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# Small Launchers - 2021 Industry Survey and Market Analysis

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**Abstract**

Small launcher field is continuing to bloom, but some scepticism has begun. Rocket Lab has performed very well since achieving orbit in early 2018 with over 21 launches. With Astra, Virgin Orbit, Galactic Energy and Firefly having made their first orbital flight attempts, new actors have also become operational.

NewSpace Index has tracked small launch vehicles (<1500 kg to SSO) since 2016 and at 180 entries.

First half of the paper presents the statistical overview of 180 surveyed small launchers. 5% are retired, 9% are operational, 56% are in development, and 30% are concept, dormant or cancelled. There was a rapid increase of new small launchers starting from 2014. None of the very small single CubeSat launchers (<50 kg) are operational yet. None of the launchers offer dedicated mission cost for <$2 million. Costs per kilogram are generally higher than the cheapest rideshare missions. Land-based launches are the most common, but 2 air launchers are operational too. Development times can be as low as 2-3 years, but some have taken more than 10 years. Development delays of 1-2 years are common, but can be much longer. Far away from achieving the planned high cadences for future launches, up to daily launches. About 30 launcher organizations have announced funding of more than $10 million, meaning most of the small launchers do not have the funding at the moment to finish development. Select are developing hybrid and methane rocket engines. Re-usability tends to be rare for small launchers with about 13% in development and 7% planned.

Space launch market revenues are predicted to increase rapidly, but assume most constellations being deployed in full, which is unlikely. On-demand flexibility and specific orbits are the main benefits of dedicated launchers, because it is cheaper to deploy constellations in batches on larger rockets. Small launchers are competing with rideshare and piggyback launches, space tugs, resupply spacecraft and on-board propulsion modules. Revenue predictions from SPACs are very large and do not account for the diverse competition. Multiple startups have over $1 billion valuations without having performed successful launches. Many small launch organizations have started developing larger rockets, satellites, space tugs and more.

With Relativity raising over $1 billion, Astra and Rocket Lab went public and Virgin Orbit planning to follow, the certainty is that next years in the small launcher industry will be compelling.

**Keywords:** launchers, rockets, small launchers, small lift launch vehicles, dedicated launchers

## 1. INTRODUCTION

NewSpace Index (www.newspace.im) has tracked new small launch vehicles since 2016. There are 180 entries as of September 2021, which makes it one of the largest public databases. There were about 30 launchers listed in 2016 and 60 by the end of 2017.

Literature review was performed and the following market surveys about small launchers were found. W. G. Naumann identified about 35 launchers capable of placing payloads of under 1000 kg to orbit in 1995, with 6 as operational.[1] Crisp et al. reviewed 17 current and 11 future launch systems in 2014.[2] C. Niederstrasser has presented small launcher surveys yearly since 2015, with the latest from mid-2021.[3] D. Lim published small launcher market survey in 2016.[4] Wekerle et al. reviewed small launch vehicles in 2017.[5] H. Burkhardt published light launcher landscape in 2018.[6] SpaceFund has curated online Launch Database since 2018, which includes suborbital and larger launchers too.[7] W. Peeters et al. wrote about launching smallsats with micro-launchers in 2020.[8] P. Lionnet has written extensively about (small) launch vehicles and their economics in 2021.[9,10]

Gunter's Space Page[11] (Gunter D. Krebs), Jonathan's Space Report[12] (Jonathan McDowell) and Space Launch Report[13] (Ed Kyle) have been keeping detailed listings of all space launches and launch vehicles for more than 2 decades.

In this paper, an overview of 180 small launch vehicles is presented. First a short history followed by a statistical overview and market discussions.

## 2. A SHORT HISTORY OF SMALL LAUNCHERS

Small-lift launch vehicles (<2000 kg payload) have been in development and operation since the middle of 1950s. In many cases, this was the performance early rockets were capable of and most of the launching states had their own series of what would be now categorized as microlaunchers or small launchers. For example, the Sputnik rocket, Vanguard, Juno I, Long March 1, Lambda 4S, Diamant, Black Arrow and SLV.

The following historical description will be non-exhaustive and not all launchers will be mentioned. The goal of this section is to show that commercial, privately developed, rapidly deployable or even reusable launch vehicles are not a novel concept, but most of them have not made it, and the quantity and likelihood of success is now much larger.

First successful launch of Scout was in 1961 and it was capable of placing 175 kg to 800 km orbit. With 118 launches until the retirement in 1991, this 4-stage rocket is one of the most successful and reliable launch vehicles of the United States.[14]

Space Services Incorporation of America (SSI) launched Conestoga I on a sub-orbital flight in 1984 and planned to launch the Conestoga II in 1985 to place a commercial satellite into low Earth orbit.[15] Between 1981-1985, The Starstruck company developed the sea-launched Dolphin rocket for suborbital commercial missions and the first flight was in 1984. At a similar time, Satellite Propulsion was independently developing Liberty launcher.[15]

Pegasus was started by Orbital Sciences Corporation (OSC, now Northrop Grumman) in 1987, because OSC could not find a cost-effective small launch vehicle to fulfill a satellite constellation business plan. Hercules Aerospace partnered to support with motor expertise. First successful launch was already after 3 years in 1990 and it is still operational as a stretched Pegasus XL. Pegasus was the first privately funded launch vehicle, but DARPA did award OSC one launch service in 1988.[16,17]

OSC also developed Taurus (now Minotaur-C), which consists of 3 stages from Pegasus with an additional first stage and an increased fairing. DARPA awarded OSC a Standard Small Launch Vehicle (SSLV) contract in 1989, which had requirements of a 5 day set-up time from arrival to the launch site and to launch within 72 hours after set-up.[18]

Russia's Moscow Institute of Thermal Technology (MITT) developed Start-1 launch vehicle, which performed the first flight in 1993. Start-1 last flew in 2006, but funding was secured in 2018 to start new commercial missions as early as 2022.[19]

Japan had the Mu or M (M-V) series of rocket active between 1966 and 2006. This was followed by Epsilon to reduce the cost. Currently, an upgraded Epsilon S is in development for commercial launch services by the integrator IHI Aerospace.[20]

Lockheed Martin started development of Athena I (Lockheed Martin Launch Vehicle until 1997) in 1993 as a privately developed launch vehicle (LV). First launch was in 1995 and together with the larger Athena II, a total of 7 launches were performed until 2001. In 2010, it was announced that launches will resume in 2012, but that did not come to fruition.[21]

SpaceX was founded in 2002 and performed the first orbital launch attempt of Falcon 1 in 2006. First successful Falcon 1 launch was in 2008. The second and only commercial launch was completed in 2009. An improved Falcon 1e was proposed, but both were retired in favour of much larger Falcon 9, which has been successfully flying since 2010.[22]

Rocket Lab was founded in 2006 and performed the first orbital launch attempt of Electron in 2017, after 11 years of development, and the first successful mission to orbit in 2018.[23]

Firefly Space Systems was founded in 2014 and Vector Space System in 2016 and both have entered bankruptcy and come back. Firefly Aerospace made their first unsuccessful orbital launch attempt in 2021.[24] The renamed Vector Launch was aiming to start launches in 2022,[25] but instead a wind down plan was approved in January 2021.[26]

Finally, briefly about larger and reusable launch vehicles, because there were many being planned and in development before SpaceX. At least two firms had entered into negotiations to buy and operate a fifth Space Shuttle in the 1980s.[15,27] Kistler Aerospace was founded in 1993 and planned a K-1 reusable launcher. In 2000, Kelly Space & Technology was developing the Astroliner vehicle with the first launch planned for 2002. Rotary Rocket Company was developing Roton C-9 with launches planned to start in 2000.[28] Beal Aerospace was founded in 1997 and tested BA-2 rocket engine, but closed in 2000 after peaking at 200 employees, and their Texas test facility became SpaceX's McGregor test site. In addition, there were many United States programs including X-33, many international projects like AVATAR from India, HOPE-X and SSTO from Japan and all 15 or more Ansari X Prize competitors with various designs.[28]

The quantity of small launch vehicle developers started to increase rapidly approximately after 2014, as discussed later during Figure 8.

## 3. MARKET SURVEY

This section describes the survey criteria, which has resulted in the 180 entries and provides explanation about some of the classifications used to categorize and compare the small launch vehicles.

### *3.1 Survey Criteria*

- **Small launcher** - 1500 kg to Sun-Synchronous Orbit (SSO). Previously, the NewSpace Index's database payload criteria was set to 1000 kg, but it was recently increased, because the previous limit started to filter out some promising new market players. Due to the very recent payload increase, some launchers might be missing. In literature, micro-launchers have been defined as <500 kg and small launchers as 501 kg - 2000 kg.[5,8,29] NASA has also used <2000 kg for the small launch vehicle class.[30]
- **Commercial and civilian** - It is preferred that rockets must be or planned to be available in the commercial market or they have launched such missions. This criteria excludes small launch vehicles from Israel (Shavit), Iran (Safir) and North Korea (Unha) for example, but there are exceptions at the moment resulting in multiple entries.
- **Performance to SSO orbit** - Different entities publish varying payload performance values for the rockets. In this case, payload to 500 km SSO is the most preferred one and thus some values might look smaller compared to other sources. When suitable official values have not been publicized, as for many rockets, then any available specifications have been used. No effort has been made to re-calculate payload masses into the same orbit. In other words, performances are not strictly comparable because the orbits can be different.
- **Orbital class** - Must be capable of putting a payload into orbit. Suborbital launch vehicles have not been included in this survey.
- **First launches after 1990** - This limit exists currently to include commercial Pegasus and Athena launchers, while excluding early and often non-commercial rocket families like Scout (USA), Thor-Delta (USA), Diamant (France), Long March 1 (China), M or Mu (Japan), Kosmos-3M (Russia) and others.

### *3.2 Status Classification*

One of the following statuses has been assigned to each small launcher, based on all available public information, and in some cases by the lack of it.

- **Retired** - Launchers that were operational, but have since been officially discontinued, or no further launches have been announced, or many years have passed since the last update.
- **Operational** - Launches to orbit have been performed (successfully or not) and the next launches will likely have useful payloads and high likelihood of achieving orbital velocity.
- **Development** - Suitable indicators are two or more of: the company and project is visibly active, the year for the first launch has been announced, relevant updates on social media channels and news, team size is increasing, private funding has been announced and/or governmental projects awarded.
- **Concept** - Alternatively, idea or study stage. Possible indicators are: study project and not yet approved for hardware development, lack of proof about sustained technical development, active development is unlikely based on funding level, types of updates on social media and via news media, team very small and not increasing and have alternative jobs based on LinkedIn. In other words, creating a website with some renders and specifications (in the best case) does not equal a new launcher in development. This status may be the most debatable, but still leaves a possibility that active development will start in the future.
- **Dormant** - The first step towards Cancelled. Possible indicators are offline website, lack of recent (1+ year) posts on all social media channels, very small team or a single person according to LinkedIn, and/or no announced funding. Some could be in stealth mode and time will show. For example, Astra developed in stealth, but they still had 50+ persons on LinkedIn, and plethora of activity and rumours in the space industry.[31]
- **Cancelled** - Indicates a launcher, which project has been announced to have been stopped, or which website has been offline for years, or no indication of the launcher on the organization website when it used to be before, or company officially bankrupt and closed.

