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Small Launch Vehicles – A 2015 State of the Industry Survey

Carlos Niederstrasser, Warren Frick
Orbital ATK, Inc.
45101 Warp Drive, Dulles, VA 20166 USA; 703-406-5000
Carlos.Niederstrasser@orbitalatk.com

ABSTRACT

The first half of the 2010's has seen a dramatic increase in potential small launch vehicle contenders, defined as rockets capable of carrying at most 1000 kg to Low Earth Orbit. Spurred on by government programs such as FALCON, SALVO, RASCAL, SWORDS, NEXT, and VCLS and the rapid proliferation of CubeSats and nanosatellites, more than 15 different commercial, semi-commercial, and government entities worldwide are now working on new entrants of this class. This paper presents an overview of all of the small satellite launch systems under development today We will compare capabilities, stated mission goals, and cost and funding sources where available. We purposely avoid making any judgements on vehicle maturity as we do not have personal insight into the design and development of many of these new entrants. The nature of this survey limited us to publically available information – whether on the web, social media, traditional media, or published papers. The authors welcome any comments, feedback, or corrections.

BACKGROUND

The Tradition of Small Launch Vehicles

Today's intermediate and large launch vehicles, - Atlas Delta, Falcon and Ariane 5 started their lives in a smaller form. The Delta as Thor, growing from an Intermediate Range Ballistic Missile with space launch capabilities a bit above a metric ton to the heaviest launch vehicle the US is currently flying. Atlas 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 V grew from the purpose-designed Ariane I. Similarly SpaceX's Falcon 1 was quickly abandoned in favor of the larger Falcon 9. Only the Scout stayed small – limited by its technology and eventually being replaced by the Pegasus to fulfill NASA's need for a small space launch vehicle. Pegasus has a capacity that can't be easily expanded to exceed even a half metric ton. 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 fillers.

The CubeSat Revolution

Just like ORBCOMM and Iridium led the commercial perception of a need for small launchers in the 1980s and 90s (and Pegasus development directly), CubeSats are leading the demand now. As CubeSat capability increases, operators are no longer satisfied with the traditional rideshare and secondary payload opportunities available to them. For the past five years, 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 a metric ton.

CONTENDERS

New Entrants

This survey's goal was 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. 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 launch vehicle system (with the exception of carrier aircraft for air launch vehicles).

- Mentioned through a web site, social media, traditional media, conference paper, press release, etc. sometime after 2010.

- 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.

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 five years) to be indicative of the project standing down.

Existing Systems

Today only two operational systems fit into the category of "small launch vehicles" as defined by the 1000 kg to LEO limit. To give a baseline metric with the current state of mature small launch vehicles, the Orbital ATK Minotaur I and Pegasus XL will be used to contrast where the new entrants stand compared to what is currently available. To date all 11 of the Minotaur I flights and the last 28 flights of Pegasus have been successful.

Small Space Launch Systems

For our market survey, Table 1 represents an alphabetical roster of the name of the organization and launch vehicles that the organization plans on offering for commercial service. It also includes the published date of first launch (if available), and country(s) of origin. For simplicity sake, future references will only refer to the ***launch vehicle name***, as each launch vehicle has individual characteristics, whereas some organizations have multiple launch vehicles. When an organization has multiple variants of a launch vehicle, only the smallest will be considered..

Table 1: Space Launch Systems

Organization	Launch Vehicle Name	Country of Origin	Current First Launch Date
Boeing	ALASA	USA	Q1 2016
Lockheed Martin	Athena Ic	USA	After contract award
zero2infinity	Bloostar	Spain	
CubeCab	CubeCab	USA	July 2017
Scorpius Space Launch Company	Demi-Sprite	USA	
Rocket Lab	Electron	USA/New Zealand	2015
Firefly	Firefly α	USA	2017
Generation Orbit	GO Launcher 2	USA	Q4 2016
ARCA Space Corporation	Haas 2C	Rumania/USA	
Virgin Galactic	LauncherOne	USA	Q4 2016
XCOR Aerospace	Lynx Mark III	USA	2017+
MISHAAL Aerospace	M-OV	USA	
Orbital ATK	Minotaur I	USA	2000
Garvey Spacecraft Corporation	Nanosat Launch Vehicle	USA	
Interorbital Systems	NEPTUNE N5	USA	Q4 2015
Open Space Orbital	Neutrino I	Canada	
Orbital ATK	Pegasus XL	USA	1990
Celestia Aerospace	Sagitarius Space Arrow	Spain	Q1 2016
Ventions	SALVO	USA	2015
Swiss Space Systems	SOAR	Switzerland	2017
U. Hawaii, Aerojet Rocketdyne, Sandya	Super Strypi	USA	October 2015
Lin Industrial	Таймыр	Russia	

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 published.

