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GEO in a Starship World

September 2022

Starship development continues in Boca Chica while Falcon 9 flies and flies again from here at the Cape. Falcon 9 has more or less steadily reduced launch costs by almost half from ~2016 onwards. Crew Dragon, meanwhile, has made human spaceflight from American soil a routine occurrence, with the baseline Dragon craft logging 23 flights, the current Cargo Dragon logging nine reuses and multiple craft flying three times. Crew Dragon has logged 10 orbital flights from its first demo in 2019 until this writing in September 2022, carrying 26 American, allied, and private astronauts, with 15 more flights on the books after NASA purchased 5 more recently. It is getting hard to keep track of, honestly.

With this as a baseline, and crew vehicles like the Sierra Space Dreamchaser coming online, we will have ample capacity for crew launch. Particularly with their soft reentry capability of 1.5g down. Downmass is something we haven't really considered before, but we probably should, given that upmass will be reduced. That means bringing products down to the ground becomes more practical.

Starship of course promises to upend this already disrupted space.
With an aspirational goal of $10/kg to LEO, the launch will be cheaper than ever before, and moreover, a frequent and heavy lift will allow more options than ever before.
The space industry must rethink this new reality from a blank slate, or first principles, as Elon likes to say.
What will the reality be?
I want to be a bit bearish on this goal and say that only $100/kg is possible with full reuse.

Maybe even say that SpaceX never figures out how to land a Starship and only recovers the booster. That would be a large version of the Falcon 9 in stainless steel. Even with this scenario, we could expect to see an order of magnitude price drop from the current state. This brings us to $250/kg. I then want to say that the cost to GTO is 3X that amount and also requires a tug or onboard stage to circularize the orbit. That means mass and price, so $750/kg to GEO? That's still 1/3 of the 2020 cost to LEO!

I feel this clean slate leads to MEO and GEO for a lot of missions.

MEO is above LEO and below HEO – between 2,000 and 35,786 km above sea level. The MEO orbital period is between 2 and 24 hours, so MEO satellites do not stay over the same place at all times.
GEO orbit is defined as a circular geosynchronous orbit 35,786 km in altitude above Earth's Equator 42,164 km in radius from Earth's center) and following the direction of Earth's rotation.

The Current Order

Why is LEO the popular orbit today? The current generation of spacecraft are mostly committed to communications or Earth observation. For communications, the driver is latency and that is dominated by distance. The closest stable orbit provides the least latency. EO is dominated by cheap cameras. It is easier to get high resolution images from 200km than it is from 400 or 2000. The two largest sectors of the space economy are both rooted to the lowest sustainable orbit.

So what are the benefits of the higher orbits?

MEO/GEO pros

- Much larger volume makes STM(space traffic management) simpler
- Less radiative heat from Earth
- Less EM noise from Earth
- Stable orbit.
- Solar power without the need for significant batteries due to a much higher ratio of day to night than LEO or total
- Requires fewer satellites to cover the entire Earth
- The same satellite is over the same ground all the time (GEO)
- Simpler ground station architecture

MEO/GEO Cons (pre starship)

- Higher cost to orbit around 2X cost to LEO for rockets capable of GTO launch
- Significant latency of 120ms or 1/4s round trip
- Higher radiation than LEO
- Dead satellites will stay there and must be actively removed
- Entirely inside the outer Van Allen Belt
- Parts of MEO lie between the two Van Allen Belts within a band of 13,000 to 19,000km

With launch costs as I described, the cost becomes a nonissue. That leaves radiation and removal and while those require infrastructure, companies are working on recycling right now and radiation shielding apart from GCRs mostly costs extra mass.

This leaves latency as the chief inherent difficulty with GEO and to a lesser extent, MEO.

For communications platforms, this is a serious detriment, however not all space operations involve transmitting large amounts of data in a timely manner.
What are some of the uses that fulfill these requirements and also take advantage of the qualities of these higher orbits?

MEO/GEO Use Cases

What factors will drive commercial activity to higher orbits?

- Uncluttered environment with infrequent maneuvering
- Good observation of the space beyond Earth with less heat and light reflected from the Earth
- Less EM noise from the Earth, and the quietest place this side of the dark side of the Moon
- Difficulty of physical access to satellite

What Comes Down?