## 4. SURVEY RESULTS

Figure 1 lists 127 of 180 surveyed small launchers, leaving out the ones designated with Cancelled, Dormant and Concept statuses for readability. Full list is and figure will be online on NewSpace Index.[32]

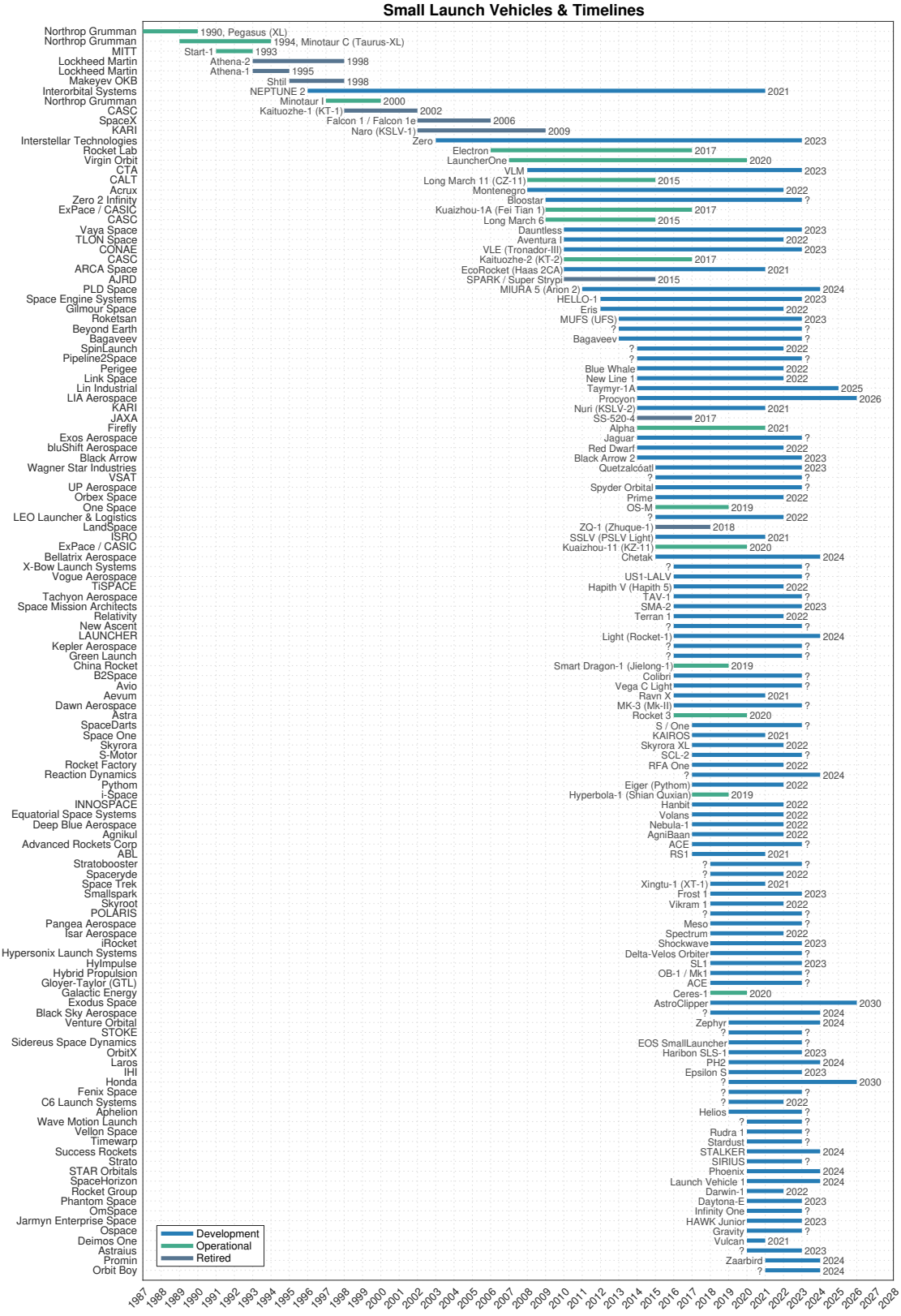


Figure 1: Small Launcher Timelines

## 5. STATISTICAL OVERVIEW

Statistical overview of the 180 entries included in this small launchers survey.

### 5.1 Development Status

Figure 2 depicts the current status of 180 small launch vehicles. 9 have been retired, incl. Athena, Falcon 1, SS-520-4, ZQ-1. 17 are operational, including Electron, Long March 6, Hyperbola-1, Rocket 3, LauncherOne and Ceres-1. Many of the currently operational will likely have rare or no future launches due to higher costs.

99 are in the development phase and about half of them have an announced first launch year. 14 are in the concept phase and 20 are in dormant stage. Both counts in the latter categories are likely higher and time will reveal.

9 have been cancelled, including Generation Orbit's GOLauncher 2, which was awarded a $2.1M NASA contract in 2013 to launch 3 CubeSats,[33] and Swiss Space Systems's (S3) SOAR.[34]

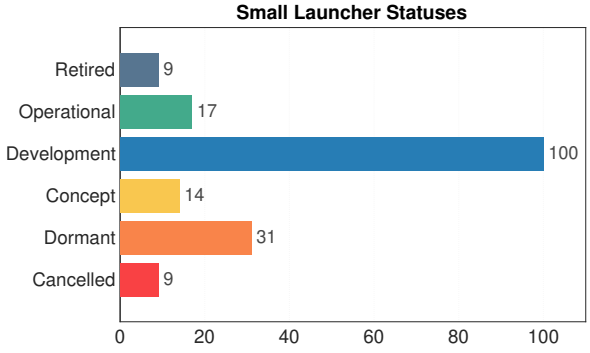


Figure 2: Current Status of Small Launchers

### 5.2 Performances

As seen on Figure 3, most launchers are aiming to offer payloads to orbit in the 50 - 150 kg and 150 - 300 kg ranges. Most of the collected specifications are for SSO orbits when data is available.

Rocket Lab's Electron is set at 200 kg.[35] Astra's Rocket 3 is at 150 kg,[36] but their website now seems to reference higher Rocket 4.0 or 5.0 specifications. Virgin Orbit's LauncherOne is set at 300 kg.[37] Firefly Alpha is set at 630 kg.[38] Relativity's Terran-1 is at 900 kg.[39] ABL's RS1 is at 1000 kg to SSO.[40]

There are approximately 3 dozen single-CubeSat launchers for masses less than 50 kg to SSO orbit, but none are yet operational and JAXA's SS-520-4 has likely been retired.

C. Niederstrasser uses the following payload categories: <20 kg CubeSat Class, 20 - 200 kg Micro Class, 200 - 500 kg Mini Class and >500 kg Small Class.[3] BIS Research uses: <20kg, 21kg - 150 kg, 151kg - 500 kg, 501 kg - 1200 kg, and 1200 kg - 2200 kg,[41] but here-forth seems more effective.

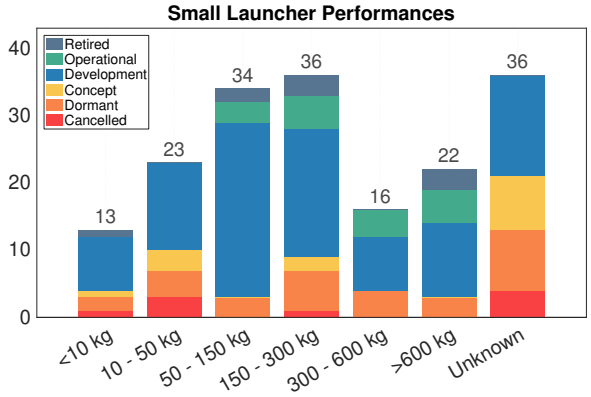


Figure 3: Payload Capacity of Small Launchers

### 5.3 Absolute Costs

Figure 4 shows the absolute costs (prices) for dedicated launches. Mission costs for over a half of the small launchers have not been publicly revealed.

None of the very low cost launchers are operational yet, which matches Figure 3 as most of those are planned to be for dedicated CubeSat missions.

Rocket Lab's Electron is $7.5M.[42] Astra's Rocket 3 is about $2.5M,[43] but in the Investor Presentation from Feb 2021, $3.75M has been used for 2025 launch revenue estimation.[44] Virgin's LauncherOne has often being quoted to cost about $12M.[45] Rocket Factory (RFA) is aiming for $3.6M.[46] Firefly Alpha is $12M.[38] Relativity's Terran-1 is $12M.[39] ABL's RS1 is $12M.[40] SpinLaunch is aiming for $0.5M.[47] Discounts are likely, more in case of recurring contracts. More details in section 5.16 and Figure 18.

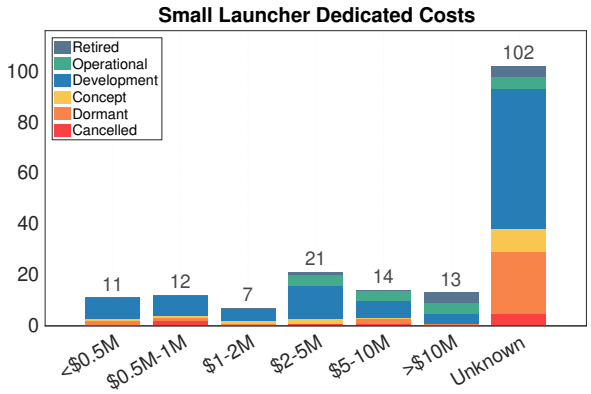


Figure 4: Dedicated Costs of Small Launchers

### 5.4 Costs per Kilogram

Figure 5 illustrates the dedicated launch costs (prices) per kilogram by different price ranges. There are only about 10% out of all small launch vehicles, which are aiming for less than $10000 per kilogram prices because that would be comparable to rideshare missions, but most will have higher costs.

For comparison, SpaceX Smallsat Rideshare Program is offering $1M for 200 kg to SSO with extra mass at $5000/kg.[48] That does not account for the adapters and deployers. Payloads with mass less than 200 kg still pay the full amount, which can increase the price per kilogram. More information in section 5.17 and Figure 17.

