetary species. Today he will provide an update on those plans first shared at IAC 2016 in Guadalajara last year.

[01:00] SpaceX has had a number of firsts including the first private company to deliver cargo to and from the International Space Station, the first entity to land an orbital class booster back on land and on drone ships out at sea, and the first to refly an orbital class booster. In addition to SpaceX, he's also the CEO of Tesla Motors and Chairman of Solar City.

[01:25] Please join me in welcoming Elon Musk.

[Applause]

Elon Musk:

[Slide: Becoming a multi-planet species]

[01:45] All right. Welcome everyone. I'm going to talk more about what it takes to become multi-planet species. And just a brief refresher on why this is important. I think fundamentally the future is vastly more exciting and interesting if we're a spacefaring civilization and a multi-planet species than if we're or not. You want to be inspired by things. You want to wake up in the morning and think the future is going to be great. And that's what what being a spacefaring civilization is all about. It's about believing in the future and thinking that the future will be better than the past. And I can't think of anything more exciting than going out there and being among the stars. That's why.

[02:28] Let me into more detail about becoming a multi-planet species. This is the updated design for the, well we're sort of searching for the right name, but the code name at least is BFR. Probably the most important thing that I want to convey in this presentation is that I think we have figured out how to pay for it. This is very important. In last year's presentation, we were really searching for what the right way, you know, how do we pay for this thing. We went through various ideas, with Kickstarter, you know, collecting underpants. These didn't pan out. But now we think we've got a way to do it, which is to have to have a smaller vehicle -- still pretty big -- but one that can serve, one that can do everything that's needed in the greater Earth orbit activity. So essentially we want to make our current vehicles redundant. We want to have one system, one booster and ship that replaces Falcon 9, Falcon Heavy, and Dragon. So if we can do that, then all the resources that are used for Falcon 9, Heavy, and Dragon can be applied to this system. So that that's really fundamental. So let's see. What progress have we made in this direction?

[Slide: Progress]

[Slide: Deep Cryo Liquid Oxygen Tank Testing: Pressure tested to 2.3 atmospheres. New carbon fiber matrix. Volume 1000 m^3. Holds 1200 tons of liquid oxygen.]

[04:27] So last time you saw the giant tank. That's actually a 12 meter tank and you can see the relative scale of it. It's a thousand cubic meters of volume inside. That's actually more pressurized volume than an A380, just to put that into perspective. We developed a new carbon fiber matrix that's much stronger and more capable at cryo than anything before. And it holds 1200 tons of liquid oxygen.

[Video: Tank on barge, rupturing at bottom and starting to launch upward while spewing LOX]

[04:58] So we tested it. So we successfully tested it up to its design pressure, and then went a little further. [Laughter] So we wanted to see where it would break and we found out where it would break. It shot about 300 feet into the air and landed in the ocean. We fished it out. But now we got a pretty good sense of what it takes to create a huge carbon fiber tank that can hold cryogenic liquid. That's actually extremely important for making a light spaceship.

[Video: Engine Testing: Over 1200 seconds of firing across 42 main engine tests. Longest test 100 seconds. 40 seconds typical for Mars landing. Test engine operates at up to 200 atmospheres.]

[05:39] Then the next key element is on the engine side. We have to have an extremely efficient engine. So the the Raptor engine will be the highest thrust-to-weight engine, we believe, of any engine of any kind ever made. We already have now 1200 seconds of firing across 42 main engine tests. We've fired it for 100 seconds. It could fire for much longer than a hundred seconds. That's just the size of the test tanks. And then the duration of the firing you've seen right now is about 40 seconds, which is the length of the firing for landing on Mars. The test engine currently operates at 200 atmospheres, 200 bar, the flight engine will be at 250 bar, and then we believe over time we could probably get that to a little over 300 bar.

