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Trends in Space

New Space Economy

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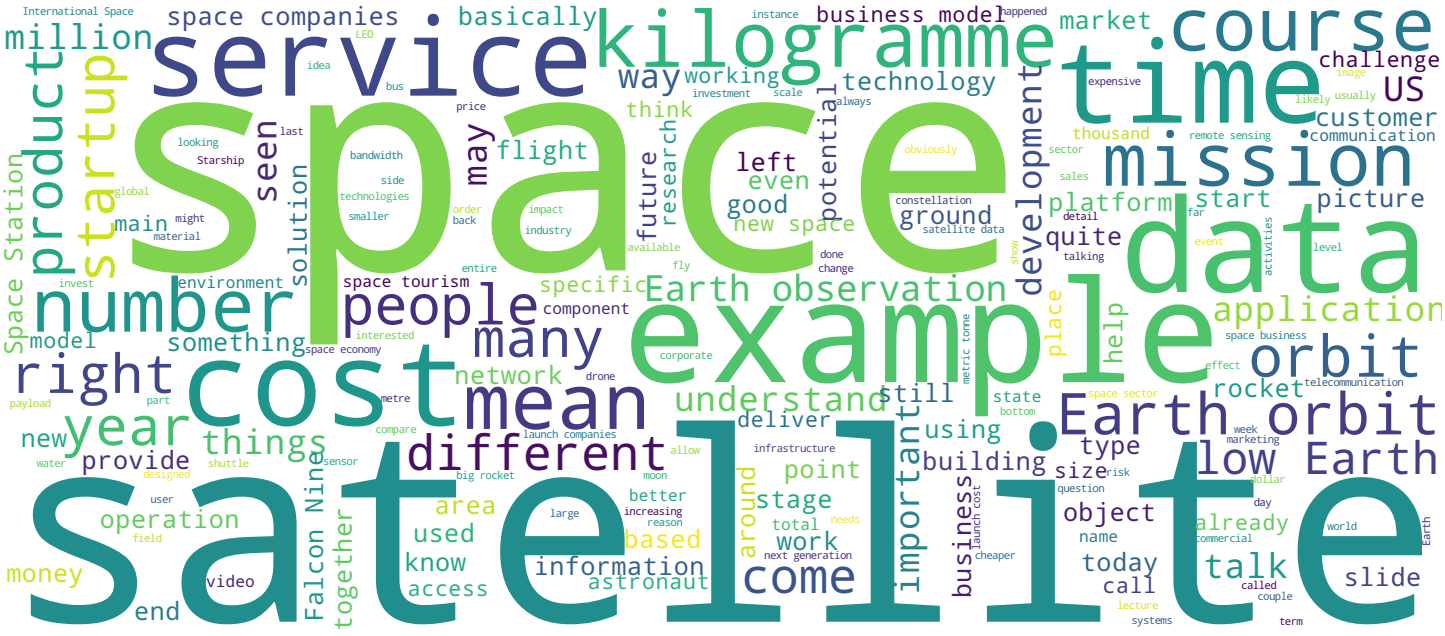


Search MOOC

Video

EPFL

Welcome

Video: SpaceX

Welcome back, everyone.

Notes

Summary

0m 05s

Welcome

Video: SpaceX

After Professor Nicollie giving you the exciting history of spaceflight to date, it is now time to look at some of the key current trends, as those will likely define the future of spaceflight.

Notes

Summary

0m 06s

Welcome

Video: SpaceX

I'm sure many, if not most of you, have seen this video on my side. It is, of course, SpaceX's next generation vehicle, the Starship. Specifically, this is prototype SN10 making a high altitude test flight. You can see its Raptor engines already shut off, and it is now going into controlled, unpowered descent, what they call the belly flop. This has been thought about in the past, but it had never been done before successfully. Now, the Starship is designed to be fully reusable.

Notes

Summary

0m 17s

Welcome

Video: SpaceX

For orbital flights, starship is actually the second stage.

Notes

Summary

0m 50s

Welcome

Video: SpaceX

The first stage, a giant booster called Super Heavy, is also designed to land, meaning the entire system is reusable.

Notes

Summary

0m 55s

Welcome

Video: SpaceX

Now, what does reusability mean? It means you no longer throw away equipment costing at least tens of millions and maybe hundreds of millions of dollars after just one use.

Notes

Summary

1m 02s

Welcome

Video: SpaceX

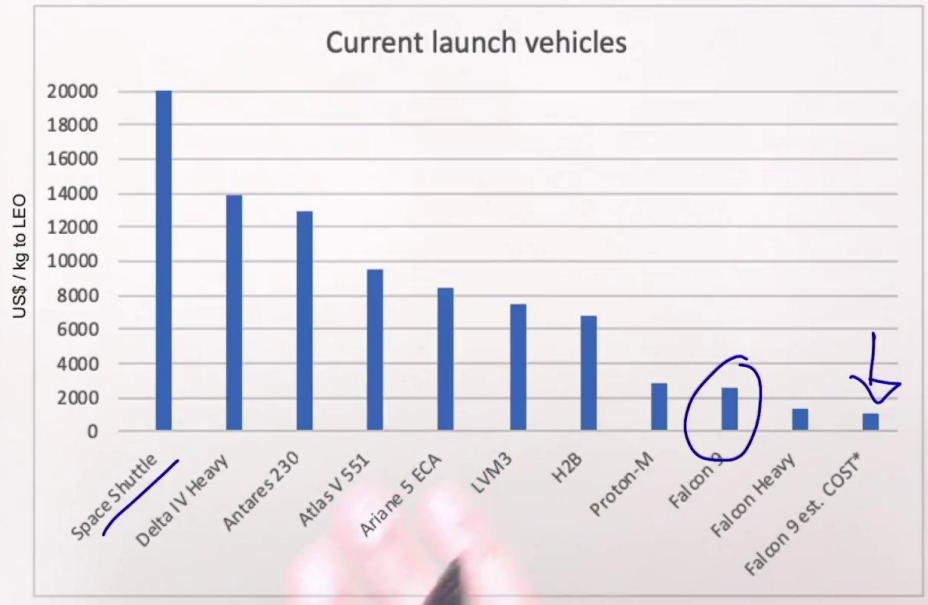
But you can amortise the investment over many uses. Let's say Starship cost $100 million. If you fly it once, you would allocate the full $100 million of cost to that one flight. If you fly it 50 times, it would be $2 million per flight. Now you see, Starship's Raptors had reignited, and it allowed it to make a propulsive landing and shut down. Unfortunately, this particular Starship prototype exploded a few minutes later. But in any event, reusability and its consequences, our first key trend of modern spaceflight. SpaceX pioneered reusing first stages with its workhorse rocket, the Falcon Nine. Let's look at the effect that had, and you can see it here.