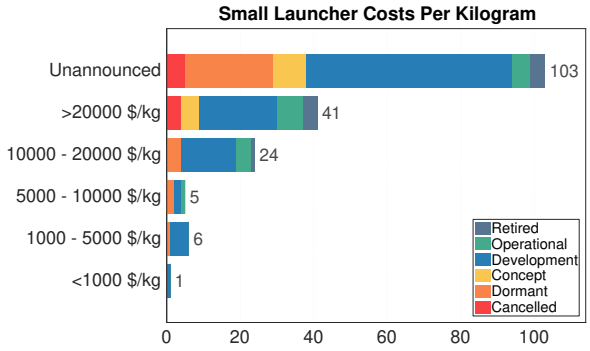


Figure 5: Kilogram Costs of Small Launchers

### 5.5 Launch Types

Launch methods or types have been categorized on Figure 6. Launching from land is the most popular choice followed by a plane and a balloon. There are 2 air launched or horizontal launchers operational, Pegasus and LauncherOne. None of the balloon and catapult projects have made an orbital lunch demonstration attempt. Shtil was launched from a submarine.

SpinLaunch is the best known catapult project and has raised about $80 million in total.[47] Second stage would still have to be a rocket to circularize orbit. There is some scepticism towards satellites being able to survive the G-forces, but it could also be used to send up bulk mass like water and other raw materials.[49] However, their publicized $0.5M and 100 kg per launch comes to $5000/kg, which is comparable to SpaceX's Falcon 9.

Spaceplanes intend to fly much higher and faster than conventional jet engine aircraft or can be Single-Stage-To-Orbit (SSTO), which take off from a runway. All are in early stages, but for example PO-LARIS from Germany.[50]

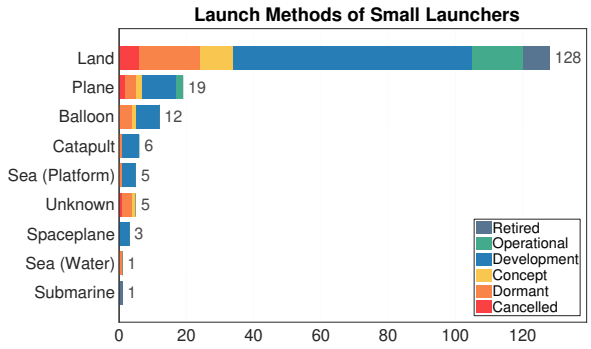


Figure 6: Launch Types of Small Launchers

### 5.6 First Launches

Figure 7 shows the first orbital launch attempts by years as they happened or by the latest public announcements. Most from 2021 will likely be delayed into 2022 or further.

Numerous dormant and cancelled small launchers had initially announced their first missions for 2020-2022. These years have been recorded on the chart, but the launches did not happen in reality. When orbital launches were attempted, then the status would be operational or retired.

Lockheed Martin's Athena I first launch was in 1995.[21] Falcon 1 first attempt was in 2006 and successful mission in 2008.[22] Rocket Lab's Electron first orbital launch attempt was in 2017 and it made to orbit in 2018.[23] Astra tried to perform a launch in March 2020 to win DARPA Launch Challenge, but missions were scrubbed.[51] Instead, Astra's first orbital launch was in September 2020 using a new Rocket 3.1, but it failed.[52] Firefly's Alpha first unsuccessful launch attempt was in 2021.[24]

Some examples of planned upcoming first launches. Gilmour Space is aiming to launch in 2022; Relativity in 2022; Skyrora in 2022; Isar Aerospace in 2022; Rocket Factory in 2022 and HyImpulse in 2023.

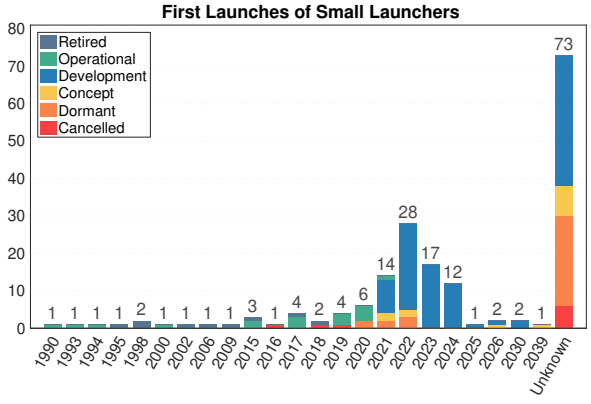


Figure 7: First Launch Years of Small Launchers

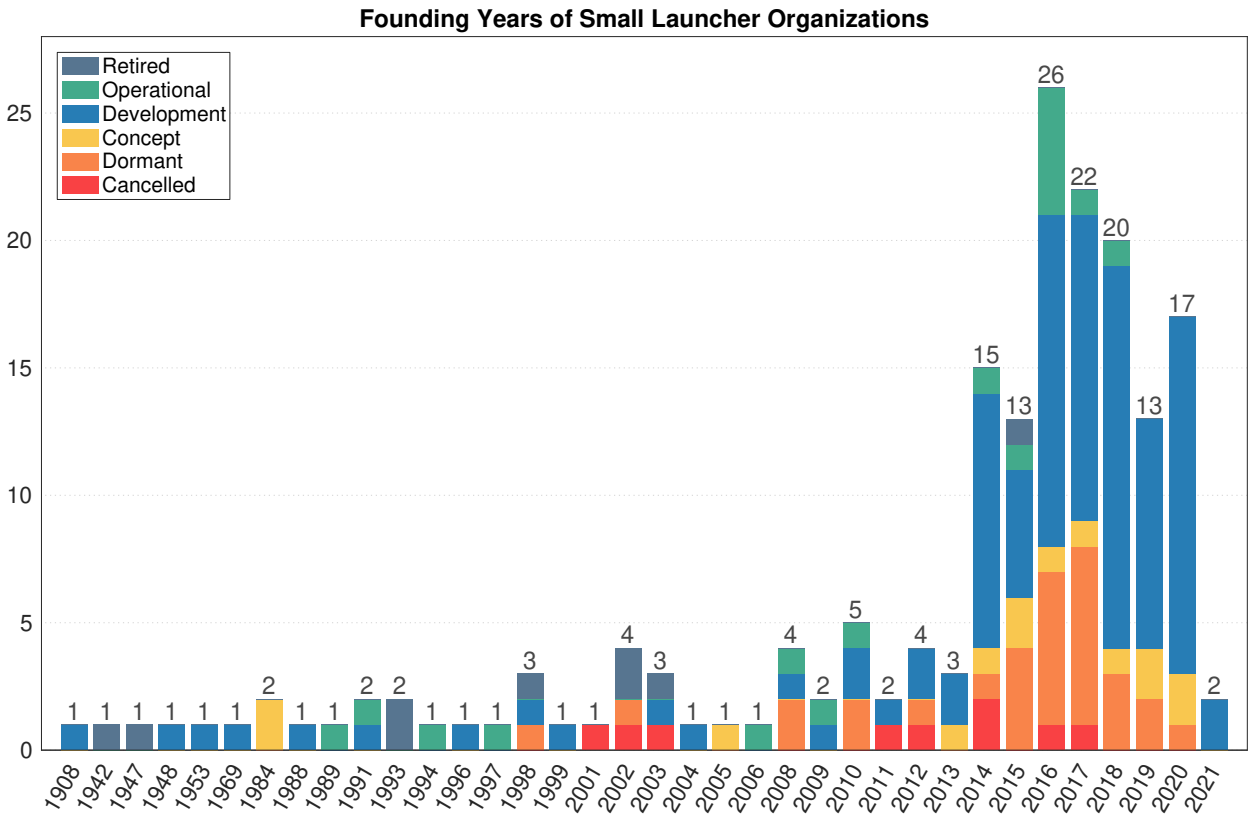


Figure 8: Small Launchers by Organizations Founding Years

### *5.7 Founded*

Founding years of small launcher organizations have been collected on Figure 8. Founding year does not match the start of the launcher projects for older organizations, but it usually does correlate for the new startups of the last two decades.

SpaceX was founded in 2002 and Rocket Lab in 2006. Virgin Orbit, then part of Virgin Galactic, announced LauncherOne in 2009, but development work had started in 2007.[53] Firefly was founded in 2014. LandSpace was founded in 2015. Relativity Space was founded in 2016.

Astra was founded in 2016,[44] but before the reincorporation, it was formerly called Ventions founded in 2005 and its about 10 employees moved to Astra.[54] Ventions had been awarded nearly 30 contracts worth about $20 million through its lifetime, most of them related to launch vehicles or propulsion.[55,56] Ventions was also part of DARPA's ALASA program to develop a very small air launched operational pathfinder rocket called SALVO, but Boeing was selected as the primary launch vehicle provider and ultimately none flew.[57,58]

Among the ended projects, Generation Orbit was founded in 2011[33] and Swiss Space Systems in 2012.[34]

The founding of new small lift launch vehicle companies peaked around 2016-2017, but has not yet collapsed. The amount for 2021, and perhaps 2020, will likely increase in the future as projects are made public and authors become aware of them. The peak years of 2016-2017 also have the largest amount of already dormant companies, which means they were founded during a broader boom, but most of them were never able to build a team, raise starting capital or progress into hardware development. Nevertheless, authors are predicting that in the next 2-3 years, the amount of new startups will be smaller because potential new actors will be waiting to see how promising companies of this time will perform.

The amount of CubeSats started to grow quickly from 2013.[59] Planet and Spire also launched their first CubeSats in 2013 and their first larger batches followed in 2014.[60] Starlink and OneWeb were publicly announced in 2015, but there were many news throughout 2014. These satellite constellation trends are possibly correlated to the large increase of small launcher projects starting from 2014 and with the general popularity increase of NewSpace.

### 5.8 Development Times

Small launcher development times in years is presented on Figure 10. The starting point is the founding year of the organization or an announced start of the project. End point is the first orbital launch attempt or the currently announced future goal, independent of the launcher making it to orbit.

The chart shows that it is possible to develop an orbital-class rocket in 3-5 years and many have achieved it. For example, Pegasus was developed in about 3 years, although subsequent upgrades have been made. Lockheed Martin's Athena took about 5 years. SpaceX's Falcon 1 took 4 years from founding until the first launch attempt. Astra took 4 years, but Ventions heritage could have helped to speed up the development. Firefly's Alpha took 7 years, but that included a bankruptcy period. Chinese new rocket startups have been relatively quick. iSpace was very fast with only 2 years required, while LandSpace needed 3 years.

At the same time, multiple small launchers have also needed 10 and more years for development. For example, there were 11 years between the founding of Rocket Lab and the first flight of Electron. Virgin Orbit's LauncherOne took 13 years since the start of the project until the first orbital mission attempt.