[Video loop: Perfecting Propulsive Landing; (several successful landing shown, both ASDS and RTLS)]

[06:37] The next key element is propulsive landing. So in order to land on a place like the moon where there is no atmosphere and certainly no runways, or to land on Mars where the atmosphere is too thin to land, even if there were runways, to land with with the wing, you really have to get propulsive landing perfect. So that's what we've been practicing with Falcon 9. So this is just a series of landing but I think these are quite mesmerizing. But we now have 16 successful landings in a row and that's with ... [Applause] So it's sixteen in a row, and that's really without any redundancy. So Falcon nine lands on a single-engine, and that the final landing is always done with with a single engine whereas the with BFR we will always have multi-engine out capability. So if you can get to a very high reliability with even a single engine, and then you can land with either of two engines, I think we can get to a landing reliability that is on par with the safest commercial airliners. So you can essentially count on the landing. It's not like the ... You want minimum pucker factor on landing. And it can land with also very high precision. In fact we believe the precision at this point is good enough for propulsive landing that we do not need legs for the next version. It will literally land with so much precision it will land back on its launch mounts.

[Slide: Launch Rate: 2012: 2. 2013: 3. 2014: 6. 2015: 7. 2016: 8. 2017: 13 7 (remaining) = 20. 2018: 30]

[08:40] The launch rate is increasing exponentially. Particularly when you take tanking or refilling on orbit into account, and taking the idea of establishing a self-sustaining base on Mars or the moon or elsewhere seriously, you need ultimately thousands of ships and tens of thousands of retanking or refilling operations, which means you need many launches per day. In terms of how many landings are occurring, you need to be looking at your watch, not your calendar. So while this is a quite a high launch rate that we're talking about here, by conventional standards, it's still a very small launch rate compared to what will ultimately be needed. But just for those who are unfamiliar with how many orbital launches occur every year, it's approximately 60 orbital launches occur per year. Which means if SpaceX does do something like 30 launches next year, it'll be approximately half of all orbital launches that occur on Earth.

[Slide: (Photo of Dragon cargo capsule berthed to ISS, with Canadarm2 attached.)]

[09:57] The next thing, a key technology, is automated rendezvous and docking. So in order to retank or refill the spaceship in orbit, you have to be able to rendezvous and dock with the spaceship with very high precision and and transfer propellant. So that's one of things that we've perfected with Dragon. Dragon 1 will do an automated rendezvous and docking, without any pilot control, to the Space Station. Dragon 1 currently uses the Canadarm2 for the final placement onto the Space Station. Dragon 2, which launches next year, will not need to use the Canadarm. So Dragon 2 will directly dock with the Space Station, and it can do so with zero human intervention. You just press 'go' and it will dock. Dragon has also allowed us to perfect heat shield technology. So when you enter at a high velocity, you'll melt almost anything. The reason meteors don't reach Earth is they melt or disintegrate before they reach the ground, unless they're very big. So you have to have a sophisticated heat shield technology that can withstand unbelievably high temperatures and that's what we've been perfecting with Dragon, and also a key part of any planet colonizing system.

[Slide: Graph: Falcon 1: 21.3 m tall, 1.7 m dia. Payload Mass in Tons: < 1. Expendable]

[11:37] So Falcon 1. This is where we started out. A lot of people really only heard of SpaceX relatively recently, so they may think, say Falcon 9 and Dragon just instantly appeared and that's how it always was. But it wasn't. We start off with just a few people who really didn't know how to make rockets. And the reason that I ended up being the chief engineer or chief designer, was not because I want to, it's because I couldn't hire anyone. Nobody good would join. So I ended up being that by default. And I messed up the first three launches. The first three launches failed. Fortunately the fourth launch which was -- that was the last money that we had for Falcon 1 -- the fourth launch worked, or that would have been it for SpaceX. But fate liked us that day. So the fourth launch worked. And it's interesting -- today is the ninth anniversary of that launch. [Applause] I didn't realize that until I was told that just earlier today. [Laughter] This is a very emotional day, actually. But Falcon 1 was quite a small rocket. When we were doing Falcon 1 we were really trying to figure out what is the smallest useful payload that we'd get to orbit. We thought okay, something around half a ton to orbit, you know that could launch a decent sized small satellite to low earth orbit. And that's why we sized Falcon one. But it's it's really quite small compared to Falcon 9.

[Slide: Extends graph: Falcon 9: 70 m tall, 3.7 m dia. Payload Mass in Tons: ~16. Partial reuse]

[13:43] So Falcon 9, particularly when you factor in payload, Falcon 9 is many times more, sort of on the order of 30 times more payload than Falcon 1. And Falcon 9 has reuse of the primary booster, which is the most expensive part of the rocket, and hopefully soon reuse of the of the fairing, the big nose cone at the front. So we think can probably get to something like somewhere between 70 and 80% reusability with the Falcon 9 system. And hopefully towards the end this year we'll be launching Falcon Heavy. Falcon Heavy ended up being a much more complex program than we thought. It sounds easy.