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 – simply the launch mode will be designated – ground, air, or water. Table 2 lists details of how the space launch system starts its journey upward.

Table 2: Launch Method and Location

Launch vehicle Name	Launch Method	Launch Location
ALASA	Air	Global
Athena Ic	Land	4 US Spaceports
Bloostar	Balloon	Int'l Water
CubeCab	Air	Int'l Water
Demi-Sprite	Land	
Electron	Land	Birdling's Flat, NZ
Firefly α	Land	Kodiak preferred
GO Launcher 2	Air	USA, PR, UK
Haas 2C	Land	
LauncherOne	Air	Int'l Water
Lynx Mark III	Land/Suborbital	KSC or Mojave
M-OV	Land	
Minotaur I	Land	VAFB, KLC, WFF, CCAFS
Nanosat Launch Vehicle	Land	
NEPTUNE N5	Land	Intl' Water
Neutrino I	Land	
Pegasus XL	Air	Int'l Water – Multiple locations demonstrated
Sagitarius Space Arrow	Air	Int'l Water
SALVO	Air	CCAFS
SOAR	Air/Suborbital	
Super Strypi	Land	Hawaii
Таймыр	Land	

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 – 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 the small rockets already on the market. 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.

ALASA – Boeing's entry under the DARPA ALASA program consists of a two-stage rocket air launched from an F15E fighter jet. Both stages utilize liquid propulsion - a monopropellant, a combination of nitrous oxide and acetylene. A key requirement of the ALASA program is that the carrier aircraft must be unmodified (or still able to fulfill its original mission). Unique to Boeing's design is a tractor propulsion system for stage 1, allowing both stages to share engines, thereby reducing cost. The rocket uses four canted fixed nozzles on each stage, achieving attitude control through differential thrust.

Athena Ic – The latest generation of Lockheed Martin's Athena I vehicle utilizes two solid stages, a liquid third stage (that can be replaced with an optional dual mode bipropellant third stage). The Athena Ic capitalizes on previous Athena designs and Lockheed Martin's long history of experience in launch vehicles, only upgrading its obsolete second stage solid motor with a currently available solid motor.

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.

CubeCab – 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.

Demi-Sprite – The Scorpius Space Launch Company (sister company of Microcosm) is developing the Demi-Sprite as part of its line of modular Scorpius vehicles. The Demi-Sprite is one of the smallest vehicles in the line. The vehicle uses six identical cores for the first stage with a seventh core as a second stage. Key to the vehicle's simplicity is the absence of turbopumps for pressurizing its LOx and RP-1 propellants.

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.

Firefly α – The Firefly α from Firefly is a two stage vehicle powered by a LOx/Methane combination (Kerosene being tested as backup propellant). Both stages utilize a newly developed aerospike engine for increased performance. One of the characteristics contributing to its low cost is the mass production of the engine components.

GO Launcher 2 – Developed by Generation Orbit, the GO Launcher 2 is lofted by a Gulfstream 3G business jet before being released. The two stage vehicle utilizes a LOx/RP-1 system for its first stage, and a solid motor for its second stage. To increase performance the vehicle is manufactured primarily from composites. To control development costs, only mature technologies are being utilized in system development; for example the design utilizes an inexpensive derivative solid motor for first stage.

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 test bed for the new engine, but has since been modified to be two stages in order to carry a payload.

LauncherOne – LauncherOne is Virgin Galactic's entry into the orbital space launch domain. LauncherOne is air launched from White Knight 2, the same carrier aircraft used for human suborbital flights. Virgin Galactic expects that sharing the same carrier aircraft will reduce aircraft system operational cost. They are also applying the experience gained in developing Spaceship Two to the development of LauncherOne. LauncherOne is a two stage vehicle powered by LOx/RP-1.

Lynx Mark III – XCOR Aerospace's Lynx Mark III is identical to their suborbital Mark II plane, but with an external dorsal pod. For orbital launch missions, the dorsal pod carries a two stage vehicle powered by liquid propellants. XCOR hopes to capitalize on flight rate and experience from their suborbital program.

