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A Small Launch Per Month? - 2022 Edition of the Annual Industry Survey

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ABSTRACT

While many, including this author, have publicly stated that the number of small launch vehicles under development is not sustainable, investor money continues to flow into this market segment. New announcements of multimillion funding rounds are occurring several times a year. Even the challenges posed by the worldwide COVID pandemic, have not slowed down this trend. In 2015 we first presented this survey at the AIAA/USU Conference on Small Satellites[1], and we identified twenty small launch vehicles under development. By mid-2022 eleven vehicles in this class were operational, 47 were identified under development, and another 47 more were potential new entrants for which there is not enough information. Many of these showed up in this annual survey for the first time in 2021 and 2022. While initially, development was spurred by renewed government investment in space, such as what we see in the U.K., segment growth has continued even when promise of government investment is not present. In this paper we present an overview of the small launch vehicles under development today. When available, we compare their capabilities, stated mission goals, cost and funding sources, and their publicized testing progress. We also review a number of entrants that have dropped out since we first started this report. Since the paper was last presented an additional system has become operational, and several have reached a steady cadence of launches.

In order to present the most unbiased, and neutral data to our audience, we purposely avoid making any judgements on vehicle maturity or business case realism. However, with 166 vehicles tracked in our research, a number of specific trends in performance, cost, and technologies can be identified. Finally, we attempt to answer the question of the validity of small vehicle development, when established players such as SpaceX and ULA believe that the continued growth area is for larger, not smaller vehicles. With several systems launching on a regular basis and directly competing against traditional ride-shares, it becomes possible to draw some initial conclusions on the reliability of the new systems as well as the potential demand for small satellite launch services. The author welcomes any comments, feedback, or corrections.

INTRODUCTION

A Launch a Month?

Dating back to the early days of the Space Age, there has always been a vision that sees space launch operations akin to air travel – with rockets taking off on a regular cadence from spaceports around the world. Initial estimates called for the Space Shuttle to fly once a week in order to meet its reusability financial goals. For the Space Shuttle that goal proved to be unattainable. More recently after twelve years of operations the SpaceX Falcon 9 appears on track to reach that milestone in 2022.

But what about small launch vehicles? Many of the new entrants discussed in this paper similarly hold goals of flying a new (or reused) rocket every week. Like was the case for their bigger predecessors, establishing a steady cadence of small launch vehicle flights has proven to be challenging. While still far from that lofty goal, 2022 may be the year in which combined launches from multiple small vehicle providers reach a milestone of monthly launches. An important first step along the way to weekly flights.

The Tradition of Small Launch Vehicles

Many of today's heavy launch vehicles – Atlas V, Delta IV, Falcon 9, and Ariane 5 – are direct descendants from small launch vehicles. The Delta IV evolved from Thor, growing from an Intermediate Range Ballistic Missile with space launch capabilities a bit above a metric ton to one of the heaviest launch vehicles the U.S. is currently flying. Atlas V traces its lineage to an InterContinental Ballistic Missile with staging engines and a pressure stabilized tank morphing to today's launch vehicle that nearly equals the Delta IV Heavy in capability. Ariane 5 grew from the small, purpose-designed Ariane 1. Similarly, SpaceX's Falcon 1 was quickly abandoned in favor of the larger Falcon 9 which in turn evolved into the Falcon Heavy. Of the small launchers in the 60s and 70s, only the Scout stayed small – limited by its technology and eventually being replaced by the Pegasus to fulfill DOD's and NASA's need for a small space launch vehicle. Athena joined Pegasus and Taurus, and several versions of Minotaur came along to utilize excess government assets in meeting the small space launch need, but the low launch rate destined these vehicles to high-priced niche markets.

The Second Small Sat Revolution

Just like ORBCOMM and Iridium led the commercial perception of a need for small launchers in the 1980s and 90s (and directly resulted in the Pegasus development), CubeSats and new constellations such as OneWeb, HawkEye 360, and Planet are creating a new wave of perceived small launch demand. Planet is now considered the world's "largest constellation of Earth-imaging satellites"[2] with over 450 satellites launched to date. OneWeb has launched 218 satellites for a constellation originally envisioned to include around 2,000 satellites, but at times reported to have a final goal of up 48,000 satellites. SpaceX has become the most prolific manufacturer and launcher of small satellites, with over 2,500 satellites launched to date and licensed for up to 42,000.

As small satellite capability increases, operators are no longer satisfied with the traditional rideshare and secondary payload opportunities available to them. During the past decade, there has been an increasing swell of interest in having new, lower cost, dedicated small launchers. Rideshare and secondary payload opportunities are invariable a compromise, the primary customer takes precedence, and the small satellite "tags along" to whatever destination the primary is destined to and follows a schedule dictated by the primary. This lack of flexibility is not overly-constraining when launching a small technology demonstrator, but is unfeasible when trying to field an operational asset or large constellation. This perceived new demand has led to a new wave of proposed small launch vehicles ranging in capability from a single 3U CubeSat (roughly 5 kg) to larger small launch vehicles reaching up to 1,000 kg to Low Earth Orbit (LEO).

These vehicles are hoping to solve the same problem that vexed the earlier generation of small launchers and satellites – large constellations are only financially feasible if launch costs are low, but launch costs can only be kept low if there is a high rate of launch. This "chicken and egg" problem proved untenable in the 90s, and it remains to be seen whether it can be solved today.

With large constellations such as OneWeb and Starlink now numbering in the thousands of vehicles launched, there is no question that the number of small satellites has reached record highs. However, it remains to be seen whether this translates to demand for small launch vehicles. To date SpaceX has launched all Starlink satellites on its own Falcon 9, while OneWeb has relied on Arianespace's Soyuz and is in the process of transitioning to Falcon 9.

Drivers and Motivation

For many of the new entrants the drive to develop a new vehicle is purely commercial. Driven by visions of hundreds, if not thousands, of small satellites launching annually, buoyed by venture capitals markets that become friendlier to space endeavors, and inspired by the highly visible success of SpaceX, entrepreneurs across the globe have embarked on what was once considered the incredibly risky and financially non-rewarding venture of designing and fielding a new rocket. Furthermore, beyond the commercial visions of economic glory, the lure of government contracts has likewise increased.

Beyond the limitations of the rideshare concept, there is also an overall perceived shortage of launch opportunities. Many of the new launch vehicle entrants habitually quote a "two-year backlog" on existing vehicles as a potential differentiator for their own endeavor. The success of firms such as Rocket Labs in filling out its initial manifest seems to back the assertion that there is significant demand in this size payload. Thus, the potential for capturing even a small portion of this market, drives many of the organizations developing new vehicles.

In recent years, The U.S. Department of Defense (DoD) and NASA have significantly increased the attention paid to small launchers. As small satellites increase in utility and capability, DoD and its associated agencies are interested not just in traditional launch services, but also in "launch on demand" services. Programs like DARPA's ALASA and NASA's VCLS promised to fund new entrants in their development of small launch vehicles. In 2018 the DARPA Launch Challenge (DLC) was announced with the aim to launch payloads with just 14-day notice to a previously unspecified orbit. The successful team would win a US$2M reward on the initial launch and US$10M reward on a second launch within two weeks. To many of the small launch vehicle contenders, DARPA's interest makes a lot of sense. "[DARPA's] seeing the same scenarios or requirements that a lot of us are seeing — the need for more responsive access," said John Garvey, president of launch services at Vector, one of the three companies selected as a finalist in the DLC.[3] However, much like the previous ALASA program, DLC failed to deliver on its promise. The challenge closed in March if 2020 with no winner selected. Nonetheless, two of the finalists have continued development, with one of them successfully launching an orbital flight; so arguably the demand and interest remain.

Across the Atlantic, European governments have not been idle either. ESA's Future Launchers Preparatory Programme (FLPP)[4] and studies funded through the European Union's Horizon 2020[5] have both contributed needed investment in the European market. More recently, the ESA Boost! Initiative awarded multi-million Euro contracts to five different European launch companies.[6] Individual countries have also taken a new interest in small satellites; for instance, the United Kingdom has been actively exploring potential launch sites for many of the new entrants and announced the selection of at least four sites across the country to field both vertical and horizontal launched vehicles[7].