[Slide: Extends graph: Falcon Heavy: 70 m tall, 12 m wide. Payload Mass in Tons: ~30. Partial reuse]

[14:39] It sounds like it should be should be easy because it's two first stages of Falcon 9's strapped on as boosters. It's actually not. We have to redesign almost everything except the upper stage in order to take be increased loads. So Falcon Heavy ended up being much more a new vehicle then we realized, so took us a lot longer to get it done. But the the boosters have all now been tested and they're on their way to Cape Canaveral. And we are now beginning serious development of BFR.

[Slide: Extends graph: BFR: 106 m tall, 9 m dia. Payload mass in tons: ~150. Full reuse]

[15:27] So you can see that the payload difference is quite dramatic. BFR in fully reusable configuration, without any orbital refueling, we expect to have a payload capability of 150 tons to low Earth orbit. And that, you know, compares to about 30 for Falcon Heavy, which is partial reusable. Where this really makes a tremendous difference is in the cost, which I'll comes to in some of the later slides. So let's go to the next slide.

[Slide: Graph: Payload Mass in Tons (Expendable): F1: < 1; F9: ~22; FH: ~63; BFR: 250]

[16:13] And just, by the way, if.

[Slide: BRF: 31 Raptor engines produce liftoff thrust of 5400 tons, lifting total vehicle mass of 4400 tons]

[16:18] So with BFR, you can get a sense of scale by looking at the tiny person there. It's really quite a big vehicle. Main body diameter is about is about 9 meters or 30 feet, and it consists of, the booster is lifted by thirty one Raptor engines that produce a thrust about 5,400 tons, lifting a 4,400 ton vehicle straight up.

[Slide: BFR Spaceship: Ship Length: 48 m. Body Diameter: 9m. Ship Dry Mass: 85 t. Propellant Mass: 1,100 t. Max Ascent Payload: 150 t. Typical Return Payload: 50 t.]

[16:59] So then, just the basics about the ship. 48 meter length. Dry mass are expecting to be about 85 tons. Technically, our design says 75 tons, but inevitably there's mass growth. And that ship will contain 1,100 tons propellant with an ascent design of 150 tons and return mass of 50. So you can think of this as essentially combining the upper stage of the rocket with Dragon. It's like if Falcon 9 upper stage and Dragon were combined.

[Slide: BFR Spaceship: Engines / Delta Wing / Propellant Tanks / Payload]

[17:38] I'll go into each of these items in detail. You've got the engine section in the rear, the propellant tanks in the middle, and then a large payload bay in the front. And that payload bay is actually eight stories tall. In fact, you can fit a whole stack of Falcon 1 rockets in the payload bay. [Laughter] Compared to the design I showed last time, you'll see that there is a small delta wing at the back of the rocket. The reason for that is in order to expand the mission envelope of the BFR spaceship. Depending on whether you're landing or you're entering a planet or a moon that has no atmosphere, a thin atmosphere, or a dense atmosphere, and depending on whether you're reentering with no payload in the front, a small payload, or a heavy payload, you have to balance the rocket out as it's coming in. And so the delta wing at the back, which also includes a split flap for pitch and roll control, allows us to control the pitch angle despite having a wide range of payloads in the nose and a wide range of atmospheric densities. So we tried to avoid having the delta wing, but it was necessary in order to generalize the capability of the spaceship such that it could land anywhere in the solar system.

[Slide: Nose of BFR Spaceship: Pressurized Volume: 825 m^3, Greater than an A380 cabin. Mars Transit Configuration: 40 cabins and large common areas. Central storage, galley, and solar storm shelter]

[19:26] Let's look at a couple of things in detail. So the cargo area has a pressurized volume of 825 cubic meters. This also is greater than the pressurized area of an A380. So, really is capable of carrying a tremendous amount of payload. In a mass transit configuration, since you'd be taking three months in a really good scenario, but maybe as much as six months, some number of months, a singlege[?] of months, you probably want a cabin, not just a seat. So the Mars transit configuration consists of 40 cabins. You could conceivably have five or six people per cabin if you really wanted to crowd people in, but I think mostly we would expect to see two to three people per cabin, and so normally about a hundred people per flight to Mars. And then there's a central storage area and galley and a solar storm shelter, entertainment area, and I think probably a good situation for at least BFR version one.

