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Small Launch Vehicles – A 2018 State of the Industry Survey

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ABSTRACT

The 2010's has seen a dramatic increase in potential small launch vehicle contenders, which we define as rockets capable of carrying at most 1000 kg to Low Earth Orbit. Spurred on by government programs such as SALVO, VCLS, and Horizon 2020, and the rapid proliferation of CubeSats and nanosatellites, more than 50 different commercial, semi-commercial, and government entities worldwide are now working on new entrants of this class. To date the most successful small launcher, the Northrop Grumman Pegasus has launched 43 times, but its flight rate has dropped to less than one a year. At the same time launch opportunities on ESPA rings, secondary slots on larger launchers, and CubeSat missions as cargo to the International Space Station have proliferated. Despite this seemingly bleak market environment, new entrants have merged looking for a new magic formula. This paper presents an overview of the small satellite launch systems under development today. We compare capabilities, stated performance goals, cost, and funding sources where available. This paper is a yearly update of a paper originally presented at the 2015 AIAA/USU Conference on Small Satellites.[1] The authors welcome any comments, feedback, or corrections.

INTRODUCTION

The Tradition of Small Launch Vehicles

Many of today's heavy launch vehicles (LVs) – Atlas V, Delta IV, Falcon 9, and Ariane 5 – started their lives in a smaller form. The Delta IV as 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 US is currently flying. Atlas V from an InterContinental Ballistic Missile with staging engines and a pressure stabilized tank to today's launch vehicle that nearly equals the Delta IV heavy in capability. Ariane 5 grew from the 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 fulfil 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 and Planet are leading the demand now. 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. This 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 1000 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.

Drivers and Motivation

For many of the new entrants the drive to develop a new vehicles 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.

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 Airborn Launch Assist Space Access (ALASA) and NASA's Venture Class Launch Services (VCLS) promised to fund new entrants in their development of small launch vehicles. The latest DARPA launch challenge aims to launch payloads with just 14 day notice to a previously unspecified orbit. The successful team stands to win a $2M reward on the initial launch and $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.[2]

Across the Atlantic, European governments have not been idle either. ESA's Future Launchers Preparatory Programme (FLPP)[3] and studies funded through the European Union's Horizon 2020[4] have both contributed needed investment in the European market. Individual countries have also taken a new interest in small satellites; for instance the United Kingdom has been actively pursuing potential launch sites for many of the new entrants.

A significant new player in the small launch vehicle arena is China. While China has been on the foreground of global launch services for many years, in the past four years they have also made significant investments in the domain of small launch vehicles. Of the 40 vehicles captured in this survey, six are from China. Three 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 Linkspace, are privately held. 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 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.[5]

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 will feel significant competitive pressure from their Chinese counterparts. This is part of an overall drive by Chinese leadership to significantly increase commercial space activities in the country.[6]

Underlying all the government and commercial investment is the very fast growth in small satellites over the past ten years. SpaceWorks Commercial in their 2018 Nano-Microsatellite Market Forecast projects up to 2,600 nano-microsatellites launching in the next 5 years as shown in Figure 1.[7] This growth matches the growth in private investment dollars and government interest throughout the world, but especially in the United States. There is also a perceived shortage of launch opportunities with many of the new entrants habitually quoting a "2 year backlog" on existing vehicles as a potential differentiator for their on endeavor. The potential for capturing even a small portion of this market is what drives many of the organizations developing new vehicles.

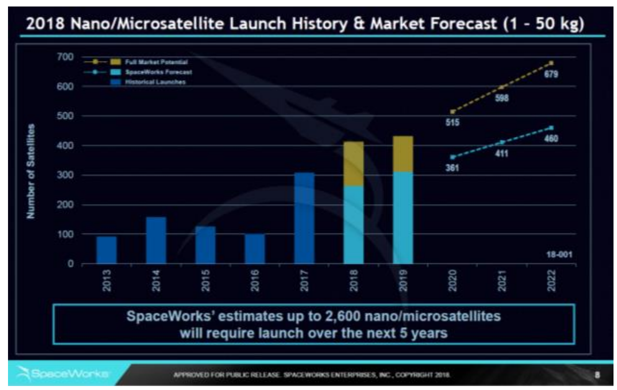

Figure 1: Growth in nano/microsatellite market (Source: SpaceWorks)

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)

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 three years, four 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, and the first successful launch of the vehicle.