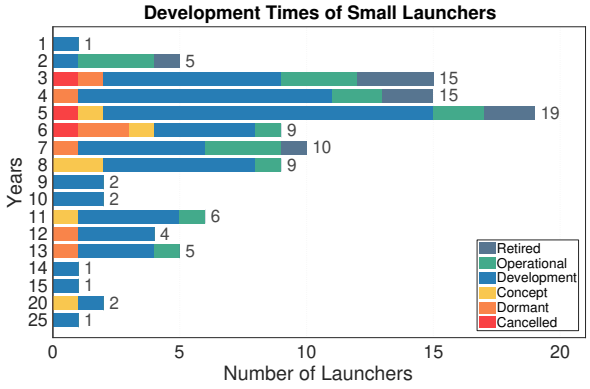


Figure 9: Small Launchers Development Periods

### 5.9 Development Delays

Development delays in years are on Figure 10. Originally announced launch years have been compared with the latest announcements or performed launches. Negative number means the launch dates have been brought forward, but it remains to be seen whether that stays true. A 2-3 years of delay is common. Large amount of launchers are unknown, because the flight date goals have not been announced.

Virgin Orbit originally aimed to perform first launch in 2016-2017.[61,62] Electron had and Alpha has had about 2 years of delays. Astra was and ABL currently is at about 1 year, but Astra has performed multiple flight attempts. Falcon 1 also required extra 2 years and 4 flights to make it to orbit.

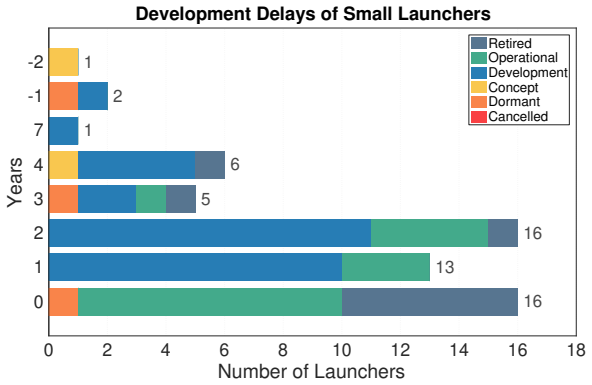


Figure 10: Small Launchers Development Delays

### 5.10 Launch Frequency

Planned launch frequencies or launch cadences have been collected on Figure 11. While many of the small launchers have recently become operational, none have yet achieved the planned flight rates.

In 2014, Rocket Lab was planning weekly launches,[63] but the authors have not come across that claim recently. In March 2019, Electron's launches were planned to be every 2 weeks by the end of the year.[64] In June 2020, monthly Electron launches were planned.[65] In reality, Electron launched 6 times in 2019 and 7 times in 2020 with 9 estimated for 2021 before the pandemic and launch failure.[66] There does not seem to be enough customers announced for a monthly cadence in 2022, but secrecy could explain it.

Astra is aiming to perform 300 flights per year by 2025.[44] Firefly and Virgin Orbit are aiming towards 2 launches per month.[38,67] In late 2017, Virgin Orbit was expecting to fly twice per month in 2020.[68]

ABL is projecting 8 launches in 2022 and 16 in 2023.[69]

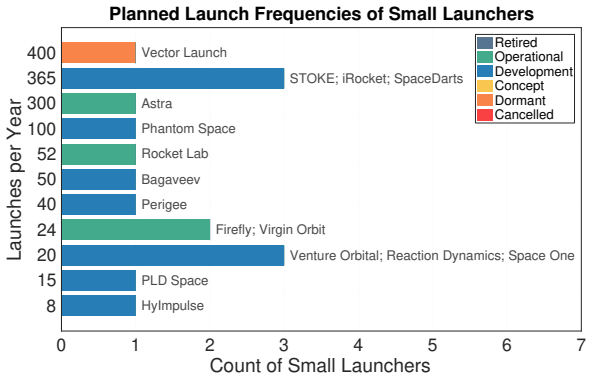


Figure 11: Small Launchers Planned Frequencies

### *5.11 Funding*

Funding amounts for small launcher organizations have been grouped on Figure 12. SpaceX, Rocket Lab and Relativity have raised over $1 billion by now, but it took much less than that to develop Falcon 1 and Electron, while Relativity has yet to attempt a launch.

Many launcher projects inside larger organizations must have received large amounts of funding too, but those values have not been made public.

Out of operational launchers or close to it, almost all have raised over $100 million, some multiple times of that. LandSpace has raised about $370M, One Space about $116M, iSpace is over $270M, Virgin Orbit about $700M, Astra has raised over $300M. Galactic Energy performed the first orbital launch attempt after having raised about $73M and is currently the lowest known commercial example.

Among the in-development launchers, ABL Space Systems has raised about $420M, Isar Aerospace is at $180M and Vector Launch has raised over $103M, but Vector likely is not moving forward after bankruptcy. Gilmour Space has raised $64M. Orbex has raised $80M. Skyrora has raised about $45M. SpinLaunch has raised $80M. PLD Space has raised about $32M. Rocket Factory (RFA) has not published fundraising figures, but they are backed by OHB.[70]

E. Berger reported in 2020 that "From its founding in 2002 to its first launch attempt in May 2006, SpaceX spent about $100 million developing the Falcon 1 rocket. Likewise, Rocket Lab CEO Peter Beck said his company spent nearly $100 million getting its Electron rocket into space. Astra has spent about the same amount on its Rocket 3.0 vehicle, which attempted first orbital launch in September. Firefly has raised and spent approximately $160 million in total after re-emerging from bankruptcy in 2016."[45]

E. Berger also reported in 2020 that Virgin Orbit has not revealed how much it has spent to date, but industry officials estimate it has expended between $500 to $700 million developing LauncherOne and the infrastructure to support it.[45] Virgin claims ∼$1 billion of expenses in investor presentation.[71] Which amounts to considerably more for similar capabilities, when compared to contemporary competitors.

L. Hoffman estimated it costs $100M to get to a first launch and $100M to scale up production.[72]

"Beyond the technical, it is also important to consider the viability of the launch vehicle provider model. Most launch vehicle developments will cost anywhere between $300 million and $700 million. If a company has only raised a small amount of money, there are valid concerns they will not be be in business long enough to get to the finish line."[73]

The minimum amount required to develop and launch an orbital class rocket seems to be at least tens of millions of dollars or close to $100M. Depending on whether engines are developed in-house or outsourced. Most of the launcher companies still have to keep fundraising to finish development, and this separates serious competitors. It is also clear that the new companies after SpaceX have not been able to lower the development costs by much yet.

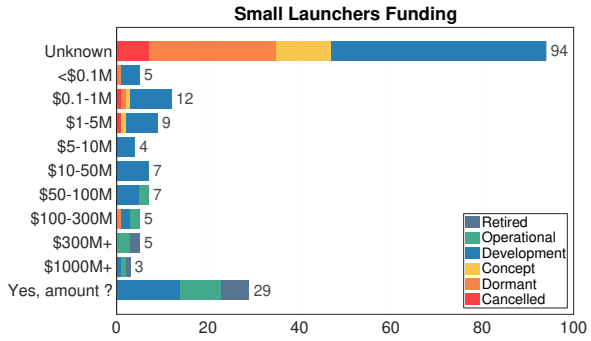


Figure 12: Small Launchers Funding Amounts

### *5.12 Launcher Stages*

The number of rocket stages is categorized on Figure 13. Where available, the criteria has been the count of stages required to reach a circular polar orbit. 4 stages is typical with solid rockets and most of them are operational in the US and China. Many new launchers have 2 stages, but some require an additional third stage to circularize orbit. There are also four 1-stage SSTO launchers in development.

Some of the 4-stage launch vehicles include Galactic Energy's Ceres-1, iSpace's Hyperbola-1, China Rocket's Smart Dragon-1, CALT's Long March 11, Lockheed's Athena-2 and Northrop Grumman's Minotaur I and Minotaur C.

Launch vehicles with 2 stages are Falcon 1, Rocket 3, LauncherOne, Alpha, RS1 and many others.

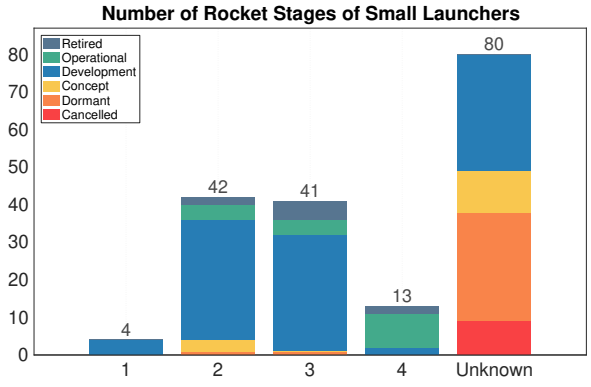


Figure 13: Small Launchers Stages

### 5.13 Propellant Types

Propellant or more accurately fuel types are shown on Figure 14. The criteria is defined by the propellant of the first largest stage or for the majority of the launcher stages.

Solid rockets are very common due to ICBM heritages and this matches with the previous list of 4 stage launchers. For example Galactic Energy's Ceres-1, iSpace's Hyperbola-1, China Rocket's Smart Dragon-1, One Space OS-M, Minotaur I and Minotaur C. Many solid launchers have 3 stages like JAXA's SS-520-4 and ExPace's Kuaizhou-11.

Kerosene and methane are the choice for many modern launchers. Many more small launch vehicles will likely use kerosene or methane, but only liquid has been announced. Small launch vehicles using kerosene include Falcon 1, Electron, Rocket 3, LauncherOne, Alpha, RS1. Methane is used by Zero 2 Infinity's Bloostar and Rocket Groups's Darwin-1.

Hybrid is a promising technology, but none have been demonstrated recently or yet on orbital-class rockets. For example HyImpulse, Gilmour Space, Smallspark Space Systems and Innospace.

There does not yet seem to exist a clear advantage between the launch costs and propellant types and such economics would have to be proven.

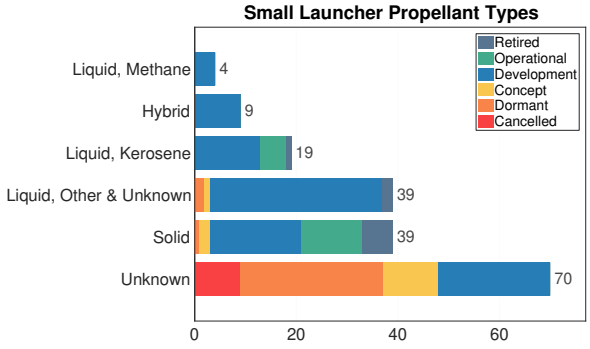


Figure 14: Small Launchers Propellant Types

### 5.14 Reusability

Figure 15 depicts the reusability status of small launchers. Partial reusability and full reusability has not been differentiated at this time.