The economics of Space today dictate that any product from space must have three common factors. The product sent to Earth must be low mass and high value, and the hardware to generate the product must not be prohibitively expensive to launch and operate. As of today, the vast majority of the products that fit those requirements are photons, or photons turned into digital signals.

For this reason, as of 2022, almost all space businesses are focused on either communications or Earth Observation, with the observation of things other than Earth mainly being carried out by NASA. However, there is a critical need for SDA observations from the USSF as well as a growing need for current information in the CisLunar area.

With the cost structure lower, the difficulty of emplacing hardware will drop, and thus the array of downstream products can increase. In short, it can become viable to not only send photons down to Earth but sending atoms down can become a viable business case. This of course is not a hard and fast line where on one side, there is no viable business case for atoms, but beyond, all the business cases close. There are viable business cases for certain physical products right now. Of course people are made of atoms, and they go to space and come back ‘changed’ by the experience. Humans have been traveling to space for decades and are doing so at an accelerated pace in the past couple of years. There is science being performed in drug production and materials science, but it has not yet been done at scale for commercial use.

This cost shift does not mean that the criteria are out the porthole as it were, but it does shift the bar a bit. The atoms brought down to Earth must have high value and low mass. This means a high cost density. Photons sent down still have value and, as they carry no mass, have the highest relative value. Still, the door is open to sending raw materials up to LEO and other possible locations, performing value-added work on them, and sending finished goods back to Earth. These goods are mostly the product of intense, precise operations and, as such, are highly data-driven. These will require on-orbit compute to achieve the efficiency and quality needed to justify the premium that will still be associated with space operations. Their raw materials will originate on Earth, but as the supply chains become established, ISRU will offer the opportunity to use space-based resources as feedstocks for Earthbound products. Some of these operations will occur in LEO and others will occur in MEO, GEO, and beyond.

High-Value Density Space Goods

Any manufacturing that occurs in space must meet a few criteria. Materials made in space must come from Earth sourced feedstocks at least initially, so less material brought up is better. While the ideal is to return less material to Earth, those models which require returning material must minimize the masses and volumes. This process will be expensive at least until ISRU is fully matured, so the finished product must be of high value. In short, goods produced in space must be small, dense, and valuable.

If these three conditions are met, the cost (still considerable) of taking raw materials up and finished products down can be recouped.

It really comes down to ROI. What are the initial costs? Material inputs? Recurring? Transport up and down? When these things are equal or lower than the profit, the business is viable and a movement on any of those prices affects that. Transport is a large, but not the largest cost, and lower transportation costs also affect design optimizations. These changes will in turn drive initial hardware costs down, which affects the total cost. Another element is available infrastructure. With a lack of support infrastructure, a builder must include all needed elements into their build. With greater infrastructure on orbit, capabilities do not require hardware on board, but only a subscription.

- Space Based Solar Power (SBSP)

In 2020, the Earth generated and consumed 2.8 Terawatts. This is a lot, but we also used a significant amount of energy that was never electricity to power cars, ships and planes. Estimates suggest that in 2018, global energy investment reached around $1.85 trillion. Other figures estimate that global oil and gas exploration and production is the 8th largest industry in the world by revenue, worth $2.7 trillion in 2021. While more energy production is more sustainable than before, what if it didn't even occur on the Earth?

SBSP has long been considered unrealistic due to the high costs of building the infrastructure. Solar is one of the few pure photon business cases in this list. It is, of course, cost-prohibitive with current launch costs, but with heavy, frequent, affordable launch, the math changes. SBSP, at scale, technically counts as a megastructure. In deployment, it resembles Starlink. A Starship class ship deploys several independent satellites, each with a compact solar array rolled up, maybe like the Redwire The Roll-Out Solar Array (ROSA). Each satellite will deploy several football fields worth of solar panels, and a few weeks after launch, it will add its output to the already existing constellation. With these sizes and the sheer number of satellites, LEO does not make sense. Particularly since latency is a nonissue and platforms will be in service for decades at least.

This distributed power generation grid has three use cases.
One up, one down, one that doesn't move.