Notes

Summary

1m 12s

Cost of launching 1kg of payload to LEO

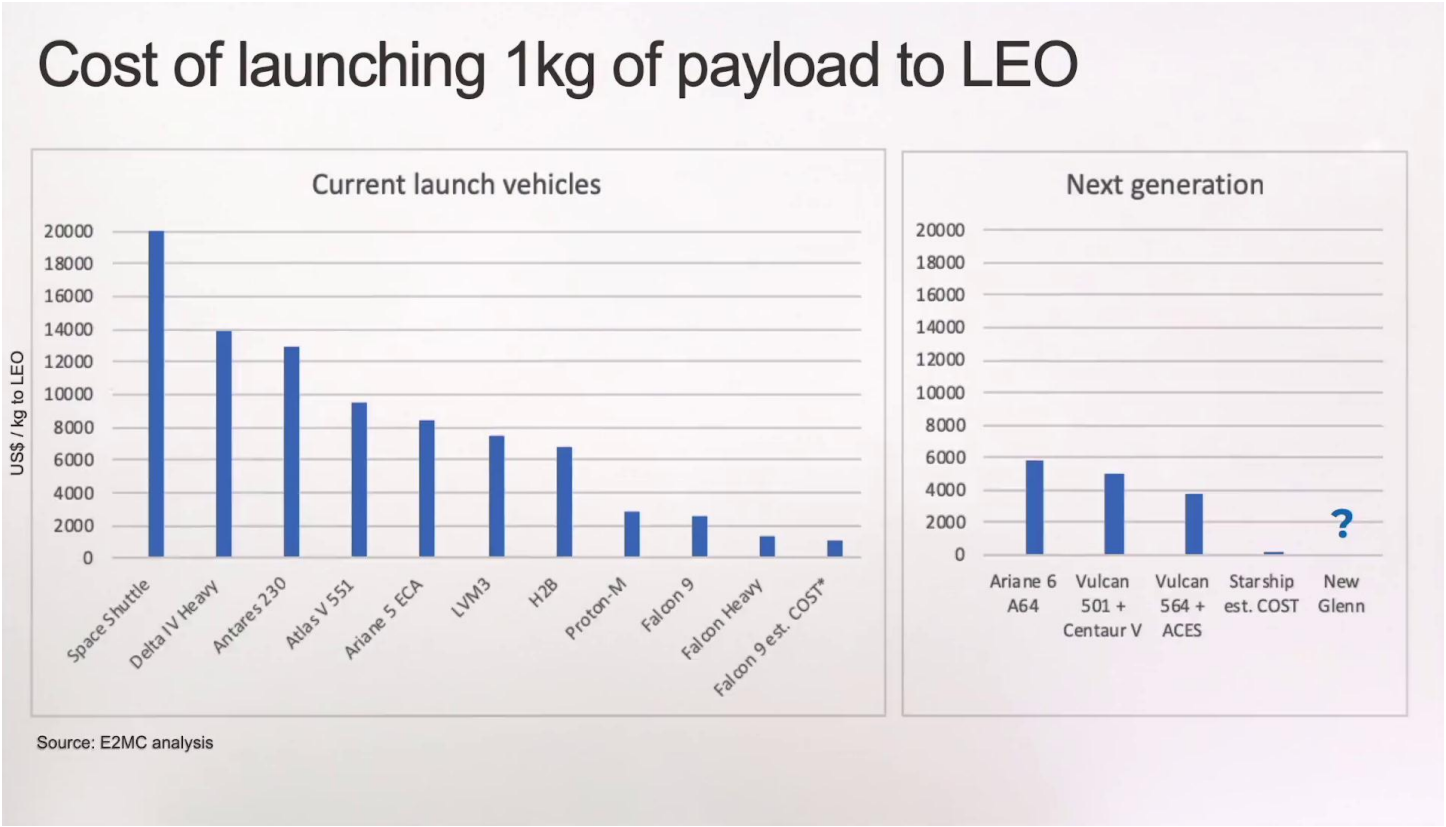


This is a comparative bar chart of the cost of getting one kilogramme to low Earth orbit on various heavy-lift rockets. The Falcon Nine, SpaceX's Falcon Nine, can get one kilogramme to orbit for under $3,000. If you triangulate some data that Elon gives you here or there in tweets and other places, you can guess their cost is actually much lower than this. But they don't have to price cheaper, as almost no one comes close anyway. Now, I would be amiss not to comment on the space shuttle here. The shuttle was almost entirely reusable.