Table 1: Operational Small Launch Vehicles

Organization	Vehicle Name	Country	First Launch
China Aerospace Science and Technology Corporation	Chang Zheng 11	China	25 Sep 2015
Rocket Lab	Electron	USA/New Zealand	21 Jan 2018
China Aerospace Science and Technology Corporation	Kaituozhe-2	China	3 Mar 2017
ExPace	Kuaizhou-1A	China	9 Jan 2017
Northrop Grumman	Minotaur I	USA	27 Jan 2000
Northrop Grumman	Pegasus XL	USA	5 April 1990

New Entrants

For our market survey, Table 3 presents an alphabetical roster of the 34 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.

International participation

One of the hallmarks of this new wave of launch vehicle developments is the broad international representation. Table 2 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.

Table 2: Country of Origin of Launch Vehicle Developers

Country	Count
USA	20
China	6
Spain	3
United Kingdom	3
Argentina	1
Australia	1
Australia/Singapore	1
Brazil	1
Europe	1
India	1
UK/Ukraine	1
USA/New Zealand	1

Table 3: Small Launch Vehicles Under Development

Organization	Vehicle Name	Country	Latest Launch Date
ABL Space Systems	RS1	USA	Q3 2020
Aphelion Orbitals	Helios	USA	2021
Bagaveev Corporation	Bagaveev	USA	2019
bspace	Volant	USA	2018
Celestia Aerospace	Sagitarius Space Arrow CM	Spain	2016
Cloud IX	Unknown	USA	
CONAE	Tronador II	Argentina	2020
CubeCab	Cab-3A	USA	2020
Departamento de Ciencia e Tecnologia Aeroespacial	VLM-1	Brazil	2019
ESA	Space Rider	Europe	2020
Firefly Aerospace	Firefly Alpha	USA	Q3 2019
Gilmour Space Technologies	Eris	Australia/Singapore	Q4 2020
Interorbital Systems	NEPTUNE N1	USA	
ISRO	PSLV Light	India	Q1 2019
LandSpace	LandSpace-1	China	H2 2018
Launcher	Rocket-1	USA	2025
LEO Launcher	Chariot	USA	Q4 2018
Linkspace Aerospace Technology Group	NewLine-1	China	2020
One Space Technology	OS-M1	China	2018
Orbex	Orbex	United Kingdom	
Orbital Access	Orbital 500R	United Kingdom	2020
PLD Space	Arion 2	Spain	3Q 2021
Rocketcrafters	Intrepid-1	USA	Q1 2019
RocketStar	Star-Lord	USA	2018
Skyrora	Skyrora XL	UK/Ukraine	
Space Ops	Rocky 1	Australia	2019
SpaceLS	Prometheus-1	United Kingdom	Q4 2017
SpinLaunch	Unknown	USA	
Stofiel Aerospace	Boreas-Hermes	USA	2019
Stratolaunch	Pegasus (Strato)	USA	
VALT Enterprises	VALT	USA	
Vector Space Systems	Vector-R	USA	H2 2018
Virgin Orbit	LauncherOne	USA	H1 2018
zero2infinity	Bloostar	Spain	2017

MARKET SURVEY

We conducted a market survey to identify a variety of performance, design, and financial parameters. Each of the following sections presents a subset of these parameters. Not all companies will be listed in all tables, as some information may not be available. For simplicity sake, subsequent tables will only refer to the ***Vehicle Name***. Where one organization has multiple vehicles under development, the smallest vehicle will be listed. All operational vehicles are also included to provide a comparison. Operational vehicles are highlighted in **Green**.

Launch Method/Location

To start the characterization of the launch system, we will start with the fundamental base – how/where the space launch system starts its journey to space. 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), or balloon. Table 4 lists details of how the space launch system starts its journey upward, and the published launch location. It is worth noting that while ground, water, and carrier aircraft based systems already exist, balloon-based systems are a new concept not previously seen. In the "Other Potential Player" section, there are also entrants with more exotic launch methods such as electro-rails and gas guns.