Most small launchers are not planned to be reusable. Currently 22 have reusability in development, but important to note that a large number of organizations have not announced plans. Most visibly, Rocket Lab has been developing Electron's re-usability with one booster recovered from the sea and more planned for eventual mid-air catch by a helicopter.[74]

11 organizations have announced their plans to develop reusability in the future, which could and likely means new launch vehicles.

Firefly's larger Beta launcher will be partially reusable and Gamma spaceplane, while Alpha may be developed further to have it.[75,76] ABL's RS1 is designed to be expendable, but may be upgraded to be reusable in the future.[77]

Virgin Orbit has no immediate plans for recovery attempts, but is evaluating parachute recovery of the first stage and an evolved rocket called LauncherTwo, which could include reusability.[71,75]

Astra has not publicly commented reusability plans to authors knowledge and seems to prefer scaling up the production of simpler rockets in order to use the economies of scale to lower costs.[75]

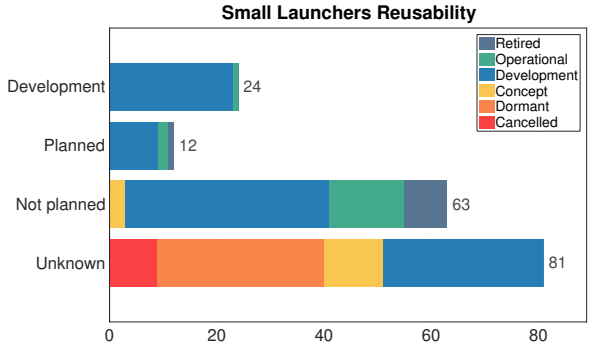


Figure 15: Small Launchers Reusability

### 5.15 Geographical Distribution

Distribution of the small launcher companies by the locations of legal headquarters is on Figure 16.

For companies that have presence in multiple countries, only the first primary location has been shown. Rocket Lab has a very large presence in New Zealand including the launch site, but the legal headquarters is in the United States.

Launch sites can be based elsewhere, which is the planned situation for many European launchers.

The United States is where most of the entities are located followed by China, United Kingdom and India. Though, only USA, China and Russia have operational small launchers. UK has a relatively large number of developers including Orbex and Skyrora. France, Germany and Italy have large Ariane and Vega development workforces, but launcher companies located in those countries are relatively new. Rocket Factory, HyImpulse and Isar Aerospace are all located in Germany. India is home for Skyroot Aerospace, Agnikul Cosmos and Bellatrix.

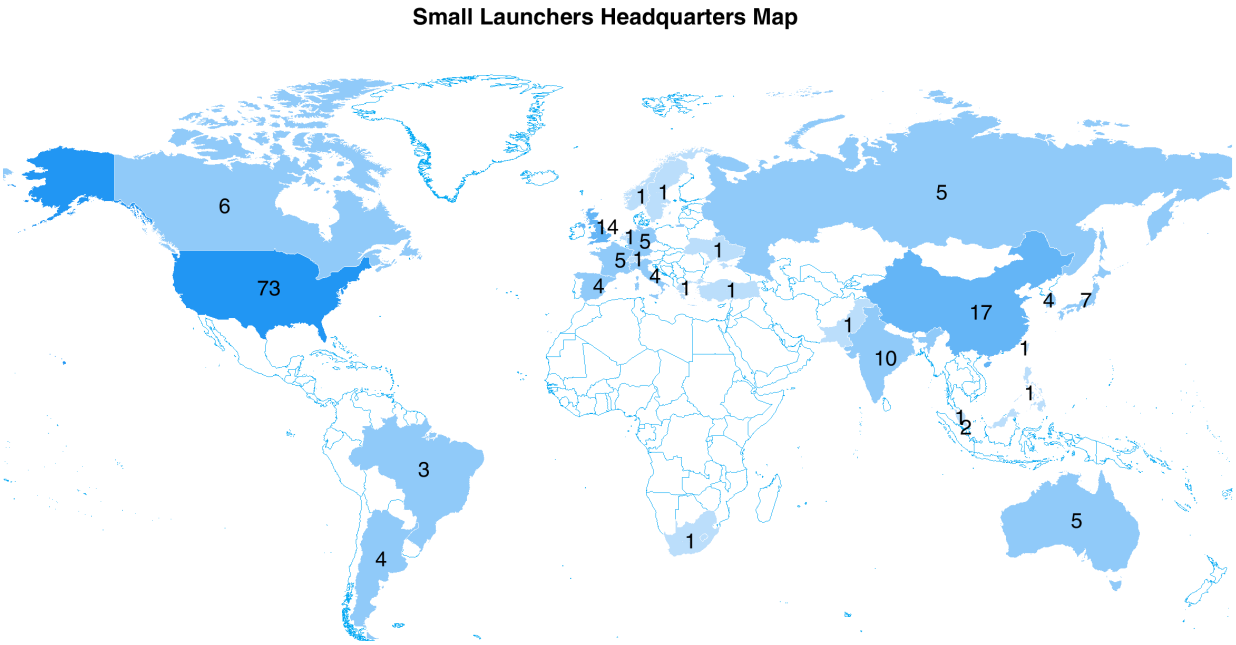


Figure 16: Headquarters Locations of Small Launcher Organizations

### *5.16 Absolute Costs vs Performance*

Figure 17 plots the absolute costs (prices) of the rockets in relation to payload capabilities in kilograms. As seen from the chart, Pegasus is relatively expensive at about $56 million for dedicated launches and the upcoming Epsilon S stands out too at $25-30 million per mission.[20]

At any payload capacity and close to operational status, Astra is currently among the lowest cost for dedicated missions with the stated launch costs between $2.5 - 3.75 million for Rocket 3.[43,44]

Rocket Factory Augsburg (RFA) has one of the lowest costs at $3.6 million per launch, while still being capable of launching over 1 ton spacecraft.

Interesting to note that SpaceX's Falcon 1 cost less, when not taking inflation into account, and planned to have more payload capability, than Relativity's Terran-1, Firefly's Alpha, Virgin Orbit's LauncherOne and ABL's RS1.

Lockheed Martin's Athena-1 is also similar in cost and payload capability to many well-funded upcoming launch vehicles and perhaps they should have reintroduced it as was planned in 2010.[78]

There are numerous lesser-known and lesser-funded startups offering even lower dedicated launch costs, but there is much work to do for them to make it to the launch pad and to attempt orbital launches.

### *5.17 Costs per Kilogram vs Performance*

While dollars per kilogram is not the single best way to estimate launch costs, because of additional adapter structures increase the cost and mass, and there can be volume limitations, it is still a good starting point for comparing launch options.[79]

Figure 18 plots the kilogram costs of launchers in relation to payload capabilities in kilograms. Some values may seem higher, because payloads to SSO orbits are preferred where available.

Japanese SS-520-4 is very expensive at approximately $875,000/kg. Pegasus also stands out with high launch costs of about $126,000/kg.

Among the retired launchers, without accounting for inflation, Lockheed Martin's Athena-1 was $21,400/kg and SpaceX's Falcon 1e was $11,000/kg.

Among the well-known or operational launchers, Rocket Lab's Electron is at $37,500/kg; Astra's Rocket 3 is at $16,700/kg; Virgin Orbit's LauncherOne is $40,000/kg; Relativity's Terran-1 is $13,300/kg; Firefly's Alpha is $23,800/kg, ABL's RS1 is $12,000/kg; Galactic Energy's Ceres-1 is $11,400/kg; iSpace's Hyperbola-1 is $16,700/kg; One Space OS-M is $42,000/kg; and Rocket Factory's RFA One is low $3,000/kg.

Other lower cost per kg are Space Engine Systems HELLO-1 at $950/kg; United Frontiers Discovery-2 at $2,000/kg; SpaceDarts S/One at $3,000/kg; Vogue Aerospace's US1-LALV at $4,000/kg; SpinLaunch at $5,000/kg and Vector Launch's Vector-R at $7,000/kg.