Notes

Summary

1m 56s

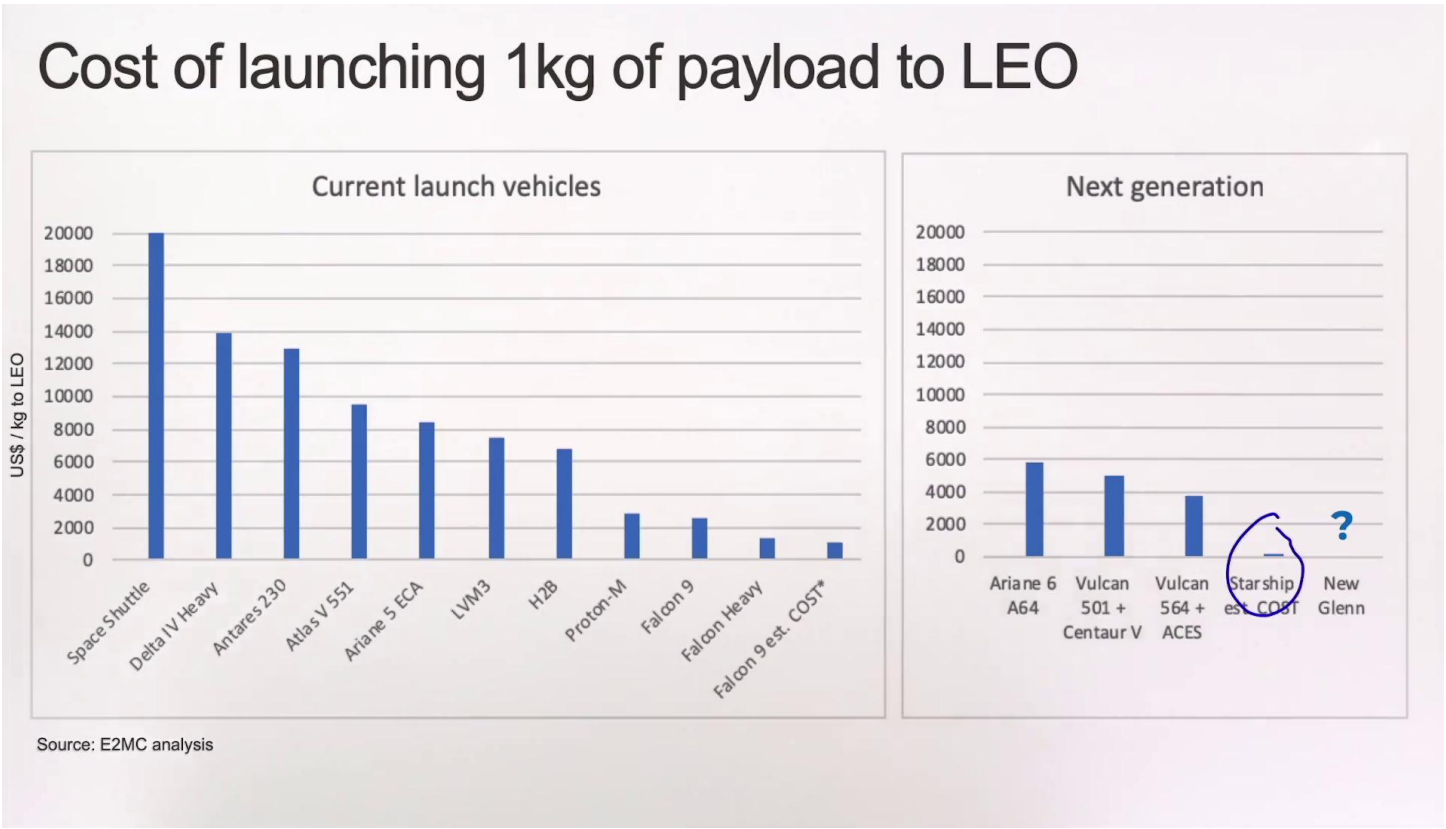


The only component of the stack thrown away was that big orange hydrogen and liquid oxygen tank that was tucked underneath the shuttle. So why wasn't the shuttle cheaper? Well, it was supposed to be. At some point, the plan or hope was that each shuttle flight would cost $5 million. Now, that was in early 1970s dollars, but even inflation adjusted, that would work out to a very cheap price, maybe around $1,000 per kilogramme of shuttle payload today. There were many plans for the shuttle, even including things like space tourism, or even disposing of nuclear waste. So what happened? A couple of things. First, the shuttle didn't fly enough, and reusability does not do you any good if you spend all the money on the rocket and then you don't use it enough. Second, the shuttle turned out to have some specific and very expensive problems inhibiting its reuse, and that has to do with things like its engines and its heat shield. But that goes beyond the scope of this course. If you are interested, there's an excellent MIT online course just on the space shuttle. But back to today, well, to the near future, actually.

Notes

Summary

2m 34s



And here, you see the same bar chart as before on the left, but now adding on the right, the expected cost per kilogramme to low Earth orbit for the next generation heavy rockets. After all, pretty much every rocket manufacturer is working on the next generation rocket, so all of them are incrementally improving. But look at Starship, which we have seen in the initial video. The ambition here is to make it almost as reusable as an aircraft. That means the cost of flight would asymptotically approach the cost of fuel and the cost of maintenance. Together, maybe a few million dollars. The Starship can lift over 100 metric tonnes. So say at $10 million per flight, you'd be at a $100 a kilogramme to low Earth orbit. I'm not saying that's the right number, but it's the direction that SpaceX wants to go to. Okay, we've been using heavy lift rockets so far to make our point. These are big rockets. For example, the SpaceX Falcon Nine can lift up to 23 metric tonnes. Most space companies do not need all that capacity. Many satellites these days just weigh a few kilogrammes, which we'll talk about shortly, and they can go on much smaller rockets. And there are many of those now.

Notes

Summary

3m 39s

Dedicated (small) launch

$12m
500kg to LEO → 24k/kg

Video: VirginOrbit

- A rocket just for your mission
- Fly <u>when</u> you want (incl. rapid response)
- Fly exactly <u>where</u> you want to
- US$10,000/kg to LEO and up (for now)
- LIKE A **TAXI / UBER**

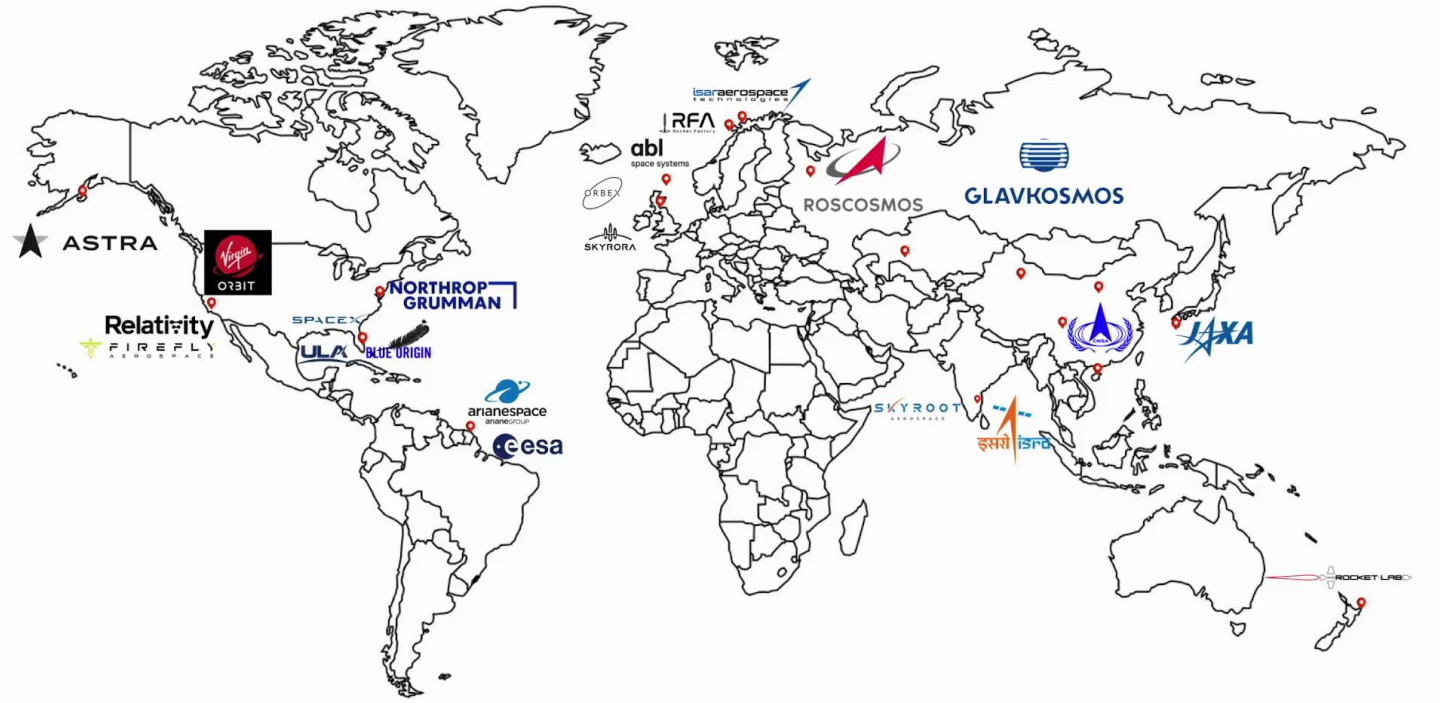
Here's an example. This is Virgin Orbit's LauncherOne, which, as you can see, is air launched. You can already tell by the size reference given by the Boeing 747 that this is a much smaller rocket. It reached orbit for the first time earlier this year in 2021. Now, it has a payload capacity of 500 kilogramme to LEO. It has a launch cost of $12 million. So this works out basically to $24,000 per kilogramme. That seems high compared to some of the other prices that we've seen, right? So why would you use such a small rocket? You can see some of the reasons here. Basically, if you have to fly only a small satellite or even a few small satellites, then on a big rocket, you'll have to wait until the rest of the rocket is filled up. Worse, you may be a secondary customer of a larger primary customer who controls timing and everything else about a rocket launch. A small launcher will get your mission to where you want to be, when you want to be. It's like taking an Uber. And so, of course, it's also a little bit more expensive. Now, many new launch companies now want to get in on that action, particularly with regard to small launch, say up to about a metric tonne or so of payload. Let me illustrate that.