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,

Table 4: Launch Type and Location

Vehicle Name	Launch Type	Launch Location
Arion 2	Land	South Europe
Bagaveev	Land, Sea	
Bloostar	Balloon	Int'l Water
Boreas-Hermes	Balloon	
Cab-3A	Air	KSC, Int'l Water
Chang Zheng 11	Land, Sea	China
Chariot	Air	
Cloud IX	Air	
Electron	Land	Birdling's Flat, New Zealand
Eris	Land	Queensland, Australia
Firefly Alpha	Land	VAFB, Cape Canaveral, Spaceport Camden, Wallops
Helios	Land	
Intrepid-1	Land	Kennedy Space Center
Kaituozhe-2	Land	China
Kuaizhou-1A	Land	China
LandSpace-1	Land	Wenchang, Hainan, China
LauncherOne	Air	Int'l Water
Minotaur I	Land	VAFB, KLC, WFF, CCAFS
NEPTUNE N1	Land, Sea	Moody Space Centre, Australia. Int'l Water; also US?
Orbital 500R	Air	Malta
Pegasus (Strato)	Air	Mojave, CA
Pegasus XL	Air	Int'l Water – Multiple locations demonstrated
Prometheus-1	Land	
PSLV Light	Land	
RS1	Land	Camden, GA; Kodiak, AK
Sagitarius Space Arrow CM	Air	Int'l Water, Spanish airport
Skyrora XL	Land	Scotland
Space Rider	Land	Kouru
Star-Lord	Sea	KSC, 20 km offshore
Tronador II	Land	Puerto Belgrano Naval Base
VALT	Land, Sea, Air	
Vector-R	Land, Sea	Kodiak, Cape Canaveral, Wallops
VLM-1	Land	Alcatara, Brazil
Volant	Land	Kodiak

evaluate, or in any other way judge the described technology.

Arion 2 – PLD Space's vehicle is 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°. Unique amongst most vehicles here, PLD also lists potential payload mass delivered to lunar orbit (5 kg).

Bagaveev – Bagaveev's rocket is a very small launch vehicle optimized for CubeSat-class spacecraft. It will utilize a 3D printed engine (the company claims to have been the first to successfully test-fly a 3D printed engine). The vehicle is a two stage rocket which can be launched from land or a sea-faring platform.

Bloostar – Zero2Infinty offers a unique launch vehicle design that is lofted via high altitude balloon before being air launched. Since the powered flight occurs in the upper atmosphere where atmospheric density is negligible, the Bloostar utilizes three concentric, toroidal stages rather than traditional, elongated, in-line stages. All stages utilize liquid cryogenic propellants and identical engines – varying the number of engines per the stage requirements.

Boreas-Hermes – The Hermes is launched from a balloon system dubbed Boreas being developed by Stofiel Aerospace. Key to their design is what the company claims is the first solid fuel rocket to thrust, throttle, and vector, as well as a proprietary thermal coating. The system is designed to have a wide range of payload scalability from 15 kg to 250 kg.

Cab-3A – CubeCab's small launch vehicle is optimized for launching a 3U CubeSat. The CubeCab is launched from an F-104 fighter yet. Details on the rocket design are not publically available, but the propellants will be room-temperature storable to facilitate aircraft-like operations.

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.

Cloud IX – This currently unnamed rocket by Cloud IX is a balloon lofted vehicle which will deploy from an altitude of 41 km. It is a relatively small two stage, solid motor rocket. Cloud IX is aiming for rapid deployment within 60 days of contract authorization anywhere in North America.

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 – 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.

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).

Intrepid-1 – The Rocketcrafter's Intrepid-1 uses a patented and proprietary hybrid rocket technology to power its two stages. Initial plans are to launch Intrepid-1 from existing pads at the Kennedy Space Center in Florida. The company has previously looked at point-to-point delivery systems as well as larger variants of the Intrepid.

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.

LandSpace-1 – Sometimes billed as the "Chinese SpaceX" LandSpace plans to offer one-stop-shop solutions to its customers, including launch services, logistics, TT&C, and insurance. The LandSpace rocket is a four stage solid motor rocket that is small enough to fit on a mobile launch platform and be transported by cargo container.

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.

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.

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.

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.

Pegasus Strato – Stratolaunch is developing a custom-built carrier aircraft specifically designed for air launching rockets. In its initial configuration the Stratolaunch aircraft will be able to carry up to three Pegasus XL rockets. Different from all the other entrants in our list, this is primarily an aircraft development effort rather than a launch vehicle development effort.