SBSP can be beamed down to the Earth or satellites in other orbits. For Earth beaming, GEO offers the quality of a given satellite being stationary relative to the Earth's surface. A satellite deployed to collect and send power to a specific location will stay over that location as long as it functions, requiring little stationkeeping. This use case is most attractive in areas where it is otherwise difficult to build conventional power generation facilities. Regions with insufficient sun or wind places where a sensitive environment makes new power plants undesirable, places where populations are climbing the prosperity ladder rapidly enough that power becomes a bottleneck for further development. For terrestrial applications, there is also the possibility of surge capacity apart from natural disasters where existing supply lines are disrupted. The European situation regarding Russian comes to mind here.

For a satellite to satellite power, beam steering facilitates the transmission, and MEO might be a more attractive option. This could be provided to satellite operators on a SaaS model, as power infrastructure would facilitate faster, cheaper satellite construction. This has a significant advantage over Sat to Ground models, as the power loss from transmission is minimized by not traveling through the atmosphere.

There are a lot of power-intensive operations that will occur in space, and those could benefit from megawatts of power on the station. Here, we see things like massive data centers, metal, and ceramic smelting and refining, the general class of in-space manufacturing apart from assembly as well as other work that we cannot forecast yet. For this case, the solar array could be dedicated to a specific use or even attached to the platform that does the work.

It is also worth noting that SBSP is the very first example of viable ISRU since solar power is a resource that is used in situ or sent to where it is needed. In the future, solar panels can be produced from mined minerals found on the Lunar surface and asteroids. These locally produced solar panels will be used on those surfaces and ultimately be placed in orbits to send the power to other locations around the solar system.

- Orbital Data Centers

As a company dedicated to putting high power compute in space, we should definitely include orbital data centers on this list. What does an orbital data center even look like? Is it a giant warehouse of servers in space, or is it a distributed constellation of satellites occupying different orbital shells for different purposes and to deliver different levels of latency? I feel the answer is self-evident, partly because of the way I framed the question. What roles will orbital data centers fulfill? They will play many of the same roles as terrestrial data centers, but initially for space based data. They will compile and amass large databases of Earth Observation data for later, comparative and immediate analysis via directed searches as well as AI that will find unexpected insights due to large databases with frequent revisits. This capability will significantly improve the quality, volume and frequency of insights from space based platforms.

- In Space Assembly And Manufacturing (ISAM)

ISAM is a precursor to many other large scale technologies. It facilitates many of the follow on capabilities by providing infrastructure to ease their operation and maintenance. With ISAM capabilities, large structures can be assembled from flat packs, expanded, repaired and modified. This can also reduce total launch mass for cargo, as structures can be designed for stowage and then deployment instead of being designed around launch.
This capability also ties into ISRU as the stocks that originally came from Earth can be replaced by stocks that originate on the Moon or asteroids.

- Discipline Specific Research

Autonomous laboratories will happen and due to their data being produced and consumed locally, the need for continuous high volumes of data sent to the Earth are greatly reduced. This means that latency ceases to matter for this use case. Further, these facilities, both crewed and uncrewed exist to take advantage of microgravity and that gravity is disturbed when the station/satellite has to maneuver to avoid other satellites or stations. Some of these laboratories will be dedicated to life science, medicine, materials science, or any of the other use cases I list here. Some will begin as general purpose, but the trend will be towards specialization. While the initial impulse would be to think that the company that carries out initial research will follow on to the commercialization of that research result at scale, that is often not the case, as research and manufacturing are often different skillsets and research will be easier to do than scale manufacturing.

- Crystallography

Research and later manufacturing done in space will cover a great many different disciplines, but one core technology will unite many of the early efforts. Crystallography is the study of crystal structures and their behavior and formations. Crystallography ties into metallurgy, optics, ceramics, medicine and other verticals. With microgravity, crystal formation can be manipulated and imperfections can be either avoided or introduced when and where they are desired. These crystal formations can take moments or months depending on the application. This can deliver tougher, lighter metals and ceramics, clearer optics and lifesaving drugs. The key thing in making it work though is the need for long term physical stability. This means a minimum of maneuvering to include pointing. Researching and producing crystal structures at scale is a data intensive process with lots of telemetry, and that means it needs significant compute capabilities on station and likely on demand as a hybrid orbital cloud infrastructure. I included this one as a separate element because of the great importance this specific discipline will have. It is also quite a broad area of research itself, and covers many industries.