A significant new player in the small launch vehicle arena is China. While China has been on the forefront of global launch services for many years, in the past six years they have also made significant investments in the domain of small launch vehicles. Of the 58 vehicles captured in this survey, nine are from China. Six of them are currently operational, the most of any country. One of the factors that makes Chinese involvement particularly interesting is that several of the companies, such as iSpace and Linkspace, are privately held and funded with venture capital. In the past all of Chinese launch efforts were carried out through state-owned companies or agencies. It is not clear at this point how much government involvement, technology, or funding has been given to these companies, but it is evident that, at least on paper, there is a formal separation between the Chinese government and some of the launch vehicle developers. This is all part of a big bigger effort in China; the Beijing-Based consulting firm Future Aerospace recently stated that there are over 60 private Chinese firms in existence.[8]

Although at the moment U.S. companies are prohibited from using Chinese launch services, companies in most of the rest of the world do not have such limitations. Thus U.S. launch companies may feel significant competitive pressure from their Chinese counterparts even if some of their customers are restricted from flying on Chinese vehicles. This is part of an overall drive by Chinese leadership to significantly increase commercial space activities in the country.[9]

The finance world has not been blind to these trends, which has led to an increase in venture capital flowing into the space market. While there was some investment during the first wave of small satellite and launcher developer in the 90s, those investments pail to the hundreds of millions that have been invested in the past ten years (plus billions more contributed by self-funding billionaires).

Underlying all the government and commercial investment is the very fast growth in small satellites over the past ten years. SpaceWorks Commercial in their 2020 *Nano-Microsatellite Market Forecast* revised its previous projections down by about 15% but still projects up to 2,400 nano-microsatellites launching in the next 5 years as shown in Figure 1.[10] This perceived market growth is matched in the growth of private investment dollars and government interest throughout the world, but especially in the United States. With the slowdown of the world economy and other world crises in 2022, it will be interesting to see whether the relatively unincumbered venture capital streams dry out or remain available to new and growing companies.

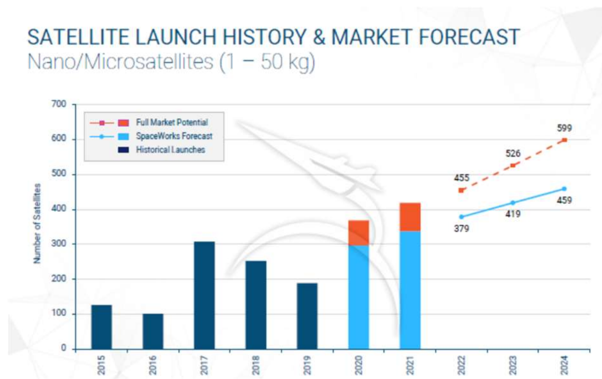

Figure 1: Growth in nano/microsatellite market (Source: SpaceWorks)

SURVEY CRITERIA

This survey's goal is to identify active commercial (or so designated) efforts in the field of small launch vehicles. Before starting the survey, we laid down some requirements for inclusion in the list. This was needed both to limit the field and to provide some clear definition of what an "active effort" entails. These requirements are neither scientifically rigorous nor complete; rather they are simply designed to serve as a filtering mechanism. The requirements, with some minor variations have remained the same in every yearly edition of the survey (the 2016 edition limited the upper mass of the payload performance to 500 kg, with only 3 vehicles dropping out of the survey).

To be included in this list a launch vehicle under development must meet the following requirements:

- Have a maximum capability to LEO of 1000 kg (definition of LEO left to the LV provider).
- The effort must be for the development of an entire space launch vehicle system (with the exception of carrier aircraft for air launched vehicles).

- Some indication through a web site, social media, traditional media, conference paper, press release, etc. that the effort has been active in the past two years.

- No specific indication that the effort has been cancelled, closed, or otherwise disbanded.

- Have a stated goal of completing a fully operational space launch (orbital) vehicle. Funded concept or feasibility studies by government agencies, patents for new launch methods, etc., do not qualify, but have been included in the "Other Potential Players" section.

- The launch vehicle must be available on the open, commercial market. (With the understanding that some countries are restricted with regards to what vehicles their space systems can launch on)

- Sufficient detail (technical, financial, business) to imply work in progress

The philosophy behind the guidelines to be considered "active" is based on the fact many of these efforts require some amount of confidentiality and secretiveness or may go dormant as a result of funding gaps. Therefore, we do not consider the absence of new information (in the last two years) to be indicative of the project standing down.

Beyond these criteria the authors have not attempted to validate the technology, business plan, feasibility, or realism of the systems documented herein. **We do not make any value judgements on technical or financial credibility or viability.**

CONTENDERS

Operational Systems

When the survey was started in 2015[1] only two operational systems fit into the category of "small launch vehicles" as defined by the 1000 kg to LEO limit. Northrop Grumman's (then Orbital ATK) Pegasus XL and Minotaur I were fully operational with a combined flight total of 53 flights. At the time, Lockheed's Athena I was dormant and was not included as "operational", although it too met the operational criteria with four flights.

In the intervening seven years, nine more new entrants have fielded a new vehicle and conducted a successful flight. Table 1 presents all the organizations that have an operational small launch vehicle, the vehicle's name, the published country(s) of origin, the first successful launch of the vehicle, and the overall success rate of the vehicle.

New Entrants

For our market survey, Table 2 presents an alphabetical roster of the 47 different organizations that qualified under the criteria set forth in the previous section. It also includes the vehicle's name, the published country(s) of origin and last announced date of first launch (if available). It is worth noting that a number of organizations have not updated their estimated date for first launch, and this date now lies in the past. This year the rate of change has significantly slowed with only five new entrants being recorded. Most notably Celestia Aerospace, which had previously been marked as status unknown is back on the list after a €100M fundraising round. Five previous entrants dropped out due to a lack of recent updates or changes in the developing organization. Astra transitioned out of the list of new

Table 1: Operational Small Launch Vehicles

Organization	Vehicle Name	Country	First Success	Success	Failures	Success Streak
Northrop Grumman	Pegasus XL	USA	5 Apr 1990	42	3	31
Northrop Grumman	Minotaur I	USA	27 Jan 2000	12	0	12
China Aerospace Science and Technology Corporation	Chang Zheng 11	China	25 Sep 2015	13	0	13
ExPace	Kuaizhou-1A	China	9 Jan 2017	13	2	1
China Aerospace Science and Technology Corporation	Kaituozhe-2	China	3 Mar 2017	1	0	1
Rocket Lab	Electron	USA/New Zealand	21 Jan 2018	23	3	6
iSpace	Hyperbola-1	China	25 Jul 2019	1	3	0
China Rocket Co, Ltd	Jielong 1	China	17 Aug 2019	1	0	1
Galactic Energy	Ceres-1	China	7 Nov 2020	2	0	2
Virgin Orbit	LauncherOne	USA	17 Jan 2021	3	1	3
Astra	Rocket 3.3	USA	20 Nov 2021	2	3	0

Table 2: Small Launch Vehicles Under Development

Organization	Vehicle Name	Country	Latest Launch Date
Aevum	Ravn X	USA	Q1 2022
Agnikul	Agnibaan	India	Dec 2020
Aphelion Aerospace	Helios	USA	1H 2022
ARCA Space Corporation	Haas 2CA	USA	2021
B2Space	Colibri	United Kingdom	
Bellatrix Aerospace	Chetak	India	2023
Black Arrow Space Technologies	Black Arrow	United Kingdom	2023
bluShift Aerospace	Red Dwarf 50	USA	2022
C6 Launch Systems	Unknown	Canada	2021
Celestia Aerospace	Sagittarius Space Arrow CM	Spain	2016
Comisión Nacional de Actividades Espaciales	Tronador II	Argentina	Q4 2020
CubeCab	Cab-3A	USA	2022
Dawn Aerospace	Mk-3	Netherlands/New Zeland	2024+
Deep Blue Aerospace	Nebula-1	China	2020
Departamento de Ciencia e Tecnologia Aeroespacial	VLM-1	Brazil	2022
Equatorial Space Industries	Volans Block I	Singapore	2023
ESA	Space Rider	Europe	2023
Firefly Aerospace	Firefly Alpha	USA	Q3 2020
Gilmour Space Technologies	Eris-S	Australia/Singapore	2022
HyImpulse	SL1	Germany	2023
HyPrSpae	OB-1/Mk1	France	Q4 2024
Independence-X Aerospace	DNLV	Malaysia	2023
Innovative Rocket Technologies (iRocket)	Shockwave	USA	Q3 2023
Interorbital Systems	NEPTUNE N1	USA	Q4 2019
InterStellar Technologies	Zero	Japan	2023
Isar Aerospace Technologies	Spectrum	Germany	Q3 2022
Launcher	Launcher Light	USA	2024
LEO Launcher	Chariot	USA	2021
Linkspace Aerospace Technology Group	NewLine-1	China	2020
NSIL	SSLV	India	Q4 2021
OneSpace Technology	OS-M1	China	2018
Orbex	Prime	United Kingdom	2021
Orbital Access	Orbital 500R	United Kingdom	2021
OrbitX India	ATAL 1	India	
Pangea Aerospace	Meso	Spain	
Phantom Space Corporation	Daytona	USA	Q1 2023
PLD Space	MIURA 5	Spain	3Q 2021
Pythom	Eiger	USA	
Reaction Dynamics	Aurora	Canada	Nov 2020
RocketStar	Starlord	USA	2018
Skyroot Aerospace	Vikram I	India	Q4 2021
Skyrora	Skyrora XL	UK/Ukraine	2023
SpinLaunch	SpinLaunch	USA	2022
STAR Orbitals	PHOENIX	India	2024
TiSpace	HAPITH V	Taiwan	Q4 2020
TLON Space	Aventura 1	Argentina	
Vaya Space	Dauntless	USA	2023
Venture Orbital Systems	Zephyr	France	2024
X-bow	X-bow	USA	

entrants to the list of operational systems after its successful first flight in November 2021.