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.

Prometheus-1 – SpaceLS seeks to keep costs down by optimizing the design and production of its Prometheus-1 rocket even if it comes at the expense of system performance. Prometheus-1 utilizes hydrogen peroxide/kerosene engines and will have a reusable first stage.

PSLV Light – PSLV Light is a derivative of the Indian Space Research Organization (ISRO) Polar Space Launch Vehicle (PSLV). Designed to cater to the smaller satellite market, PSLV Light will be able to undergo final assembly in 3 days and will have manufacturing costs that are one tenth of the larger variant.

RS1 – ABL Space Systems is utilizing propulsion systems from Ursa Major Technologies to outfit its RS1 space launch vehicle. The RS1 will utilize a "Dirt Simple" design in order to minimize costs. As a result launch operations are expected to require no fixed infrastructure and have service will have a one-week call up time. RS1 is a two stage vehicle with RP-1/LOX engines.

Sagitarius Space Arrow – Celestia Aerospace's Sagitarius 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.

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.

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.

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.

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.

VALT – The Vertical Air Launch Technology (VALT) rocket from VALT enterprises uses an air-breathing vertical multi-stage rocket to eliminate the need to carry oxidizers for part of the trajectory, greatly decreasing the size of the rocket. The performance of a 20,000 lb rocket should be accomplished with a rocket weighing only 3500 lbs.

Vector-R – Vector Space's Vector-R launch vehicle is a two stage all composite, pressure fed propylene/LOX liquid rocket, with an optional electric propulsion third stage. Cost control is achieved through a high flight rate. The rocket is designed to be mass produced to reduce costs. An optional electric propulsion third stage is available.

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.

Volant – bspace plans to use Orion and Star motors developed for the Pegasus and optimize them to create a 3-stage, land-launch rocket system.

KEY PARAMETERS

There are several factors that one looks at when investigating a launch vehicle, regardless of size. These are explored, to the extent possible, with the small launch vehicles.

Performance

The primary parameters of launch performance is how much mass the vehicle can lift to space. Vehicle developers do not have a standard way of quoting

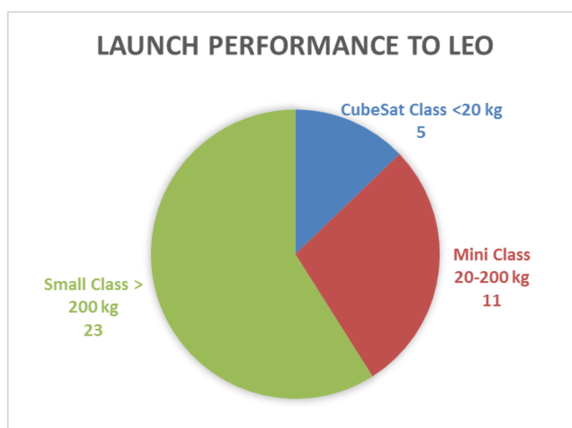

Figure 2: Performance Classes for Launch Vehicles

performance, so it is difficult to normalize across multiple vehicles. Roughly speaking vehicles can be broken down into "CubeSat" (< 20 kg), "Mini sat" (2-200 kg), and "Small Sat" (200-1000kg) classes. The distribution of entrants in these three categories is shown in Figure 2.

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
Cab-3A	5 kg	400 km
NEPTUNE N1	6 kg	310 km SS)
Bagaveev	10 kg	SSO
Rocky 1	10 kg	600 km SSO
Sagitarius Space Arrow CM	16 kg	LEO
Helios	20 kg	400 km
Cloud IX	22 kg	515 km
VALT	25 kg	500 km SSO
Vector-R	30 kg	450 km SSO
Bloostar	75 kg	600 km SSO
OS-M1	143 kg	300 km SSO
Arion 2	150 kg	400 km
Electron	150 kg	500 km SSO
VLM-1	150 kg	LEO
LandSpace-1	200 kg	500 km SSO
NewLine-1	200 kg	500 km SSO
Volant	215 kg	LEO
Orbex	220 kg	200 km
Boreas-Hermes	250 kg	LEO
Kaituozhe-2	250 kg	SSO
Kuaizhou-1A	250 kg	500 km SSO
Prometheus-1	250 kg	LEO
Tronador II	250 kg	600 km SSO
LauncherOne	300 kg	500 km SSO
Rocket-1	300 kg	200 km
Star-Lord	300 kg	185 km
Skyora XL	320 kg	600 km SSO
Chang Zheng 11	350 kg	SSO
Intrepid-1	376 kg	500 km SSO
Eris	380 kg	350 km
Pegasus (Strato)	455 kg	LEO
Pegasus XL	468 kg	200 km
Orbital 500R	500 kg	600 km SSO
PSLV Light	500 kg	LEO
Minotaur I	584 kg	200 km
Firefly Alpha	600 kg	500 km SSO
RS1	650 kg	500 km SSO
Chariot	681 kg	LEO
Space Rider	800 kg	400 km