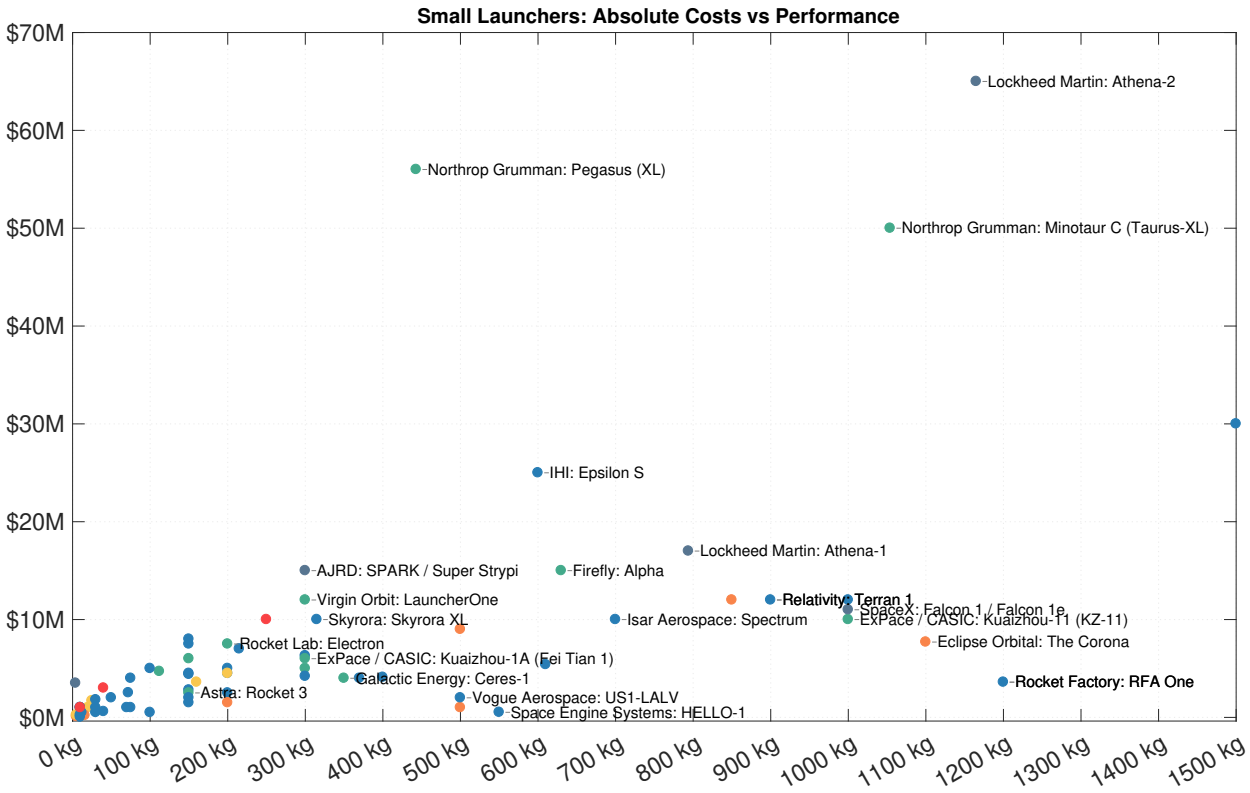


Figure 17: Absolute Costs per Kilogram vs Performance of Small Launchers

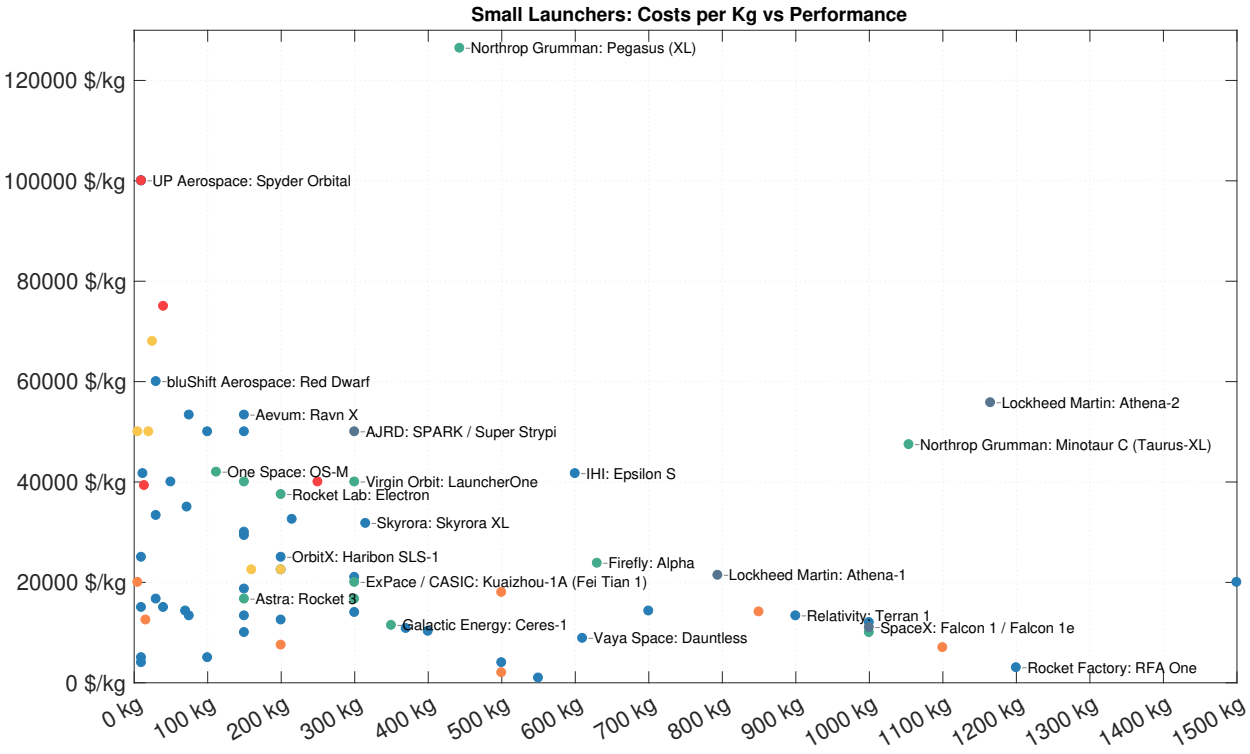


Figure 18: Costs per Kilogram vs Performance of Small Launchers

## 6. MARKET ANALYSIS

This section presents an overview of market studies, competition and revenues for small launchers.

### *6.1 Market Studies*

Most studies estimate the 2020 launch market revenue between $5-9 billion. With 114 orbital launches performed in 2020, 25 of them by SpaceX,[80] and many small launchers with costs less than $100 million, the lower numbers could be more realistic.

According to Bryce Tech, commercial launch vehicles had $5.3B of revenues in 2020, when adding up the 94 commercially procured launches with $2.1B of that in the US.[81]

M. Sheetz reported in August 2021 that Deutsche Bank estimates the global launch market will grow from $8B today to $38B by 2030, and market to be supply constrained for the rest of the decade. Launchers were categorized by ranges: small <1500 kg, medium 1500-8500 kg, heavy 8500-30000 kg and super heavy 30000+ kg. By ranges, the revenue increases from 2020 to 2030 were; small: $0.3B to $3.2B; medium: $2B to $7B; heavy: $5.2B to $14B and super heavy: $0B to $13.3B.[82]

ResearchAndMarkets estimated space launch services market at $12.86 billion in 2020 and reaching $14.92 billion in 2021 and $31.84 billion by 2026.[83]

Trends Market Research estimated in 2021 that space launch services market accounted for revenues of $8.9 billion in 2018 and is anticipated to generate $30 billion by 2026.[84]

Isar Aerospace estimates the market for launching satellites up to 1200 kg at $580 million per year.[85]

The demand for small satellite launches is estimated to grow to $11.6B by 2030. This demand will derive primarily from commercial constellations and could take the market past the $62B mark, according to a Frost & Sullivan report from Q1 2018.[86]

Euroconsult's 5th edition of Prospects for the Small Satellite Market report estimates that in the next 10 years about 8600 smallsats will be launched at an average of 835/year over the 2019 to 2023 timeframe, growing to an average of 880/year over 2024-2028. 3549 in 3 mega-constellation, 3540 in other constellation and 1469 in single satellite missions.[87] In the 6th edition of Prospects for the Small Satellite Market, Euroconsult forecasts that two mega-constellations will account for half of the smallsats to be launched between 2020 and 2029, yet only accounts for one fifth of the total smallsat market value due to economies of scale, mass manufacturing and batch launches.[88]

As an another example, smallsats in the <10 kg mass category will only account for a mere 2 percent of future total market value over 2019-2028, due to their low manufacturing and launch value compared to larger smallsats, despite accounting for a large share of the number of smallsats to be launched.[87]

SpaceTec's UK specific Space Launch Market Analysis from 2021[89] estimates yearly UK launches in 10 years to be between 50-200 at about $480M annual average revenue.

#### *6.1.1 Serviceable Addressable Markets*

Studies tracking smallsat launches and forecasting the future demand rarely mention the sizes of obtainable markets. Graphs show large increase in launched smallsats, but majority are SpaceX's Starlink, which are launched on SpaceX rockets and thus not part of the serviceable available markets. OneWeb has been using Sojuz rockets.[90] Kuiper reserved Atlas-V and said that launches will be competed,[91] but Blue Origin winning them is probable. Rocket Lab is planning their constellation,[92] very likely launched on in-house rockets. European megaconstellation will possibly use European rockets. Unknown how many will be left for open competition.

Market is growing, but in addition, constellation economics is challenging and almost none has been proven including Starlink. There is no guarantee that most of the announced 200 constellations will happen.[60] Many of the constellations that have higher probability of success like Starlink, Kuiper and Rocket Lab will use in-house launchers, because it is a major competitive advantage due to lower cost and flexibility.

High levels of uncertainty remain as the smallsat market is very volatile. The failure of a constellation may represent hundreds of satellites.[88]

According to A. Najjar of Euroconsult, it is much more economical to launch constellations on standard rockets, which can carry 60 or so at a time. Another big slice of the small satellite-business is Chinese, and they launch their own satellites. That leaves a "niche market" to feed Britain's commercial launch ambitions.[93] For example, due to geopolitical considerations, US-built satellites are unlikely to launch on Chinese launch vehicles, and vice versa. As China represents significant shares of the market, this adds to the market which cannot be addressed by non-Chinese manufacturing and launch providers.[87]

### *6.2 Small Launcher Benefits Claims*

Small launchers have benefits over larger rideshare missions in terms of on-demand flexibility, specific orbits, and in some cases, shorter time to orbit from contracting. These ensure that some market opportunity always exists. Though one rarely hears from potential constellation customers about what they think about the benefits of dedicated launchers.

#### *6.2.1 Cheaper Cost?*

Some years ago, small launchers also claimed to be able to achieve cheaper costs and these expectations were repeated.[94–96] Partially due to mass manufacturing and 3D printing. However, Rocket Lab has used 3D-printed engines from the start.[97]

Rockets do not scale down very well, which is why there is a limit to how low costs can be decreased and why almost all operational launchers have relatively high per kilogram costs.

Launch costs have decreased about 2-3 times in 30 years according to P. Lionnet,[98] when the Space Shuttle data is removed. A magnitude cost increase is possible to show, but only in specific scenarios.

Further cost decrease might happen only when many new rockets become operational and compete with each-other for the limited amount of demand.

J. Foust reports that companies offering smallsat launch services argue there is no "magic" price per kilogram that allows them to unlock greater demand, with customers willing to trade off price for responsiveness or other capabilities.[99] Price elasticity of space launch is a complicated topic, and when excluding CubeSats and small satellites, which had the advantage of lower absolute costs, authors are unaware whether there has been an increase in demand yet, apart from Starlink and OneWeb.

#### *6.2.2 Launch Site Closeness*

Many small launch providers are selling the benefit of launching from the same country where the spacecraft are being built. In such a case, rocket and equipment can be assumed to fit into a few shipping containers and only a handful of people are necessary. Nevertheless, it should be always cheaper, simpler and faster to ship only a microsatellite or a small satellite to almost anywhere in the world. Expecting to only see niche launches in different countries largely funded by governments. Most small launchers will likely limit itself to 1-3 permanent launch sites. Similar case will be true for home-country launches, which is unlikely to succeed unless prices are comparable to worldwide market.

#### *6.2.3 On-Demand Flexibility*

One of the strongest arguments for dedicated launches is ability to choose a time, and possibly relatively short wait time or even at the last minute.

What is often ignored is that satellites tend to be built according to launcher schedule and do not sit on the shelf for long. Sometimes delays are good, because spacecraft would not have been finished on time. In other words, most satellites are built for a specific launch, and production can be re-planned in case of delays. Difficulties happen when the launches get delayed at the last minute, because re-booking rockets can be difficult once payloads are already at the launch site.

A few years ago there was a launch bottleneck and backlog of CubeSats,[100,101] which drove the founding of many launch companies, but it has largely disappeared.[102] There can be a wait time and draught periods, but most customers would not pay much in extra to save a few months, and it is improving.