International participation

One of the hallmarks of this new wave of launch vehicle developments is the broad international representation. Table 3 shows the country of origin of all the current systems we list as operational or under development. While the US continues to dominate in the field, there is a significant presence building from China, as was discussed in the introduction. Spain and the United Kingdom are also well represented, partially as a result of initiatives taken by their respective governments to promote the development of new space enterprises.

Added last year to the list was India, where changes to the legal framework for the first time permit private companies to engage in space-related development efforts. This has led India to catapult to third place in the number of new entrants. Other additions over the past two years include Malaysia, Canada, and Taiwan.

Table 3: Country of Origin of Launch Vehicle Developers

Country	Count
USA	15
India	5
United Kingdom	4
Spain	3
China	3
France	2
Canada	2
Germany	2
Argentina	2
Australia/Singapore	1
Taiwan	1
Europe	1
Malaysia	1
UK/Ukraine	1
Netherlands/New Zealand	1
Singapore	1
Brazil	1
Japan	1

SYSTEM DESCRIPTION

An analysis of publicly available information was conducted to identify salient features of each system's design. This section presents top-level descriptions of the launch vehicles, while the following section highlights key operational and business parameters. Not all companies will be listed in all tables, as some information may not be available. For simplicity's sake, subsequent tables will only refer to the ***Vehicle Name***. Where one organization has multiple vehicles under development, the smallest vehicle will be listed. In the few instances where the vehicle name is not known, the organization's name will be used. All operational vehicles are also included to provide a comparison. Operational vehicles are highlighted in **Green**.

Launch Method/Location

The first step in the characterization of the launch system is to look at how and where the vehicle starts its journey to orbit. For many of the launch systems, this has not been designated at this time; in that case only the launch mode will be designated – ground, water, air (carrier aircraft), balloon, or catapult. Table 4 lists details of how the space launch system starts its journey upward, and the published launch location. Figure 2 graphically illustrates the variety of launch methods. The total adds up to more than 47 since several vehicles are able to utilize multiple methods.

It is worth noting that while ground, water, and carrier aircraft-based systems already exist, balloon-based systems and electromagnetic catapult systems are new concepts being implemented for the first time. In the "Other Potential Player" section, there are also entrants with more exotic launch methods such as electro-rails and gas guns.

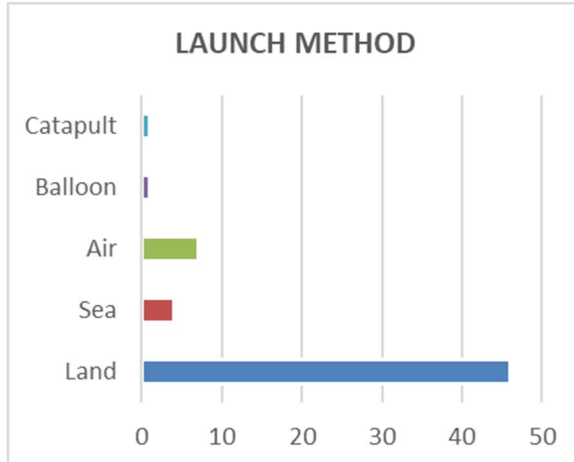

Figure 2: Launch Method for Launch Vehicles

Vehicle Technology

Many of the new entrant launch vehicles have a technology or concept that is their key to reducing the cost of space access. All are assuming that many launches will be in the manifest – almost nobody goes into this market assuming that they are only going to launch every few years. In this section, we will outline the vehicle details – number of stages, propellant, "breakthrough" idea, and any other pertinent facts that make the vehicle stand out from their competitors. The benefits of the technology described are as presented by the developer; the authors have not attempted to validate, evaluate, or in any other way judge the described technology.

Agnibaan – Originally considering an air-launch vehicle, Agnikul is now focused on a two-stage land launched vehicle. Key to the design is a plug and play engine configuration. Seven of these 3D printed LOX/Kerosene engines will power the first stage.

ATAL 1 – OrbitX is optimizing the ATAL 1 vehicle to require minimal range infrastructure. It is a reusable launcher with two solid fuel stages and one liquid fuel stage.

Aurora – Canadian company Reaction Dynamics has developed proprietary fuels and 3D printing techniques that aims to reduce the part count of the rocket from hundreds of thousands to just a few thousand. Specifics of the rocket design are not yet publicly available.

Table 4: Launch Type and Location

Vehicle Name	Launch Type	Launch Location
Ravn X	Air	Cecil Spaceport, FL
Agnibaan	Land	
Helios	Land	
Haas 2CA	Land	Spaceport America, USA; Wallops Flight Facility
Rocket 3.0	Land	KLC, CCAFS
Colibri	Balloon	Snowdonia; Shetland Space Centre, Scotland
Black Arrow	Sea	Atlantic Ocean off Ireland coast
Red Dwarf 50	Land	Cape Cutler, Maine
Unknown	Land	Shetland Space Center
Sagittarius Space Arrow CM	Air	Int'l Water, Spanish airport
Chang Zheng 11	Land, Sea	China
Kaituozhe-2	Land	China
Jielong 1	Land	Jiuquan Space Center
Tronador II	Land	Puerto Belgrano Naval Base
Mk-3	Air	
Nebula-1	Land	
VLM-1	Land	Alcatara, Brazil
Volans Block I	Land	Southeast Asia
Space Rider	Land	Kouru
Kuaizhou-1A	Land	China
Firefly Alpha	Land	VAFB, Cape Canaveral, Spaceport Camden, Wallops
Ceres-1	Land	Jiuquan Satellite Launch Center
Eris-S	Land	Queensland, Australia
SL1	Land	Esrange, UK, Australia
OB-1/Mk1	Lande	
Shockwave	Land	
NEPTUNE N1	Land, Sea	Moody Space Centre, Australia. Int'l Water; also US?
Zero	Land	
Spectrum	Land	Andøya, Norway
Hyperbola-1	Land	Jiuquan Space Center
Launcher Light	Land	KSC, Wallops, VAFB
Chariot	Air	Texas?
NewLine-1	Land	
Minotaur I	Land	VAFB, KLC, WFF, CCAFS
Pegasus XL	Air	Int'l Water – Multiple locations demonstrated
SSLV	Land	
OS-M1	Land	
Prime	Land	Scotland
Orbital 500R	Air	Malta, Scotland
ATAL 1	Land	
Meso	Land	
Daytona	Land	
MIURA 5	Land	Korou
Eiger	Land	Kiruna, Sweden
Aurora	Land	Canso, Nova Scotia
Electron	Land	Birdling's Flat, New Zealand, Wallops
Starlord	Sea	KSC, 20 km offshore
Vikram I	Land	
Skyrora XL	Land	Scotland
SpinLaunch	Catapult	
PHOENIX	Land	
HAPITH V	Land	
Aventura 1	Land	
Dauntless	Land	
Zephyr	Land	
LauncherOne	Air	Int'l Water
X-bow	Land	

Aventura 1 – Argentinian company TLON Space is focused on a CubeSat class vehicle lifting 25 kg to a sun-synchronous orbit with the focus of being the most frequent and cost-effective vehicle in the world. At only 10 meters tall, Aventura 1 has two liquid fuel stages.

Black Arrow – Black Arrow Space Technologies has as part of their team Formula 1 materials specialists that are bringing leading edge composites to their design of the rocket. The sea-launched Black Arrow is powered by LOx and Liquid Natural Gas.

Ceres-1 – Galactic Energy is one of the new commercial space companies in China. The first successful flight of the three-stage solid fueled Ceres 1 happened only 2 years after the start of the development. OPERATIONAL as of 7 November 2020.

Chang Zheng 11 – Also known as Long March 11, CZ11 is developed by China's Aerospace Science and Technology Corporation (CASTC). It is a four stage solid motor rocket believed to be derived from the DF-31 ICBM. There are reports that in addition to land launches, the CZ11 will also be compatible with sea launches. OPERATIONAL as of 25 September 2015.

Chariot – The Chariot from LEO Launcher intends to use only previously developed technology, but the details of the rocket have not been released. Some reports indicate that it may not just utilize previously developed technology, but a previously developed flight-proven system.