M-OV – The M-OV from MISHAAL Aerospace is a two stage hybrid rocket powered by HTPB and nitrous oxide. In addition to the central core the first stage also has two strap on boosters which are recoverable.

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. A larger fairing is also available to take advantage of the greater mass capability to orbit that the Minotaur I has over Pegasus XL. It has had 11launches with 100% reliability.

Nanosat Launch Vehicle – Garvey Spacecraft Corporation's NLV is a two stage rocket powered by liquid propulsion. The NLV is optimized for small spacecraft, hence its name. To reduce development and cost all key components are at TRL level 6 or higher.

NEPTUNE 5 – The N5 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 N5 utilizes 5 CPMs with an additional three or four solid upper stages.

Neutrino I – Neutrino I is Open Space Orbital's attempt to create an indigenous Canadian space launch capability. Neutrino I is powered by hybrid engines. The company has not yet published additional details.

Pegasus XL – The Pegasus XL uses three solid rocket motors and is launched from a modified Lockheed L-1011 carrier aircraft. An optional liquid fourth stage can be used to improve injection accuracy. 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. It has launched (taken off) from seven different launch sites, and used 5 different ranges over its 42 launch lifespan.

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.

SALVO – Ventions is developing a two-stage, air-launched rocket for DARPA's SALVO program. SALVO is seen as a pathfinder for larger ALASA. Key to Ventions solution is deployment from a conventional F15E fighter jet. The rocket utilizes LOx/RP-1 engines with battery-powered pups.

SOAR – The SOAR system from Swiss Space Systems consists of a carrier A300 aircraft, a suborbital space plane (known as SOAR) and an orbital insertion upper stage. The SOAR space plane utilizes a LOx/RP-1 engine. Key to the SOAR's economy is the reusability of the A300 aircraft and the space plane.

Super Strypi – The Super Strypi, being 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. It consists of three solid motor stages. During the first stage burn the vehicle is spin stabilized. It despins and reorients prior to final stage burn and satellite insertion.

Таймыр (Taymyr) – Lin Industrial's Таймыр rocket is a two stage vehicle powered by Hydrogen Peroxide and RP-1 engines. There are several variants of the Таймыр each with different capability; all variants share the same core, with multiple cores in parallel for increased performance. Like many other Russian rockets, the Таймыр core utilizes a single engine with multiple combustion chambers, but in this case it has no turbopumps. Lin Industrial is manufacturing the rocket in heavy machinery facilities rather than traditional defense or aerospace facilities.

Performance

One of the key parameters 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. Table 3 list the published payload capability to 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.

Table 3: System Performance

Launch vehicle Name	Performance	Orbit
SALVO	4 kg	LEO
CubeCab	5 kg	400 km
Таймыр	9 kg	LEO
Lynx Mark III	15 kg	400 km
Nanosat Launch Vehicle	20 kg	450 km
GO Launcher 2	30 kg	425 km 30°
NEPTUNE N5	40 kg	310 km SSO
Sagitarius Space Arrow	4-16 nanosats	600 km
ALASA	45 kg	LEO
Neutrino I	50 kg	LEO
Bloostar	75 kg	600 km SSO
Electron	100 kg	500 km SSO
LauncherOne	120 kg 225 kg	High SSO LEO
Demi-Sprite	160 kg	LEO
SOAR	250 kg	LEO
Super Strypi	250 kg	400 km SSO
Firefly α	400 kg	LEO
Haas 2C	400 kg	LEO
M-OV	454 kg	LEO
Pegasus XL	468 kg	200 km 0°
Minotaur I	584 kg	200 km 28.5°
Athena Ic	470 kg 760 kg	700 km SSO 500 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 use to support the business plans of the upcoming small satellite market expansion. Cost is also the key to continued market success of the vehicle as past vehicles have seen their cost increase significantly from original estimates. Table 4 outlines the planned launch service price, with a comparative cost basis utilizing Table 3's mass performance extrapolated in an attempt to normalize the metric. Launch costs are in millions of US Dollars; cost per kg are in thousands of dollars per kg.