Mission Cost

Perceived advantage in cost is the real key to this sudden expansion in small launch vehicles. 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. Cost containment is also the key 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.

Table 6: Launch Costs

Vehicle Name	Projected Launch Cost (US$M)	Estimated Cost per kg (US$k)
Firefly Alpha	$10.0 M	$10.0 k
Sagitarius Space Arrow CM	$0.2 M	$14.7 k
OS-M1	$3.2 M	$15.5 k
RS1	$17.0 M	$18.9 k
Kuaizhou-1A	$5.0 M	$20.0 k
Star-Lord	$6.0 M	$20.0 k
Boreas-Hermes	$5.0 M	$20.0 k
LauncherOne	$10.0 M	$20.0 k
Vector-R	$1.5 M	$22.7 k
Eris	$8.7 M	$23.0 k
NewLine-1	$4.7 M	$23.4 k
Intrepid-1	$9.0 M	$23.9 k
Bagaveev	$0.3 M	$25.0 k
Helios	$0.6 M	$27.5 k
Electron	$4.9 M	$32.7 k
Rocket-1	$10.0 M	$33.3 k
NEPTUNE N1	$0.3 M	$39.7 k
Space Rider	$32.0 M	$40.0 k
Bloostar	$4.0 M	$40.0 k
Arion 2	$7.1 M	$47.1 k
Cab-3A	$0.3 M	$50.0 k
VLM-1	$10.0 M	$66.7 k
VALT	$1.7 M	$68.0 k

Figure 3 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, we picked 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 vehicles with performance under 500kg have a cost under $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).

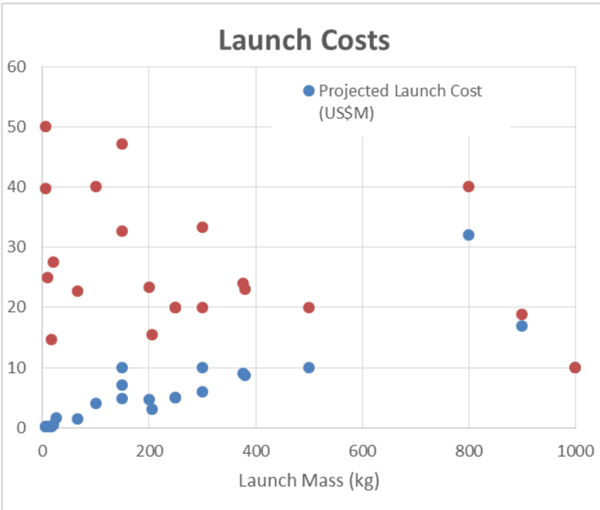

Figure 3: Launch Costs

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 publically stated what their ultimate launch rate goal is. Note that for most systems, it is expected that it will take several years before this optimal launch rate is achieved. Table 7 captures the publically announced target launch rates.

Table 7: Projected Launch Frequency

Vehicle Name	Launch Frequency
Arion 2	10/year
Bagaveev	50/yr
Electron	1/week
Firefly Alpha	2/month
Kuaizhou-1A	10/year
LauncherOne	24/yr
Star-Lord	1/month
VALT	1000s/year
Vector-R	100/yr
Volant	Multiple/quarter

Funding Source

Traditionally, 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 identified external sources of funding for each vehicle. Self-funding for all the vehicles 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 $50k. Because of strategic reasons many companies keep this information under tight control, and thus it is not publically available.