Notes

Summary

4m 53s

Launch service providers – with private entrants



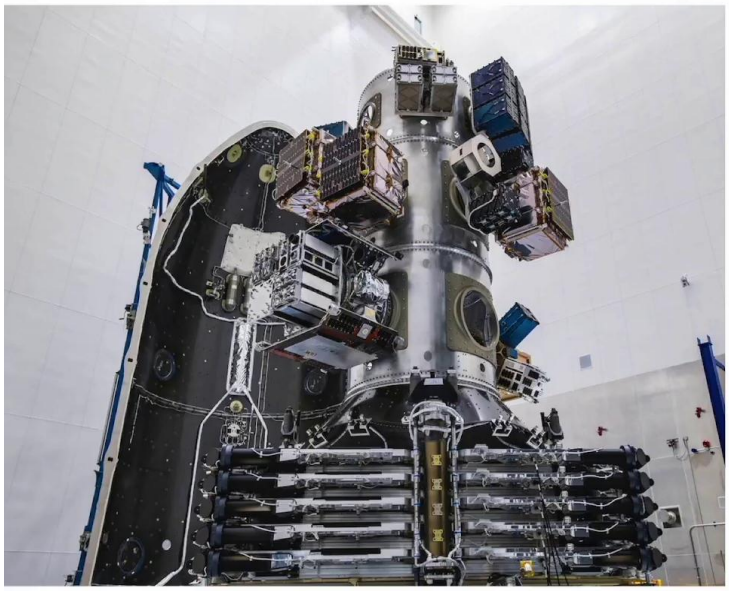
On this slide, you see many of the what we call traditional launches, mostly government connected, like Europe's Arianespace or India's ISRO. Now, look at this slide. Here, we basically left the government launches on there, but we added some of the emerging small launches, just focusing on a few that we consider more credible in terms of being further along in their development roadmap and having secured substantial financing. On paper, there's something like close to 200 launch companies. You probably know some of these names, for example, Rocket Lab from New Zealand, which has flown to orbit many times by now, or Astra, which successfully reached orbit just a few months ago.

Notes

Summary

6m 17s

Rideshare missions



Picture: Spaceflight Now

- Many payloads fly together
- Regular, scheduled flights
- Need to get to final destination by yourself … or with a space tug!
- US$5000/kg to LEO (SpaceX)
- LIKE A **BUS**

Okay, rideshare. If an Uber is too expensive for you, you may want to take the equivalent of a bus. That is what rideshares on rockets offer. You fly together with many other customers on a big rocket like the Falcon Nine. The picture on the left here is of SpaceX's January 2021 Transporter-1 mission, which carried 143 satellites for many different clients. Like a bus, it's cheaper. It's $5,000 a kilogramme to low Earth orbit on the SpaceX rideshare, but it doesn't get you to your final destination. You can then take something like a connection flight on what we call a space tug, which we will talk about in a different lecture, and you have to wait for a scheduled departure. So, again, it's very much like a bus.

Notes

Summary

6m 58s

Cost and size of spacecraft and components

Picture: National Museum of the USAF

Hexagon KH-9 reconnaissance satellite

Okay, but rocket costs, the cost of accessing space, are not the only costs that are falling. Spacecraft, including satellites, are also getting cheaper and smaller. This picture here is of something called the Hexagon KH-9, basically a US spy satellite that is a remote sensing satellite for national security purposes from the 1970s. Now, let's look and compare it to a modern remote sensing satellite.

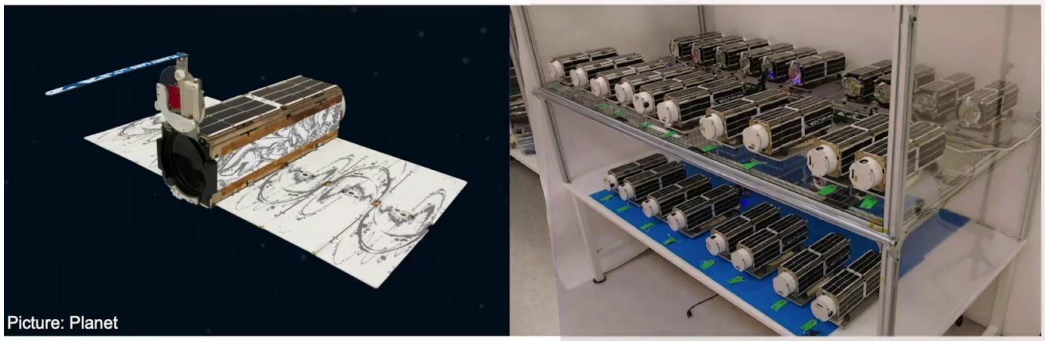
Notes

Summary

7m 44s

Cost and size of spacecraft and components

1970s
16m long
11-13 tons
$750m
6-9 metres res



2010s
30cm
kgs
$100ks
~3m

And what you have on the bottom here is... Again, it's still the Hexagon on the top, obviously. On the bottom, those are so-called Doves by an Earth observation company called Planet Labs. So if you compare it, the Hexagon KH-9 is from the 1970s. It's about 16 metres long. It weighs, depending on the configuration, between 11 and 13 tonnes. And there was a total programme of 20 flights for a total of $15 billion in today's dollars, including the launch. So that works out to about $750 million for one mission. And it had a spatial resolution, apparently of somewhere between six and nine metres. And now, the Planet Lab Doves are from the 2010s. And you can obviously see they're much smaller. They're about 30 centimetres long, they weigh a few kilogrammes. We don't actually know the exact price, but we can guess. And it's probably, including the launch, somewhere in the hundreds of thousands of dollars. And the spatial resolution is around three metres. So there, you have the advance that has been taking place. And I really do want you to understand what this means and what we're looking at here. Not only has this imaging capability... And imaging capability is just one example of a capability in space, right?