[Slide: Tankage of BFR Spaceship: Fuel Tank: Holds 240 tons of CH4. Common Dome: Separates CH4 and O2. Oxygen Tank: Holds 860 tons of liquid O2. Header Tanks: Holds landing propellant during transit]

[20:50] Then going to the main body of the vehicle, the center body area. This is where the propellant is located. And this is sub-cooled methane and oxygen. So as you chill the methane and oxygen below its liquid point you get a fairly meaningful density increase. You get on the order of ten to twelve percent density increase, which makes quite a big difference for the propellant load. So we expect to carry 240 tons of CH4 and 860 tons of oxygen. In the fuel tank our header tanks. So when you come in for landing, your orientation may change quite significantly, but you can't have the propellant just sloshing around all over in the main tanks, you have to have the header tanks that can feed the main engines with precision. So that's what you see immersed in the fuel tank.

[Slide: BFR Spaceship aft view: Raptor Engines: Chamber pressure 250 bar. Throttle 20% to 100% thrust. 2 Sea-Level Engines: Exit Diameter 1.3 m. Thrust (SL) 1,700 kN, Isp (SL) 330 s, Isp (Vac) 356 s. 4 Vacuum Engines: Exit Diameter 2.4 m, Thrust 1,900 kN, Isp 375 s.]

[22:04] Then the engine section. The ship engine section consists of four vacuum Raptor engines and two sea-level engines. All six engines are capable of gimbaling. The engines with the high expansion ratio have a relatively smaller gimbal area or gimbal range and slower gimbal rate. The two center engines have a very high gimbal range and can gimbal very quickly. And you can land the ship with either one of the two center engines. So when you come in for a landing you will light both engines, but if one of the center engines fails at any point it will be able to land successfully with the other engine. And then within each engine there is a great deal of redundancy. So we want the landing risk to be as close to zero as possible. And there are some basic stats about the engines. The sea-level engines are about a 330 Isp at sea-level. The upper stage engine is 375. You know, this is version 1, so I think over time there's potential to increase that specific impulse by 5 to 10 seconds, and as I was mentioning, also increase the chamber pressure by 50 bar or so.

[Slide: Refilling: Propellant settled by milli-g acceleration using control thrusters]

[23:46] And then for refilling, which you just saw, the two ships would actually mate at the rear section. They would use the same mating interface that they used to connect to the booster on liftoff. So we would reuse that mating interface and reuse the propellant fill lines that are used when the ship is on the booster. And then to transfer propellant, it becomes very simple. Use control thrusters to accelerate in the direction that you want to empty. So if you accelerate in this direction, propellant goes that way, and you transfer the propellant very easily from the tanker to the ship.

[Slide: Rocket Capability: Payload to Low Earth Orbit in Tons: Falcon 1: 0.7; India GSLV: 5.0; Antares: 7.0; Soyuz 2-1B: 8.2; Atlas V 551: 18.8; Japan H-IIB: 19; Ariane 5: 20; Proton M/Breeze M: 22; Falcon 9: 22.8; China LM-5: 23; Delta IV Heavy: 28.3; Falcon Heavy: 54.4; Saturn V: 135; BFR: 150]

[24:31] So going to rocket capability. This gives you sort of a rough sense of rocket capability, starting off at the low end with the Falcon 1 at a half-ton, and then going up to BFR at 150. So I think it's important note that BFR has more capability than Saturn V, even with full reusability. But here's the really important, fundamental point. Let's look at the launch cost.

[Slide: Marginal Cost Per Launch Accounting for Reusability: Ordered $ to $$$: BFR; Falcon 1; Falcon 9; Falcon Heavy; India GSLV; Antares; Soyuz 2-1B; China LM-5; Proton M/Breeze M; Japan H-IIB; Ariane 5; Atlas V 551; Delta IV Heavy; Saturn V]

[25:11] The order of reverses.