Table 8: Financial Investment Sources

Organization	Funding Source
Aphelion Orbitals	Angel investors
Bagaveev Corporation	Tim Draper, Adam Draper, DCVC, New Gen Silicon Valley Partners, Wei Guo, Data Coolective, Sand Hill Angels
Celestia Aerospace	One signed up customer
CubeCab	Biz Plan Competition, Self funded
ESA	ESA
ExPace	8 investment institutions
Gilmour Space Technologies	Blackbird Ventures, 500 Startups
Interorbital Systems	Self, Presales
LandSpace	Angel Investors; Series B (all from non-government)
One Space 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
PLD Space	Spanish government, EC, Caixa Capital Risc, Gobierno de Aragon, GMV, ESA, Gonzalo de la Pena, EC
Rocket Lab	NZ Gov, Kholsa, VBP, K1W1, LM, Promus Ventures, Bessemer, Data Collective
Rocketcrafters	State of Florida, DARPA
SpinLaunch	Adrian Aoun, Asher Delug
Stratolaunch	Paul Allen
VALT Enterprises	Office of Naval Research, Mainte Space Grant
Vector Space Systems	Seed Angels, NASA, DARPA, Space Angels, Sequoia Capital
Virgin Orbit	Virgin Group; Aabar Investments; Saudi Arabia
zero2infinity	Pre sales, Investors, Caixa Capital

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. 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". We have found out about many of these vehicles by word of mouth from readers of our previous papers.

Table 9: Watch List

Organization	Vehicle Name	Country
Aerojet Rocketdyne	Hera II	USA
Aevum	Ravn	USA
Airbus	Unknown	France
ArianeGroup	Q@ts	Europe
Astra Space	Astra	USA
Avio SpA	VegaC Lite	Italy
B2Space	Colibri	UK
Blue Origin	New Shepard+	USA
bluShift Aerospace	Unknown	USA
Cloud Aerospace	CloudOne Plus	USA
Deimos	Unknown	Portugal
FORE Dynamics	NFR-1	USA
Generation Orbit	GOLauncher 2	USA
Heliaq Advanced Engineering	Austral Launch Vehicle	Australia
HyImpulse	Unknown	Germany
Independence-X Aerospace	DNLV	Malaysia
InterStellar Technologies	Zero	Japan
iSpace	Hyperbola-1	China
JAXA	SS-520-4	Japan
JP Aerospace	Airship to Orbit (ATO)	USA
KB Yuzhnoye	Unknown	Ukraine
Leaf Space	Primo	Italy
LEO Aerospace	Rockoon	USA
MT Aerospace	Unknown	Germany
New Ascent	Unknown	USA
New Rocket Technologies	Light Satellite Launch Vehicle	Russia
Odyne Space	Unknown	USA
Onera	Altair	France
Pangea Aerospace	Meso	Spain
Pipeline2Space	Unknown	USA
Roketsan	Space Launch System	Turkey
Rose Galactic	Anthium Orbital Cannon	USA
SMILE	SMILE	Europe
Thor Launch Systems	Thor	USA
TiSpace	Unknown	Taiwan
U. Hawaii, Aerojet Rocketdyne, Sandia	Super Strypi	USA
UP Aerospace	Spyder	USA
Vanguard Advanced Systems	Athena	UK
Vogue Aerospace	Vogue RLV	USA/Italy

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

- Airbus and Avio Spa do 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)
- Blue Origin has not publically disclosed any intent to create a small sat launcher, however there has been speculation that they are modifying the New Shepard suborbital vehicle for this purpose.
- 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.
- The funding for a new Super Strypi launch is currently in question and subject to political discussions in the U.S. Congress
- JAXA had indicated that the SS-520-4 launch was a one-time effort to convert a sounding rocket into an orbital launch vehicle. After its second test flight was successful reports in the media indicated that there may be an attempt to commercialize the vehicle.

CHANGES FROM PAST SURVEYS

This is the fourth 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[8], and at the 98th Transportation Research Board Annual Meeting in early 2018[9] (2017 edition of survey). As such it is instructive to see what has over the years.

In 2015 we identified 22 organizations and their corresponding launch vehicle efforts that qualified for inclusion in our survey. This stands in dramatic contrast to the 40 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. Two of the teams identified to "watch" in 2015 have been "promoted" to the main list, with additional "watch" teams in 2016 and 2017 also being considered active now.

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 has also conducted a successful flight. The three Chinese vehicles currently operational, Chang Zheng 11, Kaituozhe-2, and Kuaizhou-1A were not in our original 2015 list.