Colibri – The Colibri is a balloon launched, three-stage vehicle from B2Space. The balloon system deploying at 35,000 m allows the vehicle to reduce costs by simplifying structural design due to the expected lower drag. To make the system more affordable B2Space plans to reuse the first stage of the rocket.

Dauntless – Rocketcrafters rebranded itself as Vaya Space and began work on a new hybrid rocket which features their unique STAR-3D motors with additively manufactured (3D printed) propellant. The Dauntless is significantly larger than Rocketcrafter's original Intrepid rocket.

Daytona – Unlike other companies, Phantom Space has chosen not to be vertically integrated, obtaining the best components from a variety of vendors. The two-stage Daytona is powered by LOX/RP-1 engines developed by Ursa Major and the flight computer has been licensed from NASA.

DNLV – Independence-X Aerospace is repurposing some of the technology it developed for its Lunar X Prize lander to develop the Dedicated Nano Launch Vehicle.

Eiger – Pythom aims to launch its two stage vehicle from the far northern range of Kiruna in Sweden. While utilizing 3D printing technologies, the rocket is fueled by traditional hypergolic propellants. The design aims for operational simplicity allowing it to be deployed in 24 hours by just 2 people.

Electron – Rocket Lab's Electron rocket is a two stage vehicle powered by LOx and RP-1. To reduce the complexity of the engines while maintaining high performance, Electron has designed electric turbopumps that are powered by batteries rather than combustion products. The Electron also utilizes a composite structure and 3D printed engines to increase performance and decrease cost. OPERATIONAL as of 21 January 2018.

Eris-S – Rocket engine developer Gilmour Space Technologies is hoping to expand its business into full suborbital and orbital launch vehicles. The Eris is a three stage rocket utilizing hybrid propulsion. Unique to its propulsion technology is hydrogen peroxide as an oxidizer combined with a proprietary high Isp fuel that will be 3D printed.

Firefly Alpha – Firefly Aerospace utilized and expanded the design of the former Firefly Space Systems Firefly α to develop a larger launch vehicle. The Alpha abandons a number of Firefly α's more exotic technologies such as a methane-based aerospike engine for "well established" technologies such as a LOX/Kerosene conventional engines. Firefly Alpha is a two stage rocket able to launch twice a month from a wide variety of sites.

Haas 2C – Arca Space Corporation's Haas 2C launch vehicle is a two-stage rocket powered by LOx/RP-1 engines. Haas 2C originally was conceived as a SSTO testbed for the new engine, but has since been modified to be two stages in order to carry a payload. Some versions of the Hass 2C utilize a linear aerospike engine. More recently, Arca has proposed utilizing a Launch Assist Stage that uses water steam as a propellant.

HAPITH V – TiSpace aims to launch the first Taiwanese rocket utilizing patented hybrid technology. The goal of the HAPITH V is to launch as many as 100 times per year.

Helios – Aphelion Orbitals is developing the Trailblazer suborbital vehicle that will also serve as the second stage for the three stage orbital Helios rocket. The Helios utilizes a combination of Lox/Methane and solid stages. An aerospike engine and proprietary high density propellant combination allow the vehicle to remain tailored for its small-sized specifications. This is one of the few vehicles that have had an *increase* in potential launch mass as the concept evolve (from 14 kg to 20 kg).

Hyperbola-1 – Hyperbola-1 from iSpace in China is an all-solid motor rocket that appears to derive heritage from the DF-11 and DF-15 missiles. Like other Chinese companies on the list, iSpace claims to be the first commercial Chinese space company. OPERATIONAL as of 25 Jul 2019.

Jielong 1 – Another entrant from the China Rocket Company, a commercial spinoff of CASTC. This four stage vehicle utilizes solid motors. The vehicle is designed for quick deployment from a movable launch platform. A unique configuration places the payload between the third and fourth stages, and thus the fourth stage is "upside down" and requires rotation before it ignites. OPERATIONAL as of 17 August 2019.

Kaituozhe-2 – Kaitouzhe-2 is another entrant from the China Aerospace Science and Technology Corporation (CASTC). While not much information is available, it is believed to be derived from the DF-31 missile. OPERATIONAL as of 3 March 2017.

Kuaizhou-1A – Sometime's also known as Fei Tian 1, the Kuaizhou-1A is believed to be a commercial variant of the Kuaizhou-2 military launch vehicle. It is developed by ExSpace, the private sector arm of the China Aerospace Science and Industry Corporation (CASIC). It is a three stage solid motor rocket designed for rapid response launches from a mobile launch platform, especially of imaging satellites. OPERATIONAL as of 9 January 2017.

Launcher Light – Launcher is developing a three-stage vehicle that includes a maneuverable "launcher orbiter" third stage. Utilizing traditional LOx/RP-1 propellants the turbopump-fed "Engine-2" may be the world's largest 3D printed liquid rocket engine.

LauncherOne – LauncherOne is Virgin Orbit's (formerly Virgin Galactic) entry into the orbital space launch domain. LauncherOne is air launched from a modified Boeing 747 as its carrier aircraft. The company is applied the experience gained in developing Spaceship Two to the initial development of LauncherOne, but has since separated operations into two different companies under the Virgin umbrella. LauncherOne is a two stage vehicle powered by LOx/RP-1 and utilizes an all composite design. OPERATIONAL as of 17 January 2021.

Meso – Pangea Aerospace's MESO rocket is a two stage rocket utilizing an aerospike engine for its first stage. The whole vehicle is optimized to decrease cost by utilizing reusable technologies and green propellants.

Minotaur I – The Minotaur I is a four stage solid launch vehicle. It uses the lower two stages from a Minuteman ICBM (USAF provided) and the upper two solid rocket motors, avionics, and fairing that were originally derived from Pegasus. It has the option for a larger fairing that takes advantage of the greater mass capability to orbit that the Minotaur I has over Pegasus. Originally developed by Orbital Sciences, which is now part of Northrop Grumman. It has had 11 launches with 100% reliability. OPERATIONAL as of 27 January 2000.

MIURA 5 – PLD Space's MIURA 5 is the new name for the Arion 2. Originally conceived a liquid fueled, three-stage rocket. In an effort to reduced costs, PLD plans to make portions of the rocket reusable. Due to its southern Europe launch site, the rocket will be able to access retrograde orbits with inclinations up to 140°. MIURA 5 recently underwent significant changes to meet ESA requirements and increase its capability.

Mk-3 – Dawn Aerospace is leveraging its experience in green engines to develop its Mk-2 suborbital plane and its Mk-3 rocket. The Mk-3 will be an air launched vehicle.

Nebula-1 – is the smallest in a new series of rockets from Deep Blue Aerospace. It will be powered by LOx/Kerosene engines and Deep Blue is investigating the possibility of recovery and reuse of stages.

NEPTUNE N1 – The N1 from Interorbital systems is the smallest in their line of modular NEPTUNE launchers. All NEPTUNE launchers are assembled from multiple Common Propulsion Modules (CPMs) with an engine utilizing a mixture of white fuming nitrous acid and turpentine. The N1 utilizes one CPMs as its first stage with two smaller tandem upper stages.

NewLine-1 – Linkspace is one of several Chinese companies claiming to be the first purely commercial Chinese launch provider. It's NewLine-1 is a two-stage vehicle powered by RP-1 and Lox with a reusable first stage. The company has conducted a number of hover flights with sub-scale testing vehicles and noted that they are developing all the critical technology in-house.

OB-1/Mk1 – The Orbital Baquette One being developed by HyPrSpace is a two stage vehicle relying on hybrid propulsion. The first stage includes a cluster of 7 motors each outfitted with aerospike engines. The hybrid propulsion being used promises a lower carbon footprint than traditional liquid fueled boostes.

Orbital 500R – Orbital Access will use an air launched scheme utilizing a converted jet liner, likely a DC-10, as the carrier aircraft. The company has not disclosed any design details for its rocket.

OS-M1 – OneSpace Technology is developing the all-solid three stage OS-M1. This launch vehicle is land launch and aims to implement a wide range of innovations, although the details have not been disclosed by the company. OneSpace attempted an orbital launch of the OS-M1 in 2019 but the flight resulted in a failure.

Pegasus XL – The Northrop Grumman Pegasus, uses three solid rocket motors and is launched from a modified Lockheed L-1011 carrier aircraft. The aircraft allows the small space launch vehicle to be launched from any site with local large aircraft landing facilities and appropriate range safety capabilities. Originally designed by Orbital Sciences (now part of Northrop Grumman), Pegasus has launched (taken off) from seven different launch sites, and used 5 different ranges over its 43 launch lifespan.

PHOENIX – This two stage vehicle from STAR Orbitals is aiming to be reusable and launch with a high flight rate. The liquid fueled first stage is powered by six engines. Hoping to reduce costs the company aims to due a majority of verification at the component level.