- Photolithography for semiconductor chips

Chip fabbing at the cutting edge nanometer range has two significant obstacles to scaling. One is optical diffusion. The best way to combat this is with a vacuum. The best terrestrial vacuums are orders of magnitude worse than opening a hatch in space. The other obstacle is vibration. The vibration of a human walking within several feet of a lithography machine in operation is enough to ruin a batch of chips, so vibration damping is clearly a challenge. A spacecraft without moving parts, or at least one where all movement can be halted for the duration of lithography operations, this other obstacle can be overcome. This process could lead to chip fabbing in space for the very smallest resolution chips that cannot be produced on Earth at scale.

- Human organ 3D Printing

One of the difficulties in printing organic structures is the difficulty in keeping the cells where you put them. Gravity causes things to shift over the weeks needed to grow an organ. Preliminary results from Redwire on the ISS have indicated that microgravity can increase the ability to keep cells where they need to be. This can lead to an organ industry in orbit. Cells and feedstock are sent to the facility, the organ is grown and brought back to Earth on a low g reentry vehicle such as the Dreamchaser and landed at any major city in the world.

- Genetics

For reasons that need not be elaborated on, there are entire classes of genetics and virus research that are best carried out off the Earth. Crewed, occasionally crewed and uncrewed space stations are the best path. If a station is intended to be uncrewed most of the time, then by necessity, it is a robot filled with robots.

- Telescopes

While many atom based products will make sense, so will many photon based products. The Hubble telescope is at an altitude of 550km, so that it could easily be reached by the Space Shuttle. The JWST is sending down new and breathtaking images from shortly after the dawn of time and it is at the second Legrange point, and intended to never be serviced.

With a frequently flying Starship, an even larger class telescope is feasible and an undisturbed orbit is attractive. This will be a data intensive operation and significant compute will be a definite advantage for on station analysis, processing and compression.

Also, if one telescope can be built, so can ten or one hundred In LEO, GEO, all the Earth lagrange points and beyond. These telescopes can study different parts of the spectrum and do work from mapping asteroids, to searching for other civilizations to seeing the earliest moments of Creation. There is also an urgent need for better space situational awareness (SSA/SDA) and a constellation of satellites can help with this effort and add greater precision to our mapping of orbital bodies.

- Space Hotels

The Overview Effect is often cited, and most of us have experienced it as part of commercial air travel.
You can go higher with a balloon flown by Space Perspective and see the world from 30km. You get a better view still from Blue Origin today with a height of 100km, although this option might be grounded for a bit due to the anomaly that was recently experienced. SpaceX is flying customers to the ISS and orbits higher than that at 400km, but no destinations available.
That is today and there are several space stations in the world in the works. They are currently all planned for LEO, and customers seeking new experiences will flock to them.
And then, they will want a new experience.
Hundreds of people have seen the ISS view and any new stations will be in the same orbital plane as the ISS, so the view will be the same.

As a person reaches GEO, the view of the Earth will be different. You will no longer feel like you are standing over the Earth. It will not fill the viewscreen anymore. You will be far enough away to see the stars well when you look away from the Earth.

The attraction will be in seeing a newer, more rarefied view. For this reason,as well as stability, and safety, MEO and GEO will be desirable locations for space hotels.

Space Tourism might not be considered of benefit to Humanity, but it is. Tourism is an industry that treads lighter on the land than resource extraction and many other industries in less developed places. It also supports other pieces of the infrastructure and logistics chain that will be necessary to support the next link in the chain.

Building Industry in Space for Earth

In order to move more of our industrial processes off the Earth and into space, the transition must be economically viable and of benefit to humanity to garner and maintain support for this and subsequent steps. Easing the constraint of building power generation, restoring sight and life to people, providing faster computers, and expanding our minds with a greater understanding of the Universe will all benefit humanity. These steps will build the infrastructure necessary to make the next advances and move us forward to more fully embrace our destiny and carry light into the darkness of space while lessening the impact humanity has on the Earth itself.