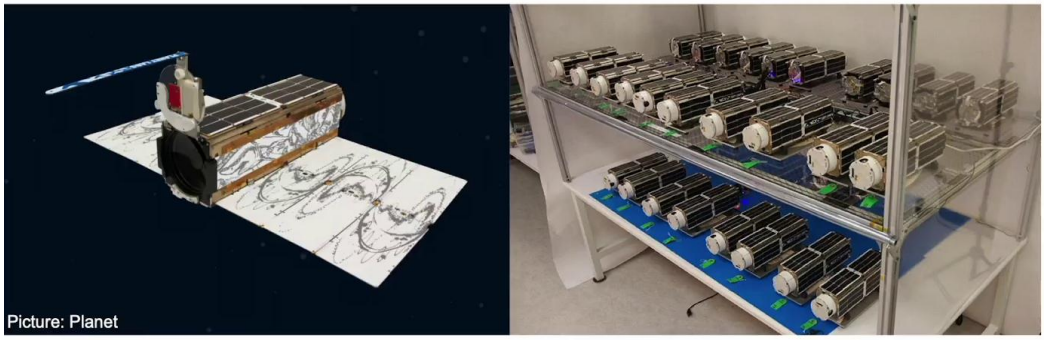
Notes

Summary

8m 12s

Cost and size of spacecraft and components

1970s
16m long
11-13 tons
$750m
6-9 metres



2010s
30cm
kgs
$100ks
~3m

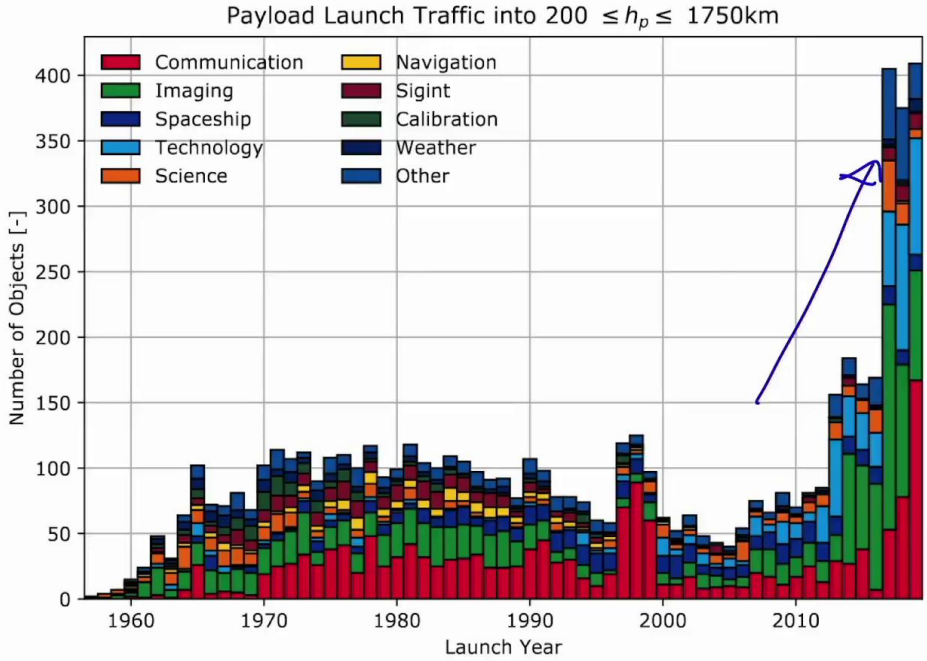
Not only has this capability come down in price so much in line with other price decreases in technology, but the size has decreased significantly, as I can see, is very impressively demonstrated in these pictures. We talk about miniaturisation. Now, smaller size also means less weight. And we already know that weight is substantially what drives launch cost. So when we are talking about the cost of getting some specific capability deployed in space, we effectively have a double whammy in a good sense. First, the cost of launching one kilogramme to space has gotten much cheaper, as we've seen on previous slide. But you also need fewer and fewer of those kilogrammes to achieve a certain capability. And that means a lot more space business models are now already or will be soon economically viable.

Notes

Summary

9m 45s

Evolution of man-made objects in Space



ESA Space Debris Office. 2020. ESA's Annual Space Environment Report. p.21

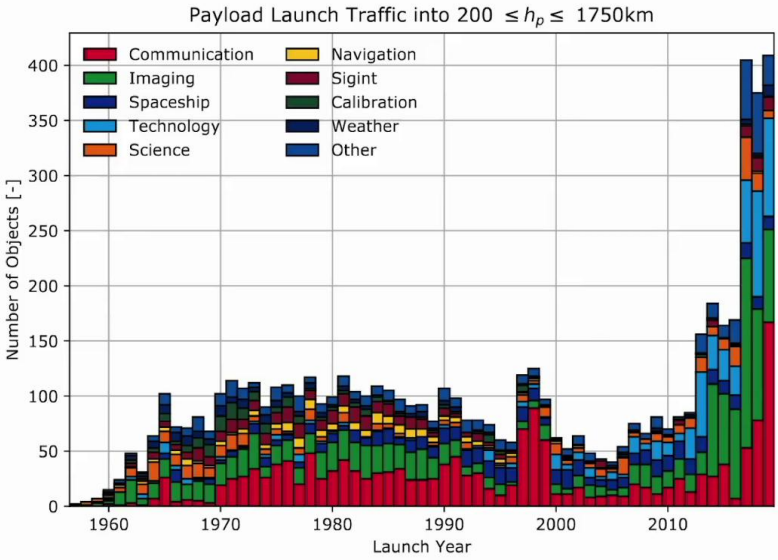
Okay, and people really believe those trends and they are building those businesses in space. And you can see it in some of the numbers. Look here what happened to low Earth orbit destination payloads starting in the mid-2010s. I mean, it was just shooting almost vertically up. This chart stops in 2019, but 2020, even despite COVID, it would have continued in large part thanks also to SpaceX deploying its Starlink constellation. But there is so much more to come.