Prime – Orbex states that its Prime launch vehicle is lighter and more efficient than any other vehicle in its category. A patent pending technology is expected to reduce dry mass by 30%. Its engine utilizes laser smelting technology to create the world's largest rocket engine produced as a single piece. The vehicle is propelled by a combination of clean-burning LOx and biopropane.

Ravn X - Aevum has booked its first USAF customer for RavnX and has also entered the vehicle into the OSP-4 procurement. The two-stage vehicle is launched from a hypersonic drone aircraft and can deliver a satellite to space 78 times faster than any other launch vehicle. The first stage uses a proprietary propellant while the second stage utilizes LOx and Jet-A fuel.

Red Dwarf 50 – bluShift Aerospace is building a line of "ecofriendly" rockets starting with its Red Dwarf 50. To achieve its environmental goals, the three-stage rocket utilizes a biofuel hybrid technology.

Rocket 3.0 – Rocket 3.0 from Astra space traces its heritage to the SALVO vehicle developed by Ventions LLC. The company is very secretive, sometimes going by "Stealth Space". Rocket 3.0 utilizes LOx/Kerosene. To control costs Astra is vertically integrated and not relying on traditional aerospace suppliers. An attempt at an orbital launch from the Kodiak launch range in Alaska in December 2020 resulted in failure due to unexpected propellant consumption ratio. OPERATIONAL as of 20 November 2021.

Sagittarius Space Arrow – Celestia Aerospace's Sagittarius Space Arrow is a flexible air launch system utilizing existing fighter jet and missile vehicles. The modified missiles are carried aloft by a MiG 29 UB fighter. The MiG 29 permits use of two different configurations: four smaller rockets, or one larger rocket. The rockets utilize solid propellants for their propulsion.

Shockwave – This two-stage vehicle from iRocket aims to become "the FedEx of Space". The vehicle may be available in multi-core versions and has a goal of 20x reusability and 24-hour response time. Initial design is for a two-stage vehicle powered by Methane LOx engines.

Skyrora XL – The same Ukranian team that helped develop the first engine from the Antares and Sea Launch rockets has spun off to develop a new launch vehicle known as Skyora XL. It will be a three stage rocket utilizing Hydrogen Peroxide and RP-1.

SL-1 – HyImpulse's three-stage rocket uses a hybrid propellant mixture of LOx/Paraffin. The paraffin formulation is unique in Europe and features a high-regression rate. Light weight composite tanks are used to improve vehicle performance.

Space Rider – Funded by ESA, the Space Rider is a reusable space plane launched on top of a Vega-C. The Vega-C itself is a four stage vehicle (3 solids + 1 liquid) with performance that exceeds the 1000 kg threshold for this survey. However, the Space Rider system will have a lower payload capability. Reusability of the spaceplane is partially achieved by a parafoil landing system.

Spectrum – The Spectrum from Isar Aerospace will offer 2 fairing sizes to accommodate a variety of customers. It is a two-stage rocket powered by nine Isar Aerospace "Aquila" engines utilizing LOx/hydrocarbon propellants.

Spin Launch – Spin Launch is a unique company aiming to "revolutionize the space-launch industry". Very little is known about their solution other than it is based on a centrifuge/sling shot that achieves 4800 km/hr. While there does not seem to be enough information to include them in this survey, financial findings indicate that they have raised as much as $55M USD, warranting inclusion due to their being one of the best funded companies on our list.

SSLV – The Small Satellite Launch Vehicle is being marketed by New Space India Limited (NSIL). SSLV, previously referred to as PSLV Light, is a derivative of the Polar Space Launch Vehicle (PSLV) developed by the Indian Space Research Organization (ISRO). Designed to cater to the smaller satellite market, SSLV will be able to undergo final assembly in three days and will have manufacturing costs that are one tenth of the larger PSLV.

Star-Lord – RocketStar is developing the two stage Star-Lord vehicle. The first stage utilizes a cluster of eight engines to create an aerospike engine. Production will utilize a significant number of 3D printed parts. This LOX/Methane system is baselined to launch form an off-shore platform. The ultimate goal of the company is to achieve a Single Stage to Orbit (SSTO) design.

Tronador II – Comision Nacional de Actividades Espaciales (CONAE)'s two stage Tronador II uses LOX/RP-1 in the first stage, and hydrazine/nitrogen tetroxide for the second stage.

Unknown Name/C6 – C6 Launch Systems in Canada is developing two-stage rocket that maximizes the use of COTS components in the design of their proprietary launch vehicle. The LOx/Kerosene fueled rocket can be launched form new space ports in Brazil and Scandinavia and provides customers continuous "live communications" with its payload.

Vikram I – Skyroot Aerospace's rocket is a solid fueled three-stage rocket that requires minimal launch infrastructure and can be assembled and launched within 24 hours from any launch site. An optional fourth stage uses liquid propellant to provide a re-startable orbital adjust module.

VLM-1 – The VLM-1 is being designed by Brazil's Department of Aerospace Science and Technology (CTA by its Portuguese initials). It will utilize the VS-50 suborbital vehicle's first stage motor. The German DLR is assisting with the qualification of the motors. It is a two stage vehicle utilizing solid propellants.

Volans – Volans is developed by Equatorial Space Industries of Singapore. It is a two-stage rocket utilizing hybrid propulsion with a proprietary HRF-1AL fuel and innovative oxidizer delivery system of cryogenic nitrogen oxide. Their unique fuel combination provides specific impulse comparable to KerOx engines.

X-Bow – Not much is known about this company, but they were awarded one of the USAF OSP4 contracts. The only content of their web site is a picture of Super Strypi. The Super Strypi, was originally developed by the University of Hawaii, Aerojet Rocketdyne, and Sandia National Labs is a three-stage derivative of the Strypi sounding rocket. Like its predecessor, the Super Strypi is a rail launched system. X-Bow has received a DARPA contract for investigating additive manufacturing of solid propellant.

Zephyr – Venture Orbital Systems will use new manufacturing technologies to reduce costs. 3D printed engines utilizing LOx/RP1 power the two-stage Zephyr from the company that was originally known as Prometheus Space Industries.

Zero – With its suborbital rocket, Momo-3, InterStellar Technologies became the first Japanese private company to reach space. Zero is an evolution of that system into a larger vehicle capable of orbital launches. One distinguishing characteristic is that the Zero vehicle is advertised as being "ITAR free".

KEY PARAMETERS

There are several key parameters that one looks at when investigating a launch vehicle, regardless of size. These are explored, to the extent possible, with the small launch vehicles captured in the survey. Because values for these parameters are gathered from public sources, underlying assumptions and definitions are not always known.

Performance

The primary parameter of launch performance is how much mass the vehicle can lift to space. Vehicle developers do not have a standard way of quoting performance, so it is difficult to normalize across multiple vehicles. To simplify analysis vehicles have been distributed by performance into four categories: "CubeSat" (< 20 kg), "Micro class" (20-200 kg), "Mini class" (200-500 kg), and "Small class" (500-1000kg) classes. The distribution of entrants in these three categories is shown in Figure 3. For the past couple years there has been a significant shift from the lower end of the performance spectrum to the higher end, including several entrants that fell off the list due to exceeding the 1000 kg limit. It remains to be seen whether this trend continues and whether it calls into question the viability of really small launchers.

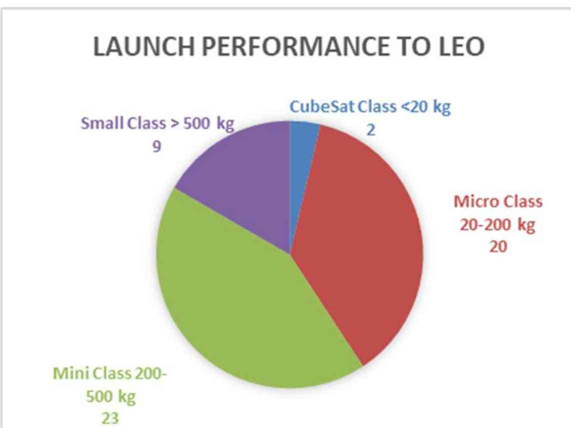

Figure 3: Performance Classes for Launch Vehicles

Table 5 lists the published payload capability for each vehicle. When a developer has specified it, a definition for a reference "LEO" orbit is provided. Unless labeled as Sun Synchronous Orbit (SSO), it is assumed that the reference LEO orbit is between 0° and 28.5° inclination. For vehicle's that are part of a multi vehicle family, performance for the smallest vehicle is given. For vehicles that have enhanced/optional upper stages the highest vehicle performance is given when available. No accounting has been made for the mass of supporting hardware (for example, separation systems). Different systems treat this differently, for instance: for Minotaur USAF missions, the separation system mass is considered payload weight; for Pegasus NASA missions, it is Launch Vehicle weight. For small missions, this is not insignificant. Because the performance numbers are not normalized a one-to-one comparison is not necessarily possible, even though we have presented the vehicles sorted by their nominal performance value.