[Applause]

[25:24] I know at first glance this may seem ridiculous. But it's not. The same is true of aircraft. If you bought, say, a small, single-engine turboprop aircraft, that would be one and a half to two million dollars. To charter a 747 from California to Australia is half a million dollars, there and back. The single-engine turboprop can't even get to Australia. So a fully reusable giant aircraft like the 747 costs a third as much as an expendable tiny aircraft. In one case you have to build an entire aircraft, in the other case you just have to refuel something. So it's really crazy that we build these sophisticated rockets and then crash them every time we fly. This is mad. So yeah, I can't emphasize how profound this is and how important reusability is. And often I'll be told, 'but you could get more payload if you made it expendable.' I said yes, you could also get more payload from an aircraft if you got rid of the landing gear and the flaps and just parachute out when you got to your destination. [Laughter] But that would be crazy and you would sell zero aircraft. So reusability is absolutely fundamental.

[Slide: Value of Refilling: Single Launch Capability From Earth Orbit: Booster accelerates ship & returns to launch site. Ship flies into Earth orbit. Graph: Delta-V Beyond LEO (km/s) as a function of Total Payload Mass (t): approx 0 t, 3.2 km/s; 25 t, 2.4 km/s; 50 t, 1.8 km/s; 75 t, 1.3 km/s; 100 t, 0.8 km/s; 125 t, 0.4 km/s; 150 t, 0 km/s]

[27:04] Now I want to talk about the value of orbital refilling. This is also extremely important. So if you're just fly BFR to orbit and don't do any refilling, it's pretty good. You'll get a hundred and fifty tons to low Earth orbit, and have no fuel to go anywhere else.

[Slide: Value of Refilling: One Tanker: 1 Tanker refills ship and returns to Earth. Graph: Delta-V Beyond LEO (km/s) as a function of Total Payload Mass (t): approx 0 t, 5.3 km/s; 25 t, 4.5 km/s; 50 t, 3.8 km/s; 75 t, 3.2 km/s; 100 t, 2.7 km/s; 125 t, 2.3 km/s; 150 t, 1.9 km/s; 175 t, 1.5 km/s; 200 t, 1.2 km/s]

[Slide: Value of Refilling: Two Tankers: 2 tankers refill ship & return to Earth. Graph: Delta-V Beyond LEO (km/s) as a function of Total Payload Mass (t): approx 0 t, 6.5 km/s; 25 t, 5.7 km/s; 50 t, 5.0 km/s; 75 t, 4.4 km/s; 100 t, 3.9 km/s; 125 t, 3.4 km/s; 150 t, 3.1 km/s; 175 t, 2.7 km/s; 200 t, 2.5 km/s]

[Slide: Value of Refilling: Full Tanks: Tankers fully fill ship & return to Earth. (Five tankers shown.) Graph: Delta-V Beyond LEO (km/s) as a function of Total Payload Mass (t): approx 0 t, 9.2 km/s; 25 t, 8.4 km/s; 50 t, 7.8 km/s; 75 t , 7.3 km/s; 100 t, 6.8 km/s; 125 t, 6.4 km/s; 150 t, 6.1 km/s; 175 t, 5.8 km/s; 200 t, 5.6 km/s]

[27:27] However, if you send up tankers and refill in orbit, you can refill the tanks all the way to the top and get 150 tons all the way to Mars. And if the tanker has high reuse capability, then you're just paying for the cost of propellant. And the cost of oxygen is extremely low. And the cost of methane is extremely low. So if that's all you're dealing with, the cost of refilling your spaceship on orbit is tiny and you can get 150 tons all the way to Mars. So automated rendezvous and docking and refilling, absolutely fundamental.

[Slide: Satellites / ISS / Moon / Mars]

[28:20] So then getting back to the question of how do we pay for this system. This was really, I said quite a profound -- I won't call it breakthrough but realization -- that if we can build a system that cannibalizes our own products, makes our own products redundant, then all of the resources, which are quite enormous, that are used for Falcon 9, Heavy, and Dragon, can be applied to one system. Some of our customers are conservative and they want to see BFR fly several times before they're comfortable launching on it, so what we plan to do is to build ahead and have a stock of Falcon 9 and Dragon vehicles so that customers can be comfortable. If they want to use the old rocket, the old spacecraft, they can do that, because we'll have a bunch in stock, but all of our resources will then turn towards building BFR, and we believe that we can do this with the revenue we receive for launching satellites and for servicing the Space Station.

[Slide: Satellites]

[Slide: (BFR payload ship launching large satellite from payload bay.)]