Notes

Summary

10m 37s

Evolution of man-made objects in Space



ESA Space Debris Office. 2020. ESA's Annual Space Environment Report. p.21

Examples of proposed constellations

Constellation	Use case	Size*
GW	satcom	13000
SpaceX Starlink	satcom	12000
Amazon Kuiper	satcom	3236
Hanwha	satcom/IoT	2000
OneWeb	satcom	650
SDA Tr. Layer	satcom	300
Telesat	satcom	298
Swarm	satcom/IoT	150
Astrocast	satcom/IoT	100
Geely	satcom/IoT	?

*Best estimate of planned size, excluding planned or rumored filings

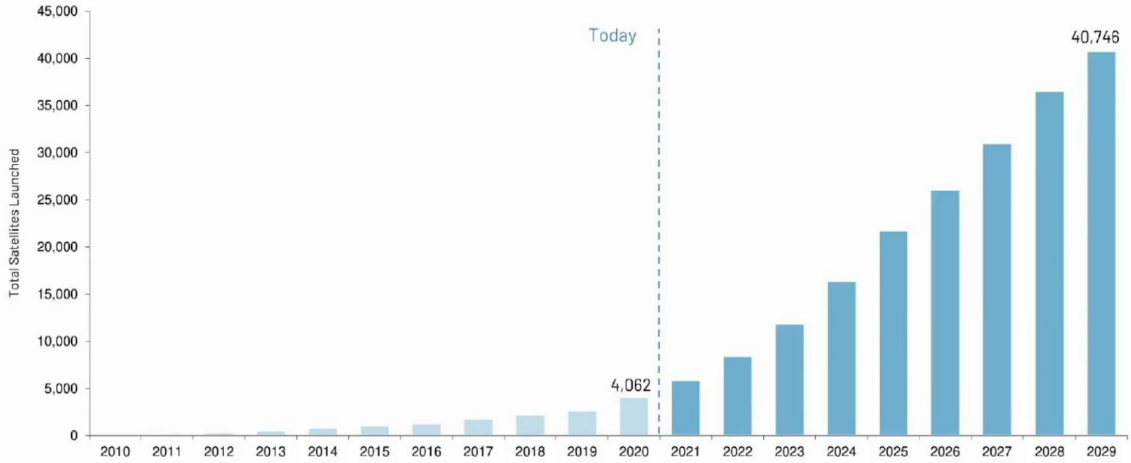
Look at the sizes of some of the other planned constellations. So again, SpaceX Starlink is up there. But there's, for example, also a Chinese constellation called GW that's supposedly might even in the end be bigger than SpaceX's Starlink. You have Amazon Kuiper, another low Earth orbit broadband internet constellation, which will compete with Starlink, with thousands of satellites and many others. So in total, we're talking about tens of thousands of potentially new satellites going up here. And if we wanted to expand the graph on the left, we'd almost need to change the scale.

Notes

Summary

11m 06s

Satellites 2010-2030 (cumulative)



Source: Wall Street Research, Space Capital.
(1) Based on Euroconsult and Astra Management estimates.
(2) Based on Euroconsult estimates derived based on 7,015 satellites with known mass.
(3) Factors in Euroconsult and Management estimates for satellite launches.

Holicity Inc. 2021. Form 8-K exhibit 99.2

So in this slide, there's another forecast. This was presented by Astra, one of the small launch companies in a recent investor presentation a few months ago. And this chart shows the cumulative objects they think will be in space. This is not the objects per year, but again, you can see this number just rising very, very sharply from the late 2010s. And they're thinking it's going to be almost 41,000 in 2029.

Notes

Summary

11m 39s

Largest satellite operators (current active objects on-orbit)

Operator (constellation)	Use case	Size
SpaceX (Starlink)	satcom	1369
Planet (Flock)	remote sensing	187
OneWeb (OneWeb)	satcom	146
Spire (Lemur)	remote sensing	112
Russia / SU (Cosmos)	various	98
USA (USA)	various	85
Iridium (Iridium)	satcom (IoT)	75
Swarm (SpaceBEE)	satcom (IoT)	75
PRC (Yaogan)	remote sensing	73
PRC (Beidou)	GNSS	50

Source: Celestrak & E2MC analyses

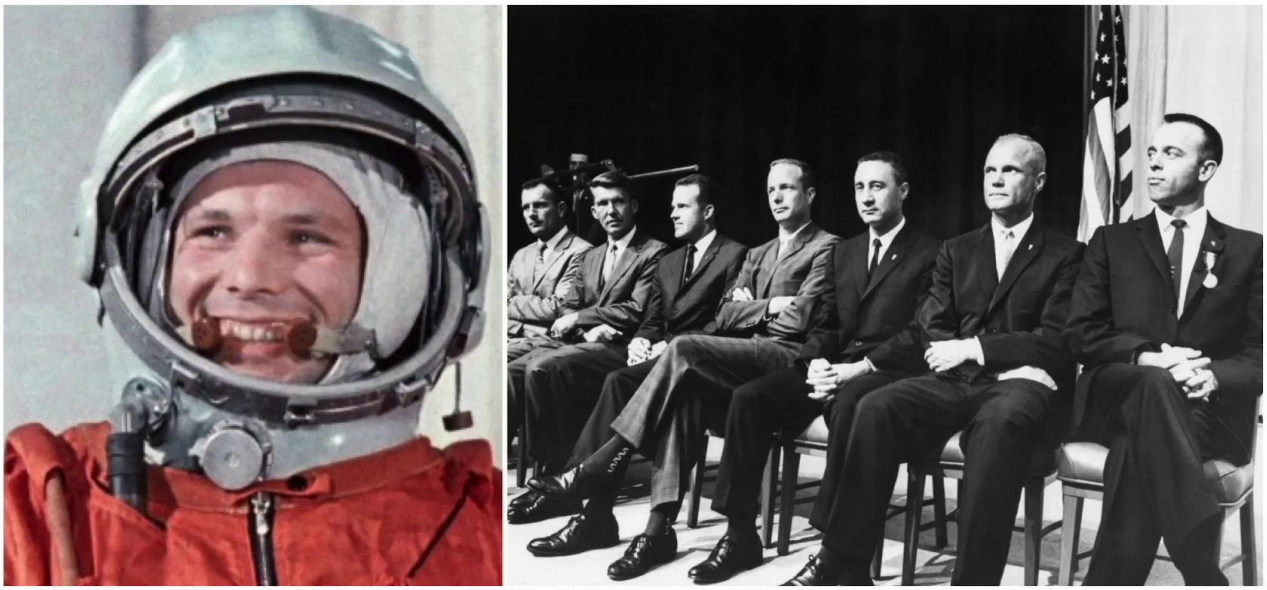
And just a final slide on this and a final table just to show you that people seem to be serious, here are some of the top constellation operators as measured by active objects already on orbit. And here you have SpaceX with almost 1400 Starlink satellites in orbit already. And this number grows almost every week. This is the number as at the time of recording. And it will almost certainly be the most outdated number in this lecture if you don't keep on updating it all of the time.