Table 5: System Performance

Vehicle Name	Performance	Orbit
NEPTUNE N1	6 kg	310 km SSO
Sagittarius Space Arrow CM	16 kg	LEO
Aventura 1	25 kg	500 km SSO
Aurora	30 kg	500 SSO
Unknown	30 kg	600 km SSO
Eiger	50 kg	SSO
Red Dwarf 50	50 kg	SSO
Zephyr	70 kg	600 km SSO
Agnibaan	100 kg	700 km
Haas 2CA	100 kg	LEO
Helios	100 kg	400 km
Ravn X	100 kg	500 km
SpinLaunch	100 kg	LEO
Zero	100 kg	500 km SSO
Launcher Light	105 kg	500 km SSO
OS-M1	143 kg	300 km SSO
Meso	150 kg	LEO
PHOENIX	150 kg	500 km SSO
Rocket 3.0	150 kg	500 km SSO
Shockwave	150 kg	SSO
VLM-1	150 kg	300 km
Volans Block I	150 kg	LEO
Colibri	200 kg	LEO
DNLV	200 kg	500 km
Electron	200 kg	SSO
Jielong 1	200 kg	500 km SSO
NewLine-1	200 kg	500 km SSO
OB-1/Mk1	200 kg	LEO
ATAL 1	210 kg	500 km SSO
Eris-S	215 kg	500 km SSO
Prime	220 kg	200 km SSO
Vikram I	225 kg	500 km SSO
Ceres-1	230 kg	700 km SSO
Kaituozhe-2	250 kg	SSO
Kuaizhou-1A	250 kg	500 km SSO
Tronador II	250 kg	600 km SSO
Hyperbola-1	260 kg	500 km SSO
Black Arrow	300 kg	SSO
LauncherOne	300 kg	500 km SSO
MIURA 5	300 kg	500 km SSO
SSLV	300 kg	SSO
Starlord	300 kg	185 km
Skyrora XL	315 kg	490 km SSO
Chang Zheng 11	350 kg	SSO
HAPITH V	350 kg	SSO
Daytona	450 kg	LEO
Pegasus XL	468 kg	200 km, 0°
Nebula-1	500 kg	500 km SSO
Orbital 500R	500 kg	600 km SSO
SL1	500 kg	400 km
Minotaur I	584 kg	200 km, 28.5°
Firefly Alpha	600 kg	500 km SSO
Dauntless	610 kg	500 km SSO
Chariot	681 kg	LEO
Spectrum	700 kg	SSO
Space Rider	800 kg	400 km

Mission Cost

Perceived advantage in cost is one of the keys to this sudden expansion in small launch vehicles. Many of the current launch vehicles on the market are seen to be far too expensive to support the business plans of the upcoming small satellite market expansion. While some of the new launch vehicles focus on the benefits of dedicated launches (vs. traditional ride shares), others place significant emphasis on potential cost savings. Future cost containment is also important to continued market success of the vehicle as past vehicles have seen their cost increase significantly from original estimates once they became operational. Table 6 outlines the planned launch service price, with a comparative cost basis utilizing Table 5's mass performance extrapolated in an attempt to normalize the metric. Launch costs are in millions of US Dollars; costs per kg are in thousands of US Dollars per kg.

Figure 4 shows the same data graphically. The cost per kg metric should only be used as a rough comparison metric. Absent more specific data, a number of assumptions had to be made in order to normalize the data. For instance, mass to a nominal low LEO orbit (e.g., 200 km) was treated the same as mass to a high sun-synchronous LEO orbit. When multiple orbits or a range of launch costs were given, the computation uses the numbers that resulted in the lowest cost per kilogram. No obvious trend is discernable in the cost per kg, but it is interesting to note that all but one of the vehicles with performance under 500kg have a cost under \$10M. There are also preferences for certain round numbers in launch cost such as \$250k, \$1M, and \$10M. Nonetheless, none of the vehicles come close to the much lower per kilogram cost of larger rockets such as the Falcon 9 (\$2.7k/kg for the reusable variant).

Table 6: Launch Costs

Vehicle Name	Projected Launch Cost (US\$M)	Estimated Cost per kg (US\$k)
Aventura 1	\$0.1 M	\$2.0 k
SpinLaunch	\$0.5 M	\$5.0 k
ACE	\$0.9 M	\$6.0 k
Daytona	\$4.0 M	\$8.9 k
Agnibaan	\$1.0 M	\$10.0 k
Ceres-1	\$4.0 M	\$11.4 k
Haas 2CA	\$1.4 M	\$14.0 k
OS-M1	\$3.1 M	\$15.0 k
Firefly Alpha	\$15.0 M	\$15.0 k
Rocket 3.0	\$2.5 M	\$16.7 k
Kuaizhou-1A	\$5.0 M	\$20.0 k
Starlord	\$6.0 M	\$20.0 k
LauncherOne	\$10.0 M	\$20.0 k
NewLine-1	\$4.3 M	\$21.3 k
DNLV	\$4.5 M	\$22.5 k
Eris-S	\$4.1 M	\$23.0 k
Red Dwarf 50	\$1.3 M	\$25.0 k
Bagaveev	\$0.3 M	\$25.0 k
Electron	\$7.5 M	\$25.0 k
Orbital 500R	\$15.0 M	\$30.0 k
Jielong 1	\$6.0 M	\$30.0 k
NEPTUNE N1	\$0.3 M	\$39.7 k
Space Rider	\$32.0 M	\$40.0 k
Volans Block I	\$1.0 M	\$40.0 k
MIURA 5	\$14.1 M	\$47.0 k
Ravn X	\$5.0 M	\$50.0 k
Cab-3A	\$0.3 M	\$50.0 k
Launcher Light	\$10.0 M	\$66.7 k
VLM-1	\$10.0 M	\$66.7 k

It is apparent, that cost, cannot be a primary differentiator relative to large vehicles. Where small launch vehicles stand out is in their ability to be dedicated launches where a small satellite does not need to share requirements or schedule with a larger primary passenger. As more vehicles become operational it will be interesting to see whether they are able to retain their initial price goals or whether cost changes in response to production realities and/or market forces.

One key driver for cost is the prospect of reusability. Conceptually, stage or full vehicle reusability may result in higher up-front development costs while lowering long-term recurring costs. For most entrants, reusability was seen as not economically or technologically viable. However, in recent years there has been a significant increase in the number of small vehicles exploring reusability, including the operational Electron. This is presumably a direct result of SpaceX's reusability success over the past 5 years.

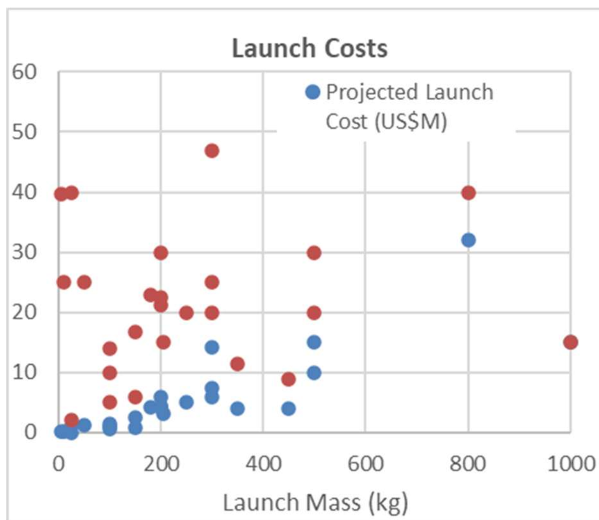

Figure 4: Launch Costs

Launch Frequency

A key aspect of many of these newer systems is the goal of achieving very high launch rates. These high launch rates are seen as critical to helping drive costs down. Several of the teams designing new vehicles have publicly stated what their ultimate launch rate goal is. Table 7 captures the publicly announced target launch rates.

Table 7: Projected Launch Frequency

Vehicle Name	Launch Frequency
Aurora	Weekly
Colibri	30/year
Electron	1/week
Firefly Alpha	2/month
HAPITH V	100/year
Kuaizhou-1A	10/year
LauncherOne	24/year
MIURA 5	10/year
Ravn X	2/week
Red Dwarf 50	12-52/year
Rocket 3.0	52/year
Starlord	1/month
Unknown/C6	24/yr
Volans Block I	150/yr

For any new system it is understood that it may take several years of operations before achieving the target flight rate. Of these systems, Electron has now been in operation for five years. Since the return to flight in July 2021 after its last failure, Electron has launched eight times in twelve months, getting closer to a launch pr month, but still quite far from its desired weekly launch. With possibly another ten launches manifested for 2022, Electron could conceivably get closer to that goal this year. None of the other operational systems have launched more than twice a year, with the exception of Pegasus in the late 1990s. Even the combined launch cadence of all the operational systems has not reached a monthly launch rate yet. This fact raises the question of whether business plans that rely on monthly or weekly launches are realistic at all given the market demand.