Peter Beck, CEO of Rocket Lab, and others have drawn an analogy between bus and taxi.[72]

J. Foust reported in 2021 that Rocket Lab and OHB emphasized that the dedicated mission went from contract signing to launch in less than six months. However, SpaceX has achieved similar timelines.[103]

Rocket Lab is seeing customers willing to pay more to launch to a specific orbit on a set schedule and has been working to accelerate the schedule from contract signing to as little as five months. Cubesats can be launched within six months and in some cases within three months. Some other launch companies are making no effort to compete on cost.[99]

Launching larger batches is still much cheaper with rideshares and those missions can often wait. There are numerous opportunities currently and expanding. Steve Jurvetson has been unconvinced by arguments that small launchers can provide "nimble" dedicated launch services because the vast majority of smallsat launch demand will come from constellations. "Why would you launch one at a time at a higher cost per kilogram when you can put everything up into a particular plane in a single go?"[104]

#### *6.2.4 Specific Orbits*

There are constellation ideas and scientific missions which require specific orbits. For example, Aerial & Maritime and Sky and Space Global constellations wanted to launch to low inclination equatorial orbits, but have been cancelled. Specific orbits are also used for replenishments of single constellation spacecraft. Still, these cases are likely to be small percentage of the overall market.

### *6.3 Wider Market Competition*

Small launchers are not only competing between themselves for customers. Rideshare or piggyback launches, space tugs, deployment from space stations and on-board propulsion can all achieve the same goal of putting a spacecraft into desired orbit.

With so many upcoming launchers and likely available capacity, one should be able to find opportunities much faster in 1-2 years.

#### *6.3.1 Rideshare and Piggyback Launches*

As larger rockets get cheaper, the rideshare or piggyback costs decrease. As more all types of launchers enter operational status, the competition will increase and the amount of opportunities for rideshares will increase also. Many larger and reusable small launchers are aiming for weekly launches, which may then stop to be an unique value proposition.

Falcon 9 first launched in 2010 and now 11 years later, there still does not exist an operational competitor in terms of low costs for rideshare. SpaceX regular Transporter rideshare is $1M for 200 kg.[48] Market demand increase could incentivize more frequent missions. Competitors like Neutron and Terran-R were announced in 2021 with the first launches planned for 2024.[42,105] While SpaceX is aiming to attempt the first orbital launch of Starship in 2021.

SpaceX President and COO Gwynne Shotwell said that while the market shows greater promise for dedicated small satellite launchers today, SpaceX will not be reviving its first vehicle, which was dedicated to this market.[106]

J. Foust quoted Satellogic CEO Emiliano Kargieman saying the following in an interview "The new rideshare program that SpaceX has put together has reduced the price on the order of four or five times on a per-kilogram basis."[103]

#### *6.3.2 Orbital Transfer Vehicles (Space Tugs, OTV)*

Space tugs are a relatively new competition to small launch vehicles and they have been enabled by decreasing costs of rideshare missions. Many have become operational in the last years. Space tugs can be capable of releasing spacecraft into specific orbits, removing one dedicated launcher advantage. J. Foust added that the development of in-space transportation services, to move satellites dropped off on rideshare missions to desired orbits, negates some of the advantages of small launchers.[103]

The space tug economics and sustainability is currently unknown, because the OTV development, build and launch costs will be added to the satellite costs. These expenses can be high, but space tugs will likely become reusable and Starship is designed to decrease the costs per kg significantly.

"A customer looking to send a relatively uncomplicated satellite to sun-synchronous orbit (SSO) at 500 kilometers, for instance, might find the lowest launch cost with a rideshare mission because that orbit is heavily serviced. Because of this, there isn't likely room in the industry for dedicated space tug providers, thus consolidation can be expected."[107]

#### *6.3.3 Space Stations and Re-Supply Spacecraft*

Hundreds of CubeSats[108] and microsatellites have been launched from the ISS taking advantage of the available capacity of the cargo re-supply vehicles and their relatively low costs per kilogram of mass. Soon after, satellite deployers started to be attached directly to the re-supply spacecraft like Cygnus. After departing from the ISS, they increased orbital altitude and then deployed the nanosatellites. This generally did not add much the actual costs, while taking advantage of additional capabilities which would not have been used otherwise.

Similar scenario is likely to repeat with future (commercial) space stations like Axiom and Lunar Gateway. Same with free-flying spacecraft, for example ESA's Space Rider orbital spaceplane may be used for CubeSat deployment. While the range of orbits is limited, there are large number of customers for who cost is the primary driver.

#### *6.3.4 On-Board Propulsion Modules*

Most of the operational constellation spacecraft likely prefer to have on-board propulsion for collision avoidance, station-keeping and de-orbiting. Thus, there are many scenarios where adding a more capable propulsion module for small orbital changes ends up being lower cost compared to using a space tug or dedicated launcher. This is what Starlink and OneWeb satellites have been doing, increasing their orbit altitudes after deployment from the rocket.

Kineis booked Rocket Lab's Electron to deploy 25 IoT satellites across five dedicated missions. The Kick Stage will act as an orbital transfer vehicle to deliver each satellite to precise orbital planes at a 650km altitude, allowing Kinéis to avoid sacrificing spacecraft mass for propulsion and to begin operational service as quickly as possible.[109] Kineis likely required 5 different orbital planes, which would have been slower to serve with other methods. In general, they are paying about $1M per spacecraft in launch costs and propulsion modules can be much less.

### *6.4 Revenues and Profitability*

E. Berger wrote well that "running a rocket company is an expensive proposition. You need hundreds of employees, lots of expensive machines, plenty of hardware, and at least one launch site."[110]

A. Najjar from Euroconsult warned that investors should be wary of some of the SPAC revenue predictions calling them "very overly optimistic".[111]

Astra's revenue estimation from February 2021: \$4M and 3 launches in 2021; \$47M and 15 launches in 2022; \$206M and 55 launches in 2024; \$619M and 165 launches in 2024; \$1125M and 300 launches in 2025.[44] Astra justifies SPAC's \$2.1 billion valuation by performing 300 launches in 2025 at an average \$3.75M per launch, carrying payloads in the range of 50-150 kg.[112] After emerging from stealth in early 2020, Astra said they are able to profitably deliver payload at \$2.5M per launch and were aiming for as little as \$1M per launch with daily launches.[31] Astra's backlog as of August 2021 is \$150M and pipeline is \$1.2B.[113] Astra's S-1 filing shows an operating loss of \$24.7M in Q1 2021 and \$73.5M for the year of 2020.[114] One note about Astra's 2025 revenue, this means over \$1 billion to launch 30 tons of spacecraft at 100 kg average. SpaceX's Falcon 9 can do that in 2-3 launches for approximately 10 times lower cost and Starship in less than 1 launch.

Virgin Orbit is projecting \$2063M revenue in 2026 and \$1627M of that would be from launches. Before that, \$15M is being estimated for 2021, \$70M for 2022, \$331M for 2023, \$914M for 2024 and \$1554M for 2025. Subtracting revenue from space solutions gives \$766M in 2024 and \$1240M in 2025 for space launches. Virgin also claims ∼\$300 million in active contracts and ∼\$1.3 billion in active proposals.[71]

Interesting to note that Virgin Orbit has been investing in constellation companies, which are then buying launch services. Virgin planned to take a stake in Sky and Space Global in late 2020 in return for launch services and 3-year \$1M per year consulting agreement.[115,116] Virgin invested \$5M in Arqit in 2021 and has been contracted to launch their first 2 satellites.[117] OneWeb booked 39 launches in 2015, but with dispute cancelled all but 4 due to cost.[118]

Rocket Lab's historical and estimated revenues from 2021 March are (launch in parenthesis): \$13.5M in 2018; \$48M in 2019; \$35M (\$33M) in 2020; \$69M (\$49M) in 2021; \$176M (\$115M) in 2022; \$267M (\$141M) in 2023; \$450M (\$232M) in 2024; \$749M (\$399M) in 2025; \$1159M (\$658M) in 2026; \$1571M (\$915M) in 2027.[119] Covid shutdown of New Zealand spaceport to limit 2021 revenue to \$52M.[120]

E. Berger reported in 2021 that according to a new proxy statement, Rocket Lab experienced net losses of \$30M and \$55M in 2019 and 2020, respectively, and an independent auditor "expressed substantial doubt" about Rocket Lab's "ability to continue as a going concern."[110] With 3 launches in 2018, 6 in 2019, 7 in 2020, and 4+ in 2021,[121] these losses show that launch cadence must improve.

Rocket Lab has announced 2 recurring constellation customers. BlackSky has booked 3 dedicated launches of 2 spacecraft each for 2021, 3 satellite launches have been performed in 2019-2020, and one launch failed in 2021.[122,123] Kineis bought 5 dedicated launches starting from 2023.[124] Rocket Lab's backlog as of June 2021 is \$141.4 million.[125]

ABL has a backlog of 75 launches, but 58 are likely from Lockheed Martin, who is also an investor.[126]

Small launch companies publicize contracts for single CubeSats. Virgin Orbit has announced the launch of CubeSats,[127] which likely pays only about 10% of single launch, and a MOU with SatRevolution.[128] Rocket Lab has done the same[129,130] and recently with SAIL,[131] which contract is worth ∼\$1.1M.[132] Rocket Lab's stock increased about 10% the next day,[132] increasing company's valuation by over \$500M, but could have been due to other reasons. Due to those financially small news, it leaves a possibility that most customers are being announced. As such news have been limited, it might imply that the backlogs are relatively small.

#### *6.4.1 Adding Up Revenues*

Adding up the estimated small launch revenues for 2025 for Rocket Lab, Astra and Virgin Orbit comes at \$2.7 billion. This \$2.7B for dedicated small satellite launches is larger than the Bryce Tech commercial estimate of \$2.1B for the whole US in 2020.[81] It does not include other promising launcher companies worldwide nor the other types of competition, especially rideshare on larger vehicles. It would also mean 1-3 daily launches across a year in just 4 years.

Constellation economics is challenging even with the lowest launch prices available on the market. Megaconstellations are very likely to choose batch deployment on larger rockets as it will be about 10 times cheaper than dedicated rockets. This means most revenue for small launchers must come from one-off or small batch spacecraft by a large number of customers. Such a scenario, with daily launches and increase in spacecraft diversity, seems unlikely to happen in 4 years. Geographical intricacies will further skew the market. Tracking constellations funding and batch manufacturing announcements should help to predict the demand 1-3 years ahead.

### *6.5 Valuations*

First some context, SpaceX was estimated to be worth $4.8 billion in 2012 after the first Dragon capsule docked with the ISS plus billions of dollars in awarded NASA and private contracts. By that time, SpaceX had performed 2 successful launches of Falcon 1 and 3 of Falcon 9.[133] Before the Dragon COTS Demo Flight 2, other estimates put SpaceX valuation at $1.3B and NASA funding at $400-500M.[134]

Rocket Lab went public in August 2021 at $4.8 billion valuation, providing it with $777M in capital.[135] In March 2021, the valuation was $4.1B.[136] In SPACs, redeeming the money is possible, and redemption rate was only about 3%.[137] They had 20 launches, Photon spacecraft, and much larger plans.