[29:42] So going to the satellites portion. The size of this being a 9 meter diameter vehicle is a huge enabler for new satellites. We can actually send something that is almost nine meters in diameter to orbit. So for example, if you want to do a new Hubble, you could send a mirror that has ten times the surface area of the current Hubble, as a single unit. Doesn't have to unfold or anything. Or you can send a large number of small satellites. You do whatever you like. You can actually also go around and, if you wanted to, collect old satellites or clean up space debris. You can just use the sort of chopper over there and go around and collect satellites or collect space degree if you want. So that may be something we have to do in the future. But that fairing would open up and retract and then come back down, so it enables launching of Earth satellites that are significantly larger than anything we've done before or significant more satellites at a time than anything that's been done before.

[Slide: International Space Station]

[Slide: (BFR passenger ship docked at ISS.)]

[31:04] It's also intended to be able to service the Space Station. [Laughter] I know it looks a little big relative to the Space Station, but the shuttle also looked big, so it'll work. Looks a little out size but it'll work. So it'll be capable of doing what Dragon does today in terms of transporting cargo and what Dragon 2 will do it in terms of transporting crew and cargo. So good at Space Station servicing. It can also go out to much further than that, like, for example, the Moon.

[Slide: Moon]

[Slide: Lunar Surface Missions: Elliptic Orbit Prop Transfer; Trans-Lunar Injection; Ship Lands on Moon with sufficient propellant to return directly to Earth]

[31:54] Based on calculations we've done we can actually do lunar surface missions with no propellant production on the surface of the Moon. So if we do a high elliptic parking orbit for for the ship and retank in high elliptic orbit, we can go all the way to the moon and back with no local propellant reduction on the moon. So I think that would enable the creation of Moon Bse Alpha, or some sort of lunar base. [Applause] Yeah, it's quite captivating.

[32:43] You can also see, for example, how do you transfer cargo from the cargo bay down to the ground is a crane, it's not very complicated. But this will enable the creation of a lunar base. It's 2017. I mean, we should have a lunar base by now. What the hell's going on.

[Laughter, Applause]

[Slide: Mars]

[Slide: BFR passenger ship landing on empty Martian plane.]

[33:16] And then, of course, Mars. Becoming a multi-planet species. Beats the hell about of being a single plant species. So we'd start off by sending a mission to Mars where it would be, obviously, just landing on rocky ground or dusty ground.

[Slide: Mars Transportation Architecture: Earth: Booster accelerates ship/tanker & returns to launch site; Ship flies into Earth orbit; Tankers refill ship & return to Earth; CH4 & O2. Mars: Refilled ship travels to Mars. Ship refilled on Mars using local resources. H2O & CO2 -> Power / ISRU -> CH4 & O2; Ship performs Mars ascent & direct return to Earth]

[33:40] And it's the same approach that I mentioned before, which is you send the spaceship up to orbit, you retank it or refill it until it has full tanks, and it travels to Mars, lands on Mars. For Mars you will need local propellant production. But Mars has a Co2 atmosphere and plenty of water ice. That gives you CO2 and H2O, so you can make, therefore, CH4 and O2 using the Sabatier Process and or, probably the Sabatier Process.

[34:15] And I should mention that, long term, this can also be done on Earth. So sometimes I get some sort of criticism for why are you using combustion and rockets and you have electric cars. Well there isn't some way to make an electric rocket. I wish there was. But in the long term you can use solar power to extract CO2 from the atmosphere, combine it with water, and produce fuel and oxygen for the rocket. So the same thing that we're doing Mars, we could do on Earth in the long-term.

[34:51] But that's essentially what happens. Similar to the moon, you land on Mars, but the tricky thing with Mars is we do need to build a propellant Depot to refill the tanks and return to Earth. But because Mars has lower gravity than Earth, you do not need a booster. So you can go all the way from the surface of Mars to the surface of Earth just using the ship. Albeit, you need to go to a max payload number of about twenty to fifty tons for the return journey to work. But it's a single stage all the way back to Earth.

[Slide: Mars Entry: 15X Real Time: Hyperbolic entry at up to 7.k km/s. Leverages ablative heat shield materials developed for Dragon vehicles. Peak acceleration of 5 g's (Earth referenced). Graph of Altitude (km) plotted against Velocity (m/s): 60 km @ 7500 m/s; 40 km @ 7000 m/s; 35 km @ 5500 m/s; 5 km @ 1800 m/s; back up to 10 km @ ~800 m/s; 3 km @ 600 m/s; 0 m/s @ 0 km.]