Funding Source

Historically, governments have been the main source of funding for launch vehicle development; however, much like in the wave of development in the 1990s, many of vehicles under development today are utilizing private funding. Some are entirely founder-funded, while others are funded through venture capital, prizes, and other mechanisms. This section details a key parameter to system achieving initial launch success. Any space launch vehicle can be made to successfully achieve launch if funding is adequate to overcome all obstacles that will be encountered in development. Table 8 lists all the known external sources of funding for each organization. Some amount of self-funding for all the organizations is assumed and therefore not called out in the table. The amount of external funding varies from a few thousand dollars to millions of dollars in investment; e.g., NASA may have provided the company a small SBIR contract valued at US$50k. Because of strategic reasons many companies keep funding information under tight control, and thus it is not always publicly available. There is no established metric for how much capital a company must raise to successfully field a launch vehicle. However, one can look at Rocket Labs for a baseline, since they were the first non-Chinese company to successfully launch a new small rocket in the past decade. Rocket labs is reported to have raised US$288M over several rounds. [11] This is roughly in line with SpaceX's development of Falcon 1 or Orbital Sciences development of Pegasus. An organization that claims to be able to develop a new vehicle for significantly less needs to be looked at judiciously.

A new development in funding mechanism is the use of Special Purpose Acquisition Companies (SPACs). A developer will merge with a SPAC which provides it access to the public markets without the need to go through an IPO. This mechanism is particularly advantageous to launch vehicle developers since upfront capital needs are very high and significant expenditures need to be made before the first revenue generating flights.

Due to the lack of full visibility into company's fund raising, this study does not attempt to track investments in individual organizations. However, a rough estimate of funding, both government and private, that has been invested into the small launch vehicle market over the past decade ranges between US$1.5B and US$2.5B.

OTHER POTENTIAL PLAYERS

A number of other proposed launch vehicles were identified in the course of our research. They failed to meet one or more of the criteria for inclusion in the survey. These have been placed on a "watch" list; for completeness and future reference, they are listed in Table 9. Many of these vehicles are "paper studies" funded by governments. For other vehicles, not enough public information is known to warrant inclusion in the main list. Others can be classified as unconfirmed "rumors". A number of organizations are developing suborbital vehicles with a long-term goal of fielding an orbital launch vehicle, but efforts on the later have not yet started. Many of these efforts were discovered by word of mouth from readers of previous editions of this paper.

In addition to traditional launch methods a number of these entrants are exploring electromagnetic catapults, gas guns, and other exotic methods of propulsion.

Several of the vehicles on the watch list warrant some additional notes:

Table 8: Financial Investment Sources

Organization	Funding Source
Aevum	Angel Investors, USAF
Agnikul	Speciale Invest, Mayfield India, BEENEXT, Glovevestor, Lion Rock and more
ARCA Space Corporation	Individual private investors
Astra Space	NASA, Acme, Adcance, Airbus Ventures, Canaan Partners, Innovative Endeavors, Marc Benioff
bluShift Aerospace	Own funding, Maine Technology Institute, WeFunder crowdsource
C6 Launch Systems	CSA
CubeCab	Biz Plan Competition
Dawn Aerospace	IQCapital, Tuhua Ventures, Callagahn Innovation, Movac
Deep Blue Aerospace	Shunwei Capital
Equatorial Space Industries	Angel Funding
ESA	ESA
ExPace	8 investment institutions
Firefly Aerospace	Noosphere Ventures; Data Holdings, Astera Institute
Galactic Energy	Yuanhang Capital, Fengcai Capital, Beihang Investment, Kexin Capital, New Potential Energy Fund; Puhua Capital, Huaqiang Capital
Gilmour Space Technologies	Blackbird Ventures, 500 Startups, Advance Queensland, Main Sequence Ventures
Gloyer-Taylor Laboratories	DARPA, NASA, USAF
HyImpulse	DLR, European Comission, Rudolf Schwarz
Innovative Rocket Technologies (iRocket)	USAF, seed
Interorbital Systems	Presales
InterStellar Technologies	Kushiro Manufacturing Co
Isar Aerospace Technologies	Unternehmertum Venture Capital, Vito Ventures, Global Space Ventures, Earlybird, Airbus Ventures, Bavaria One, DLR, ESA/Boost!
iSpace	Huaxing Growth Capital, Tianfeng Securities, Maxtrix Partners, Fosun Group, Baidu, Shuairan Investment Management, Didi Chuxing, Citic Juxin, Venture Capital Fund of New England and Shunwei Capital.
Launcher	USAF; Max Haot (founder); Boost VC
OneSpace Technology	Legend Holdings, HIT Robot Group at Harbin Institute of Technology, Chun Xiao Capital, Land Stone Capital
Orbex	High-Tech Gründerfonds, private investors, the UK Space Agency and the European Commission Horizon 2020 programme, Sunstone Technology Ventures, BGF, Octopus Ventures; ESA Boost!
Orbital Access	UK Space Agency, Crowdfunded; Cornucopia Capital
Pangea Aerospace	ESA/EC Horizon 2020; angel; seed (Inveready, Primo VC, Dozen Infest; CDTI)
Phantom Space Corporation	Seed investors
PLD Space	Spanish government, EC, Caixa Capital Risc, Gobierno de Aragon, GMV, ESA, Gonzalo de la Pena, EC; Private investors; Arcano Parnters
Rocket Lab	NZ Gov, Kholsa, VBP, K1W1, LM, Promus Ventures, Bessemer, Data Collective, Greenspring Associates, Accident Compensation Corporation
Skyroot Aerospace	Mukesh Bansal and Ankit Nagori, Solar Industries
Skyrora	Seraphim Capital, UK
SpinLaunch	Adrian Aoun, Asher Delug, Lauder Partners, ATW Partners, Bolt, Starlight Ventures, Airbus Ventures, Kleiner Perkins, GV (Alphabet), Catapult Ventures, Byers Family
Venture Orbital Systems	Region Grand Est
Virgin Orbit	Virgin Group; Aabar Investments; Saudi Arabia
X-bow	DARPA

Table 9. Watch List

Organization	Vehicle Name	Country
Acrux Space Technologies	MONTENEGRO	Brazil and Paraguay
Advanced Rockets Corporation	DELV	USA
ARRC	Unknown	Taiwan
Astraius	Unknown	UK / US
Avio SpA	VegaC Lite	Italy
Beijing Xingtu Discovery Technology	Xingtu-1	China
Beyond Earth	Orbital Launch System	USA
Black Sky Aerospace	Unknown	Australia
Celestium Space	Unknown	USA
Exos Aerospace	Jaguar	USA
Green Launch	Unknown	USA
Honda	Honda rocket	Japan
Jiuzhou Yunjian	Unknown	China
Laros	LAROS-PH2	Russia
LIA Aerospace	Procyon	Argentina
Massterra Space	Unknown	United Kingdom
Merida Aerospace	Unknown	USA
NDA Company	Unknown	USA
New Ascent	Unknown	USA
New Rocket Technologies	Space rocket_M	Russia
OPUS Aerospace	Sterne	France
Orbit Boy	Unknown	Ukraine/UK
Orbital Cargo Drone	Unknown	United Kingdom
OrbitX India	ATAL 1	India

Organization	Vehicle Name	Country
Orion AST	Unknown	
POLARIS Raumflugzeuge	Spaceplane Aurora	
proximitE	Unknown	USA
Rocket Pi	Darwin-1	
Roketsan	Micro Satellite Launch System	Turkey
Sidereus Space Dynamics	EOS Beatrice	Italy
SmallSpark Space Systems	Frost 1	United Kingdom
S-Motor	Yitian	China
Space Mission Architects	SMA-2 Micro	USA
Space Transportation	Tian Xing-1	China
Space Vector	unknown	USA
Space Walker	Unit 2	Japan
SpaceDarts	Spacedarts One	Russia
SpaceRyde	Unknown	Canada
Stoke Space	Unknown	United States
Strato Space System	SIRIUS	France
StratoBooster	StratoBooster	United Kingdom
Success Rockets	Unknown	Russia
Thor Launch Systems	Thor	USA
UP Aerospace	Spyder	USA
Vector	Vector-R	
Vogue Aerospace	Vogue RLV	USA/Italy
Wagner Industries	Quetzalcóatl	USA

- Avio Spa does not have a known small vehicle effort, but there have been varying reports that Europe will develop a vehicle smaller than Vega (sometimes termed Vega Light)
- Generation Orbit and UP Aerospace appear to have abandoned any near-term goal of completing a space launch vehicle in favor of focusing on their suborbital vehicle.
- UP Aerospace appears to have abandoned any near-term goal of completing a space launch vehicle in favor of focusing on their suborbital vehicle.
- JAXA had indicated that the SS-520 launch was a one-time effort to convert a sounding rocket into an orbital launch vehicle. After its second test flight was successful reports indicate a desire to commercialize the vehicle.
- Vector Launch appears to be a re-emergence of Vector Space Systems which filed for bankruptcy in 2019.