Notes

Summary

12m 01s

Humans in space: professional astronauts



Source: NASA

Okay, changing tack. It's not only inanimate objects in space like satellites that are increasing in number and changing in type. Humans or astronauts or cosmonauts, too. Of course, it all started here in the 1960s with professional astronauts that were test pilots, Yuri Gagarin on the left, and the American Mercury Seven on the right.

Notes

Summary

12m 31s

Humans in space: private space explorers 2002-9

Source: NASA

Space tourism, on which we have an entire lecture, started in earnest in the 2000s with the first crop of private space explorers. By the way, they don't usually like to be called space tourists. Who you can see on this slide. They were on a break of quite a few years, but now it's starting out again.

Notes

Summary

12m 49s

Humans in space: private space explorers 2020s (so far)

Sources: SpaceX, Axiom

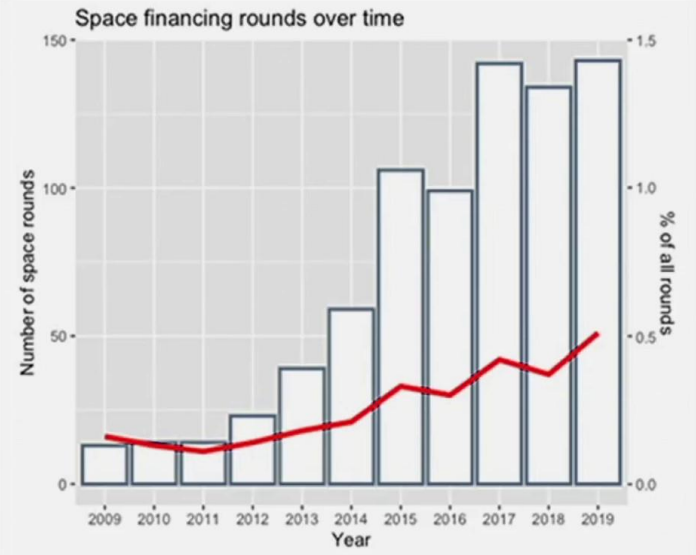
And here, you can see a couple of examples of planned private missions. On the top, you have the private astronauts of the Axiom 1 mission, four astronauts. And then also four astronauts on the bottom left, that's the Inspiration4 mission, which will not go to the International Space Station like the Axiom 1 mission, but it will stay as a free flyer in Earth orbit on the SpaceX Crew Dragon capsule. And on the lower right, together with Elon, here you have Yusaku Maezawa, a Japanese Internet billionaire who has paid SpaceX for a trip to circumnavigate the moon on Starship when it's ready, a type of Apollo 8 style trip. As I said, we will have an entire lecture on space tourism, but suffice to say, most people are now expecting the number of people going into space to increase significantly from the low historical base. And that is a very interesting trend in itself.

Notes

Summary

13m 06s

Financing for space companies



Over US$5.3 billion private markets financing in 2020

SPAC / space company merger	Merger announced	US$m raised*
Social Capital / Virgin Galactic	09-Jul-19	808
Stable Road / Momentus	7-Oct-20	348
New Providence / AST	16-Dec-20	462
Holicity / Astra	2-Feb-21	500
Osprey Technology / BlackSky	18-Feb-21	498
Vector / Rocket Lab	1-Mar-21	787
Navsight / Spire	1-Mar-21	475
Genesis Park / Redwire	25-Mar-21	241
Centricus / ArQit	12-May-21	416

*Gross proceeds from SPAC cash-in-trust and PIPE, before fees, redemptions or repayments of equity and/or debt