[35:30] So this is the true physics simulation. This will last about a minute. So you come in, you're entering very quickly, going seven and a half kilometers a second. For Mars, there will be some ablation of the heat shield. So it's just like a sort of brake pad wearing away. It is a multi-use heat shield, but unlike for Earth operations, it's coming in hot enough that you really will see some wear of the heat shield.

[Slide: Mars Entry: Real Time: Over 99% of energy removed aerodynamically, Supersonic retro-propulsion for landing burn. Graph of Altitude (km) plotted against Mach: 5 km @ Mach 2.5; 2.5 km @ Mach 2.4; 0.7 km @ Mach 0.5; 0 km @ Mach 0.]

[36:05] But because Mars has an atmosphere, albeit not a particularly dense, one you can remove almost all the energy aerodynamically. And we've proven out supersonic retropropulsion many times with Falcon 9, so we feel very comfortable about that. You can see a sort of mesh system -- it's not meant to be particularly pretty because it just tries to simulate the physics of it -- but the size of the cone gives you a rough approximation for how much thrust the entrance are producing.

[Slide: Initial Mars Mission Goals: 2022: Cargo Missions: Land at least 2 cargo ships on Mars. Confirm water resources and identify hazards. Place power, mining, and life support infrastructure for future flights.]

[36:56] That's not a typo. [Laughter] Although it is aspirational. [Laughter] So we've already started building the system. The tooling for the main tanks has been ordered, the facility is being built, we will start construction the first ship around the second quarter of next year. So in about six to nine months we should start building the first ship. I feel fairly confident that we can complete the ship and be ready for a launch in about five years. Five years seems like a long time to me. [Applause] The area under the curve of resources over that period of time should enable this time frame to be met, but if not this time frame, I think pretty soon thereafter. But that's our goal, is to try to make the 2022 Mars rendezvous. The Earth-Mars synchronization happens roughly every two years, so every two years there's an opportunity for just to fly to Mars.

[Slide: 2024: Cargo and Crew Missions: 2 crew ships take first people to Mars. 2 cargo ships bring more equipment and supplies. Set up propellant production plant. Build up base to prepare for expansion.]

[38:26] So then in 2024 we want to try to fly four ships. Two cargo and two crew. The goal of these initial missions is to find the best source of water, that's for the first mission, and then the second mission, the goal is to build the propellant plant. So we should, particular with six ships there, have plenty of landed mass to construct the propellant depot, which will consist of a large array of solar panels, a very large array, and then everything necessary to mine and refine water, and then draw the CO_2 out of the atmosphere, and then create and store deep-cryo CH_4 and O_2.

[Slides: Base buildup: (A sequence of five slides showing an overhead view of the base growing into a large city.)]

[39:19] Then build up the base, starting with one ship, then multiple ships, then start building out the city, then making the city bigger, and even bigger. [Laughter; Applause] And yeah, over time terraforming and making it really a nice place to be.

[Slide: (A close in view of several landed ships, several habitation domes, a large greenhouse dome, solar power field.)]

[39:56] [Shout from audience member, 'You can do it, Elon!'.] Thanks. [Cheers and applause] It's quite a beautiful picture. And on the prior slide, seriously note that on Mars dawn and dusk are blue. The sky is blue at dawn and dusk and red during the day. It's the opposite of Earth.

[Slide: (View of Earth from orbit showing clouds and ocean.)]

[40:24] But there's something else. If you build a ship that's capable of going to Mars, what if you take that same ship and go from one place to another on Earth? So we looked at that and the results are quite interesting. Let's take a look at that.

[Video: BFR: Earth to Earth]

[41:58] We're traveling at 27,000 kilometers an hour, or roughly 18,000 miles an hour. This is where the propulsive landing becomes very important, to be [unintelligible] get it right. [Applause] So most of what people consider to be long-distance trips would be completed in less than half an hour which is ... . [Applause] So the great thing about going to space is there's no friction, so once you're out of the atmosphere, it will be smooth as silk. No turbulence nothing. There's no weather. There's no atmosphere. And you can get to most long-distance places, like I said, in less than half an hour. And if we're building this thing to go to the Moon and Mars, then why not go to other places on Earth as well.

[43:20] All right. Thank you.

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