A number of well-known entrants such as Relativity Space and Rocket Factory Augsburg are not included in the list as they are bigger than the 1000 kg limit.

CHANGES FROM PAST SURVEYS

This is the eight edition of this market survey to be published, the fist having been presented at the 29th SmallSat Conference[1] in 2015. Subsequent editions were presented at the 64th International Aerospace Congress in 2016[12], and at the 98th Transportation Research Board Annual Meeting in early 2018[13] (2017 edition of survey), at the 32nd SmallSat Conference in 2018 [14] and at the 70th International Astronautical Congress in 2019. As such it is instructive to see what has changed over the years.

The 2015 survey identified 22 organizations and their corresponding launch vehicle efforts that qualified for inclusion as operational or in active development. This stands in dramatic contrast to the 47 efforts identified this year. However, the number of additional teams is even more impressive when one considers that a number of the 2015 entrants dropped out altogether in the intervening years. Similarly, the "watch" list has grown over the years as new entrants are identified.

Of the 19 teams we identified in 2015 only one, the Super Strypi, conducted a flight in the following 12 months, even though five teams had stated that they would conduct a flight before the second half of 2016. Unfortunately, the Super Strypi launch resulted in loss of vehicle and mission. Since then, Electron and Launcher One have also conducted a successful flight. None of the other newly operational vehicles were listed in the 2015 survey.

Some vehicles and organizations previously on the list were downgraded to "watch" status over the years and ultimately removed from the list. These included Super Strypi due to its uncertain funding status, UP Aerospace and Generation Orbit which appear to be focusing on their suborbital vehicles, and Leaf Space and Heliaq which appear to be active but show very little information on their orbital launch vehicle.

54 vehicles that appeared on the active or watch list in previous editions of the survey have been removed altogether from this year's version. These include 45 programs considered "defunct" since they have been officially canceled, the companies that were developing them have ceased operations, or their web site domain has expired. Nine programs for which no new information has been available for over two years have been marked with an "unknown" status.

Over the past four years several companies have disbanded, undergone bankruptcy proceedings, or stopped all development on a space launch vehicle thereby eliminating them from our list. XCOR Aerospace decided to stop all work on the Lynx spaceplane and focus solely on engine development. MicroLaunchers ceased operations after its founder passed away in 2015.

Swiss Space Systems and Firefly Space Systems underwent bankruptcy proceedings. Swiss Space did not re-emerge, while Firefly Space reemerged as Firefly Aerospace with significant investment from Noosphere Ventures. Garvey Spacecraft Corporation was bought out and merged into Vector Space Systems. In the case of both Firefly and Vector, the new vehicle under development utilizes technology from the previous company, but is significantly different. As such the original vehicle is considered to be "defunct" and a new vehicle has been added to the list. Aphelion Orbitals also appears to have ceased operations, with a majority of its staff and some intellectual property moving to Phoenix Launch Systems, however there does not appear to be any similarity in their vehicle design.

Subsequently Vector Space Systems filed for bankruptcy in 2019, although there are indications that it may reemerge as Vector Launch. Stratolaunch also announced in early 2019 that it was undergoing restructuring, and in October 2019 announced that it had been purchased by a new owner. The company has since pivoted to developing hypersonic launch vehicles. A number of other companies have also pivoted to presumably more lucrative endeavors. Leaf Space is now solely focused on ground segments; Zero 2 infinity is exploring the suborbital market opened up by its stratospheric balloons.

Orbital ATK was bought and merged into Northrop Grumman Corporation. Because both the Pegasus XL and Minotaur I vehicles were already operational, and no vehicle changes resulted from the acquisition, the original entries in the list have been kept, with just a change in organization name.

A unique evolution is presented by ARCA Space Corporation. Its CEO was arrested and then released without indictment, and subsequently told that he was subject to deportation causing the company to be listed as "unknown" in 2018. However, all legal troubles appear to have been cleared, and the company has renewed posting information and design updates warranting its inclusion back in the active development list. Several other companies in the survey to have been moved from an unknown/defunct category back into active status as new information became available.

CONCLUSIONS

The past decade has been an extremely dynamic period for the launch vehicle industry. Larger players have announced or introduced new rockets such as the Blue Origin New Glenn, the SpaceX BFR, the ULA Vulcan, the Arianespace Ariane 6, and the Northrop Grumman OmegA (subsequently canceled). But the real action has been in the extremely fast introduction of potential new vehicles in the sub-1000 kg to LEO class.

It is clear that the market will not be able to support most of these new entrants, but it is equally clear that both the founders and the capital markets think that there will be room for multiple players. While progress has been much slower than all new entrants anticipated, we have seen some of the new entrants commence operations, and a number of other players are likely to have their first flight in the next 24 months.

To best illustrate this growth, Figure 5Figure 4 summarizes the changes over the past eight editions of

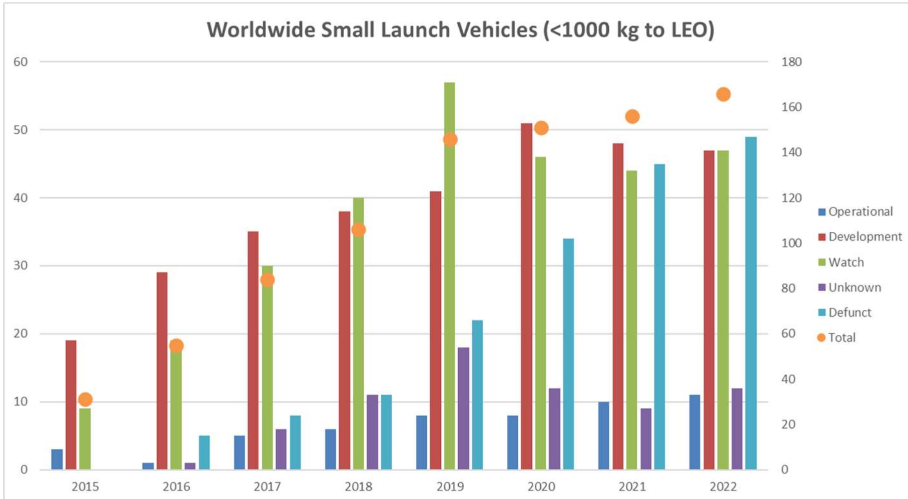

Figure 5: Growth of the Small Launcher Market 2015-2022

this survey. The bar chart shows the total number of vehicles tracked in our survey and divides them into four categories:

- **Operational –** The vehicle has conducted a successful first flight and more flights are planned.
- **Active** – The vehicle meets the criteria set out in this paper for inclusion
- **Watch** – The vehicle has the potential to meet the criteria for inclusion, but it is currently just a "paper study" or not enough information is publicly known.
- **Unknown** – The vehicle was either active or on the watch list in a previous survey but no updates have been seen in two or three years.
- **Defunct** – The vehicle development has been cancelled or the company developing it has disbanded.
- **Total** – The total number of efforts we are tracking, which has increased from a mere 31 in 2015 to 166 in 2022.

It is clear from the figure that the incredible growth seen from 2015-2019 has finally tapered down. The number of new systems being introduced has reduced to single digits, the number of organizations claiming to be actively developing a system have gone down, and the number of systems that haves stopped development (development which may never have been significant to begin with) has gone up significantly. Whether this is a result from the challenges posed by the COVID-19 pandemic or whether its stems from a realization that the market is over saturated and that launch vehicle development is very challenging remains to be seen.

One final observation is not apparent from the data alone: three launchers that were previously included in the survey, from ABL Space Systems, LandSpace, and Rocket Factory Augsburg, have been dropped from the list as their expected performance now exceeds the 1,000 kg to LEO limit. There are a number of other companies that still acknowledge development of, or operations of, their smaller rocket but are also actively developing larger rockets. These include Rocket Lab, Firefly, and iSpace. Even within the efforts still in the survey there has been a shift to larger systems compared to earlier years. This is not unlike the path that was followed by SpaceX with the development of Falcon 1, followed by the (never flown) Falcon 5, and ultimately Falcon 9. While the excitement, and investor interest, in small launch vehicles is still very much alive, there are indications starting to emerge that perhaps the business case for these vehicles is not as strong as once was hoped by many.

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