Astra went public in July 2021 at about $2.1B valuation[138] and raised nearly $464 million.[113,139] This perhaps seems high when compared to Rocket Lab, because Astra has not made it to orbit yet and their announced rockets have less potential uses compared to upcoming Neutron. Nevertheless, Astra has built numerous rockets, which have performed 3 orbital launch attempts, and completed them relatively quickly, which is more proven activity than can be said for most small launcher startups.

Virgin Orbit announced in August 2021 that it will go public at $3.2 billion valuation, while raising $483 million including $100M private round.[71,140,141] Virgin has performed 2 successful launches in 2021, but has invested about $1B to get here.[71,140] In October 2020, The WSJ reported that Virgin Orbit was raising up to $200M at $1B valuation.[142]

Firefly's latest round of $75M was announced in May 2021 and it valued the company at just over $1B. Firefly plans to raise $300M more later in 2021.[143]

Relativity Space's latest funding round announced in June 2021 was $650M and it valued the company at about $4.2B. Previous $500M round in Nov 2020 valued the company at $2.3B. Total amount raised is currently over $1.3B.[144] The first launch of Terran-1 has been delayed to early 2022.[145] The funding is also going to Terran-R and ultimate goal is to use its additive manufacturing technologies on Mars.[146]

ABL announced $170M round at $1.3B valuation in March 2021.[147] ABL has yet to perform any flights and in April 2021 the first 3 were scheduled for 2021.[148] In Oct 2021, ABL raised $200M at $2.4B valuation with the first mission now in late 2021.[69]

Viasat's Mark Dankberg compared the rush of companies going public with sky-high valuations despite little or no revenue to the dot-com bubble. Iridium CEO Matt Desch also sees similarities to the dot-com bubble and reminded about OneWeb.[149]

### *6.6 Sustainability*

Winners will likely depend on who can decrease the cost while keeping reliability. Although, with very low mission costs, there may not be enough cadence to cover companies fixed costs. Some small launch market will always exist for prototypes, governments, and for constellations that need to pick orbits and launch replenishments. Government subsidies will further enable some small launch vehicles to be developed, skewing the commercial market. Increasing small satellite market will also stimulate more dedicated rideshares. Rideshare is lower cost and piggyback missions will launch in any case, while the dedicated launchers need to make profit from theirs. Thoughts from industry have been mixed.[150,151]

Peter Beck, CEO of Rocket Lab, is not convinced there exists sufficient market demand for new launch services. Launch is not a great business, because it makes up just 4% of the overall space market and is rarely, if ever, profitable. SpaceX own satellite internet constellation, Starlink, is in part an attempt by the firm to enter a more profitable market.[93] Which is what Rocket Lab is aiming to do also.

J. Foust reported in 2021 that small launch companies appear to be increasingly turning to government customers, who are more willing to pay a premium for dedicated launch services, to close their business case.[103] Firefly's Les Kovacs said in 2019, "Of the 100-plus companies, my assessment is that you'll probably have five, six, maybe seven survive". US military will likely only support 2 vehicles.[152]

Roland Berger expects 5-7 microlauncher players to reach commercial scale in the next 10 years, and are confident at least one will be European.[153]

Chris Kemp, CEO or Astra, is likely correct in saying that the problem today is not a lack of demand but a shortage of operational vehicles,[154] but as of late 2021, many companies are 1-2 years away from achieving that regular operational status.

Charles Beames, chairman of York Space Systems, wrote well in SpaceNews op-ed, "In a growth phase, unsuspecting investors can be led astray by opportunistic huckster salesmen, thereby creating an artificially inflated market – the so called "bubble" that people keep talking about. This is not what we are witnessing in today's space industry, though. Instead, private capital is being invested to explore hundreds of different technical and business approaches to better address current and future space launch needs."[155] However, as seen on Figure 6 and others, most small launchers are similar, and well funded startups exploring new methods to get to space are rare.

### *6.7 Future Plans & Alternative Revenues*

Most launcher organizations are looking beyond expandable small launch vehicles to reusability, larger rockets and alternative revenue sources. Some are estimated to generate significant revenue.[44,71,119] Expanding the range of activities is likely the smart long-term step, similar to SpaceX and Blue Origin. The following descriptions are non-exhaustive.

#### *6.7.1 Reusability*

Reusability seems to be vital to stay competitive in the long-term. Rocket Lab CEO Peter Beck warned that anybody developing a launch vehicle that is not reusable is making a dead end product. I think reusability is absolutely fundamental.[154]

Many companies seem to be transitioning to larger reusable rockets and unknown who will fully develop and keep operating reusable small launchers.

#### *6.7.2 Larger Rockets*

Rocket Lab CEO Peter Beck noted that the demand is veering from small rockets toward larger vehicles that can launch bigger payloads.[154]

Notable trend is that numerous launcher startups are developing larger rockets after their repeated claims about the big increase in small satellite market and dedicated launch advantages. Yet most are responding to partially reusable Falcon 9 and not Starship, seemingly competing with what SpaceX is already doing, instead of planning in the future. Perhaps volume production is also more challenging.

Rocket Lab unveiled plans for its Neutron rocket in March 2021, a 8-ton payload class launch vehicle. "We've listened to our customers and the message is clear - biggest doesn't always mean best when it comes to constellation deployment." Efficiently building the mega-constellations of the future requires launching multiple satellites in batches to different orbital planes.[156] Neutron will enable significantly higher revenue per launch with its capability to deploy larger spacecraft and greater numbers of satellites per launch and will also be capable of supporting crewed flight and cargo resupply.[110]

Frefly Aerospace has plans for a larger vehicle called Beta, but work is only now starting.[157]

Relativity announced fully reusable Terran-R in Feb 2021.[105] That rocket is designed to place more than 20 tons into LEO, comparable to Falcon 9.[157]

Astra has announced Rocket 4 with increased size and performance and Rocket 5, which could also be used for point-to-point transportation.[158,159] The Verge reported in 2021 that Astra has signed a roughly $30M deal for the rights to manufacture Firefly Reaver rocket engines in-house, which would help Astra reach its stated "500kg to 500km" goal.[160]

Virgin Orbit is studying LauncherTwo as part of long-term technology development.[71] One challenge with air-launch is scalability, because the limitations of the plane and both may need to be upgraded.

Gilmour Space was planning a larger Eris-400 (Eris-L) in 2018, but current status is unknown.[161]

LandSpace has likely retired Zhuque-1 after the first failed launch and is actively developing Zhuque-2.[162] One Space is planning larger OS-M rockets.[163] iSpace is working on reusable Hyperbola-2.[164] Deep Blue Aerospace is also developing Nebula-2.[165]

#### *6.7.3 Satellite Programs*

Multiple small launch providers are working on in-house spacecraft development programs.

Rocket Lab's Photon will be used by Varda Space as a satellite platform and will be launched on Falcon 9.[166] Cheaper cost of rideshare was the primary reason over Electron's flexibility in orbit and dates.[167]

Rocket Lab has announced intentions to develop their own constellations.[92] Astra is developing disc-shaped modular spacecraft platform,[168] by the looks similar to Orbcomm-OG1. Gilmour is starting a satellite program.[169] Virgin Orbit is working with strategic partners on spacecraft constellations.[71]

#### *6.7.4 Orbital Transfer Vehicles (Space Tugs)*

Space tugs have considerable technological overlap with upper stages and satellite programs. Rocket Lab's Photon (Kick Stage) can also serve as a space tug and will fly CAPSTONE to the Moon in 2022[170] and to Venus in 2023.[171] LAUNCHER announced their orbital transfer vehicle called Orbiter, which will first launch on Falcon 9 rideshare in 2022.[172] Skyrora is developing a space tug.[173] Virgin Orbit is studying third stage and space tugs to enable orbits beyond LEO.[71]

#### *6.7.5 Miscellaneous Revenue Sources*

Rocket Lab is also selling spacecraft components and scaling up their manufacturing after acquiring Sinclair Interplanetary in 2020.[174] Firefly is also developing Blue Ghost lunar lander and received a $93.3M contract from NASA for launch in 2023.[175] Relativity wants to build an industrial base on Mars and is also looking into point-to-point space transportation on Earth.[145,146]

## 7. CONCLUSIONS

Statistical overview of 180 small launch vehicles with payloads up to 1500 kg has been presented.

- 5% of 180 small launchers are retired, 9% are operational, 56% are in development and 30% are either concept, dormant or cancelled.
- None of the very small single-CubeSat launchers with payloads up to 50 kg are yet to become operational.
- None of the small launch vehicles offer dedicated mission costs of less than $2 million.
- Costs per kilogram of dedicated rockets are higher than cheapest rideshare missions.
- There was a rapid increase of new small launchers starting from 2013-2014.
- Land-based launches are the most common, but 2 air launchers are also operational.
- 41% of small launchers have not announced any goals for their first orbital launch years.
- Development times can be as low as 2-3 years, but some have taken more than 10 years.
- Development delays in the range of 1-2 years are very common, but can be much longer.
- Some launcher have announced high cadences for future launch frequencies, up to daily launches, but far away from achieving that.
- Most operational and retired launchers have 4 stages, but new ones have commonly 2 or 3.
- About 30 launcher organizations have announced funding of more than $10 million dollars. Majority of small launchers do not have the funding at the moment to finish development.
- Solid propellants are popular for most operational launchers, but kerosene is becoming common and some new launchers are developing hybrid and methane rocket engines.
- Re-usability tends to be rare for small launchers with about 13% of rockets in development and 7% planned for the future.
- Most of the small launch vehicle organizations are based in the United States, but China also has many operational and upcoming.

From the market analysis side, a literature review of market forecasts was performed and many claims were discussed in a wider context.

- Space launch revenues are predicted to increase rapidly, but they assume most planned constellations being deployed in full, which is unlikely.
- On-demand flexibility and specific orbits has remained the largest benefit of small dedicated launchers, because it is lower cost and more efficient to deploy constellations in batches on larger rockets.
- Small launchers are competing with rideshare and piggyback launches, space tugs, space station re-supply spacecraft and with on-board propulsion modules.
- Revenue predictions from SPACs in 4 years are larger than current total US commercial launch markets and they do not account for other promising small launch vehicles companies nor all the other types competition like rideshare, thus they are unlikely to come true.
- Multiple companies have over $1 billion valuations without having performed successful launches to orbit while SpaceX was much further along when they had similar valuations.
- Many small launch organizations have started developing larger rockets, but also satellite platforms, orbital transfer vehicles and various other revenue sources.

The aim is to repeat this study annually or every two years, but the online database and public figures will be updated multiple times per year.

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