Table 4: Launch Costs

Launch vehicle Name	Projected Launch Cost	Estimated Cost per kg
Sagitarius Space Arrow	$0.24 M	No mass spec
NEPTUNE N5	$0.25 M	$13 k
Firefly α	$8-9 M	$20 k
Таймыр	$0.18 M	$20 k
ALASA	$1 M	$22 k
Demi-Sprite	$3.6 M	$23 k
SOAR	< $10 M	$40 k
LauncherOne	$10 M	$44 k
Super Strypi	$12 M	$48 k
Electron	$4.9 M	$49 k
CubeCab	$0.25 M	$50 k
GO Launcher 2	$2.5 M	$56 k

Figure 1 shows the same data graphically – excluding the heritage vehicles. 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. However, it is interesting to note the apparent bimodal distribution centered on $45k/kg and 20k/kg. Furthermore none of the vehicles come close to the much lower per kilogram cost of larger rockets such as the Falcon 9.

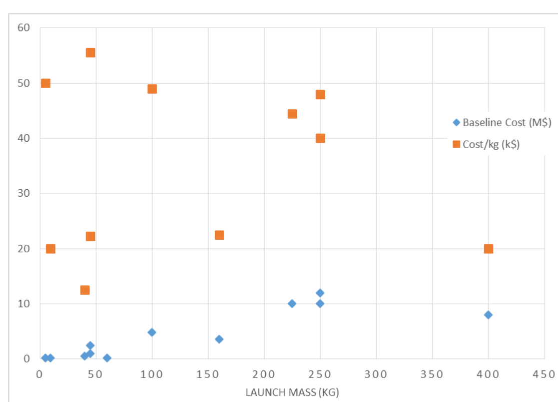

Figure 1: Launch Costs

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, a number of vehicles under development today are utilizing private funding. Some are entirely self-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 5 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.

Table 5: Funding Sources

Launch vehicle Name	Funding Source
ALASA	DARPA
Bloostar	Pre-Sales, Investors
CubeCab	Business Plan Competition
Electron	NZ Government, Kholsa, VBP, K1W1, Lockheed Martin
Firefly α	Local Government grants
LauncherOne	Virgin Group
Lynx Mark III	NASA, Haiyin Capital
Nanosat Launch Vehicle	NASA
NEPTUNE N5	Presales
Minotaur I	USAF
Pegasus XL	Orbital/Hercules, DARPA
SOAR	Brietling, pre IOP promotion
Super Strypi	USAF (ORS)
Таймыр	Sergei Burkatovsky

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 6.

Table 6: Other Players

Organization	Launch vehicle Name
Coleman Aerospace	No Name
Newton Launch Systems	No Name
Unreasonable Rocket	Unreasonable Rocket
Applied Thermal Sciences	VALT
Masten Space Systems	Xephyr

REFERENCES

The majority of the included research was collected from public references, including the web sites of the vehicles discussed. Table 6 contains a listing of the vehicle's or company's web site.

Table 7: Reference Web Sites

Launch vehicle Name	Performance
ALASA	http://www.boeing.com/space/advanced-space-access/
Athena Ic	http://www.lockheedmartin.com/content/dam/lockheed/data/space/documents/athena/Athena%20Fact%20Sheet%20Review%20vers%204.pdf
Bloostar	http://www.bloostar.com/#!launcher/c59
CubeCab	http://cubecab.com/launch-services.html
Demi-Sprite	http://smad.com/launch/scorpius
Electron	http://www.rocketlabusa.com/index.html
Firefly α	http://www.fireflyspace.com/vehicles/firefly-a
GO Launcher 2	http://www.generationorbit.com/golauncher2.html
Haas 2C	http://www.arcaspace.com/en/haas2c.htm
LauncherOne	http://www.virgingalactic.com/satellite-launch/
Lynx Mark III	http://www.xcor.com/lynxpayloads/
M-OV	http://www.mishaalaerospace.com/orbital-vehicle
Minotaur O	http://www.orbitalatk.com/flight-systems/space-launch-vehicles/minotaur/
Nanosat Launch Vehicle	http://www.garvspace.com/NLV.htm
NEPTUNE N5	http://www.interorbital.com/interorbital_05022015_012.htm
Neutrino I	http://www.openspaceorbital.com/#!launchvehicle/cipy
Pegasus XL	http://www.orbitalatk.com/flight-systems/space-launch-vehicles/pegasus/
Sagitarius Space Arrow	http://celestiaaerospace.com/
SOAR	http://www.s-3.ch/en/mission-goals
Таймыр	http://www.spacelin.ru/#!taymyr/c1wuk