Over US$4.5 billion from recent SPAC deals

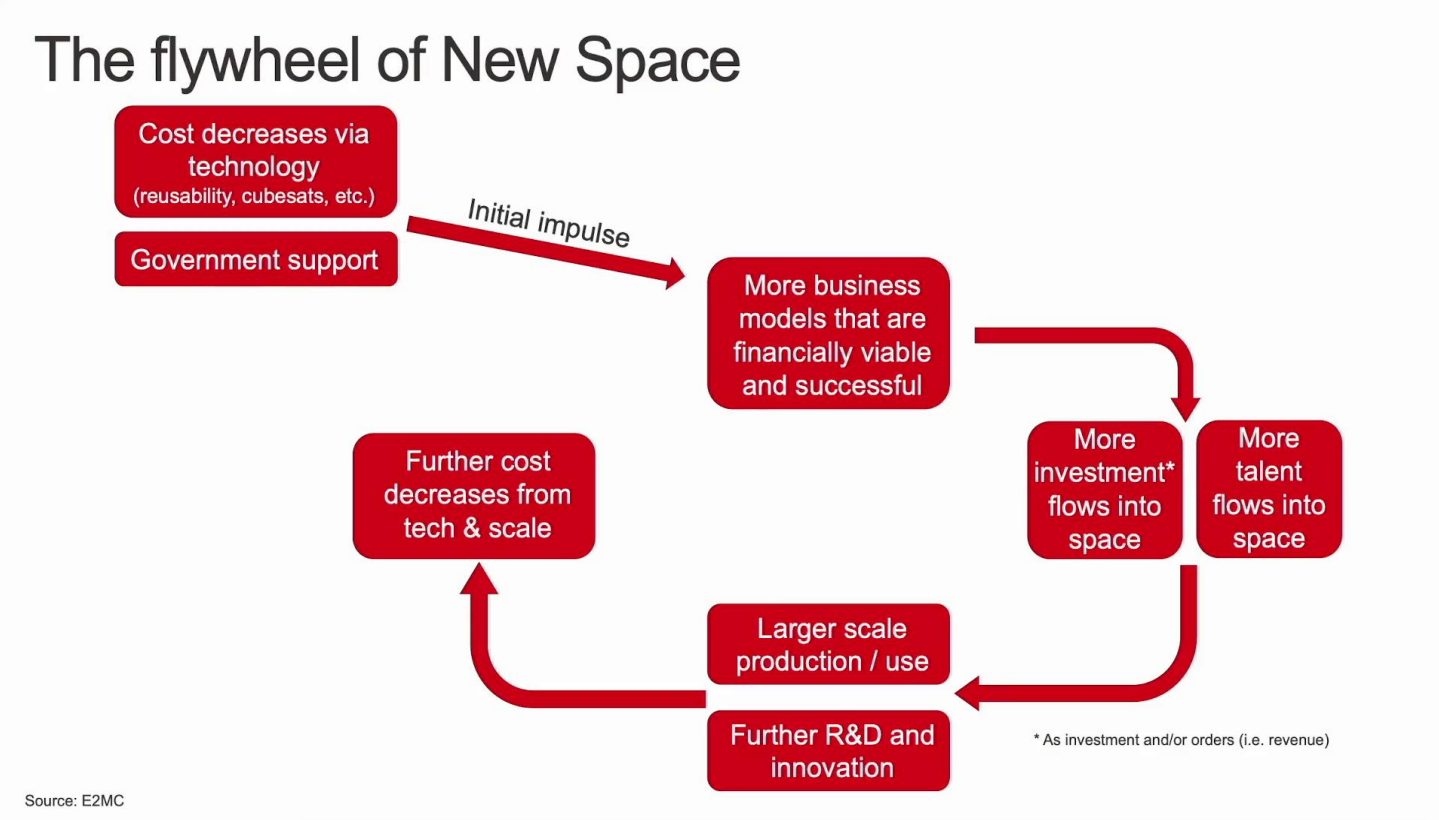
Source: E2MC analyses

Changing tech again, another trend with all the exciting potential in space. More and more people have emerged who are willing to invest money in space businesses. The table on the right shows the number of space financing rounds by year for the last decade. And it's gone only in one direction, as you can see. And those are private rounds by venture capitalists or angels. This is not including government money. And in dollars, it was a total of at least $5 billion last year, despite COVID in 2020. You'll see even higher estimates out there, and that's because people define what is a space company in different ways. But it doesn't stop at what we call private markets. Look at this here on the right. This is so-called mergers between space companies and SPAC companies. SPAC stands for Special Purpose Acquisition Companies. Without going into too much detail, which is beyond our course's scope, this is basically a way to take a space company public. And there have been quite a few transactions recently, starting with Virgin Galactic in the summer of 2019. And then the speed has been increasing, and you see there's six transactions just in 2021 so far. And these transactions have raised another four and a half billion dollars for space companies, so quite a significant amount. Okay, so let's tie this all together.

Notes

Summary

13m 55s

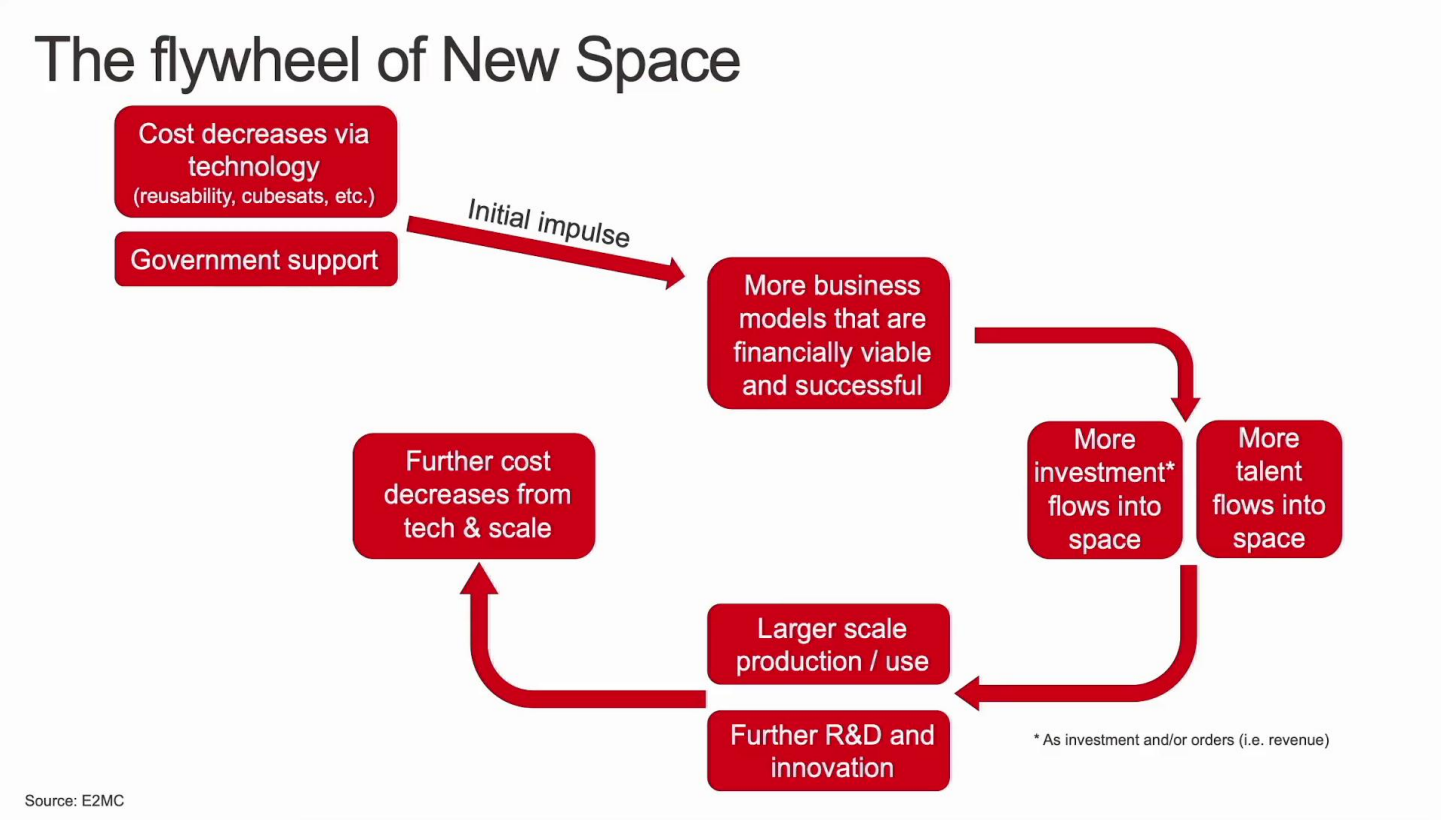


What is really going on here? We have seen that space launch costs have come down due to innovative, cheap reusability of rockets. We have seen that other costs have also come down, like the cost of components and satellites. Governments in the US and other places have supported these developments ever more, for example by giving out large contracts like the one in the US for the commercial resupply of the international space station. These developments have given perspective of having economically viable businesses in space. On we go. People started seeing the success of SpaceX and these developments, and they latched on. Visionary entrepreneurs started setting up other space companies. Investors started investing in them. That money that's invested in space companies, it effectively finds its way back into the space sector because the space companies who receive that financing, they do things like invest the money in further research and development or in scaling up their operations, for example, building a satellite factory, or building out a constellation. Now, if they invest in research and development, that's likely to generate further innovation.

Notes

Summary

15m 10s



If they scale up, that will provide what we call economies of scale. Either of those, scaling up or additional innovation, almost inevitably further will improve the economics of the space business. And then the cycle starts all over again. And that is the potential flywheel of new space. A virtual circle that maybe, hopefully, we now finally got started.

Notes

Summary

16m 18s