Some vehicles and organizations previously on the list were downgraded to "watch" status over the years. This 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.

Finally 21 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 10 programs we consider "defunct" since they have been officially canceled or the companies that have ceased operations, and 11 programs for which no new information has been available for over two years and thus have an "unknown" status.

Some programs like the ALASA program and the closely related SALVO pathfinder were canceled by their DARPA customer leading to an end of the program.

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.

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.

Of note in the status unknown category is Arca Space Corporation. Its CEO was arrested and then released without indictment, and subsequently told that he was subject to deportation. As such, the status of the company is currently unknown.

Table 10 lists the efforts that were previously considered active or on our watch list that are now considered defunct or have an unknown status.

Table 10: Defunct or Status Unknown Efforts

Organization	Vehicle Name	Status
Boeing	ALASA	Defunct
Bristol Spaceplanes	Spacecab	Defunct
Firefly Space Systems	Firefly α	Defunct
Garvey Spacecraft Corporation	Nanosat Launch Vehicle	Defunct
Lockheed Martin	Athena Ic	Defunct
MicroLaunchers LLC	ML-1	Defunct
Open Space Orbital	Neutrino I	Defunct
Swedish Space Corporation	Rainbow Smallsat Express	Defunct
Swiss Space Systems	SOAR	Defunct
Ventions	SALVO	Defunct
XCOR Aerospace	Lynx Mark III	Defunct
ARCA Space Corporation	Haas 2CA	Unknown
EXO Corp	EXO	Unknown
Horizon Space Technologies	Black Arrow 2	Unknown
Lin Industrial	Taimyr-1A	Unknown
MISHAAL Aerospace	M-OV	Unknown
Nammo	North Star Launch Vehicle	Unknown
Newton Launch Systems	Unknown	Unknown
Scorpius Space Launch Company	Demi-Sprite	Unknown
Tranquility Aerospace	Devon Two	Unknown
Unreasonable Rocket	Unreasonable Rocket	Unknown
Whittinghill Aerospace	Minimum Cost Launch Vehicle	Unknown

CONCLUSIONS

The past four years have 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, and the Northrop Grumman OmegA. 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 this new entrants, but it is equally clear that both the founders and the capital markets think that there will be room for multiple players. 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 few months.

To best illustrate this growth, Figure 3 summarizes the changes over the past four editions of 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 publically 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 over 101 in 2018.

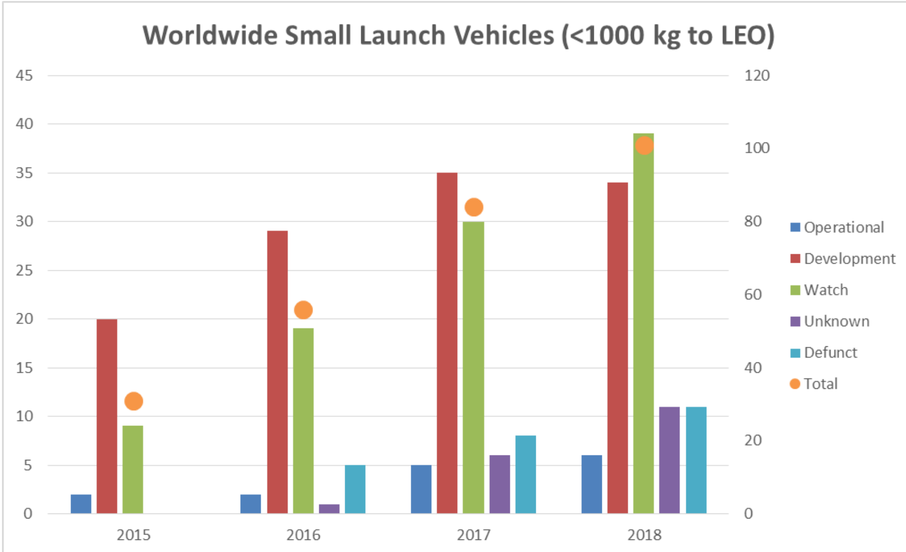

Figure 4: Growth of the Small Launcher Market 2015-2018

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The majority of the included research was collected from public references, including the web sites of the vehicles discussed and corporations discussed. Additional references are provided below.

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