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Issue Brief

Rocket Launchers for Small Satellites

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Summary

There are multiple ways of launching small satellites into the space. In recent times, there has been a growing focus on developing exclusive vehicles for the launch of a new generation of various categories of small satellites. This issue brief discusses various such efforts to develop small satellite launch vehicles, their importance and the future.

Introduction

The history of small satellites is as old as the history of satellites. In fact, the space age could be said to have begun with the launch of a small satellite, Sputnik-1, in 1957. Until almost the first decade of the 21st century, over 860 micro-satellites, 680 nano-satellites, and 38 pico-satellites were said to have been launched worldwide.[1] Though there is no precise statistics available about the exact number of small satellites launched till date, the global interest in small satellites has been growing over the years owing to various factors.

During the initial years of the development of space technologies, the focus was both on developing the satellites and the vehicles capable of launching them. Over a period of time, developments in technology allowed states to position satellites into different orbits. Developments in sensor technology further enhanced the utility of satellite applicability, from 'a space based observational platform' to a system as 'a decision making tool'. Integration of such multipurpose platforms helps governments to take critical decision in various areas, ranging from agricultural planning to disaster management to military operations. Presently, satellites are being increasingly used for meteorology, communication, navigation and other purposes. All these satellite usually have a mass of around two to six tonnes. Other missions like human space missions or development of space stations are required to carry much more mass. Hence, scientific efforts for all these years have normally revolved around designing and developing matching launch vehicles capable of carrying more weight and positioning satellites into different orbits.

With the focus being more on the launching of heavy satellites, the development of launch vehicle technology too has made progression in that direction. Also, states did not face any constraints in regard to their small satellite programmes as it was possible to launch them as 'piggyback' to the heaver satellites.

There are different reasons for growth in small satellite market globally. Since 1950s, development of a rocket launcher for putting satellites into the space has been technologically the most challenging task. Even today, almost six decades after the first satellite was launched, only a handful of states are in a position to launch satellites on their own. All other states are depending on space-faring states (in the recent past, limited private industry players have also developed launch vehicle technology) to launch their satellites.

Today, many smaller states are keen to launch their own satellites (mostly small in type) and are collaborating with space-faring agencies for this purpose. Also, with increase in the capabilities of small satellites owing to various recent technological developments and also understating their increasing strategic utility, space-faring states are found taking renewed interest towards expanding their small satellite development programmes. All this is pushing various space agencies into developing an exclusive new generation of small satellite launch vehicles.

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1 Henry Helvajian and Siegfried W. Janson (eds.), *Small Satellites: Past, Present, and Future*, Aerospace Press, June 01, 2008, at http://www.aerospace.org/publications/aerospace-books/small-satellites-past-present-and-future/ (Accessed November 03, 2015)

Small Satellites

Small satellites serve as low-mass and low-volume platforms that can be sent into orbit in less cost. Satellites could be classified according to their weight, orbit, purpose, etc. As per a standard convention, large satellites are known to have weight above 1000 kg/1tonne, medium satellites fall in the range of 500 kg–1000 kg, and small satellites are known to have maximum of 500 kg weight. Small satellites are further sub-categorised as follows[2]:

- Mini-Satellite: 100 Kg to 500 Kg (Wet mass*)
- Micro-Satellite: 10 Kg to 100 Kg (Wet mass*)
- Nano-Satellite: 1 Kg to 10 Kg (Wet mass*)
- Pico-Satellite: 100 g to 1 Kg
- Femto-Satellites: 10 g to 100 g

* including fuel

A major advantage with small satellites is that they allow non-spacefaring states, business/scientific establishments, educational institutions, non-governmental organisations and even individuals a low-cost access to space. Small satellites have some limitations owing to power and other sensor-related constraints, though. However, at times, a group of small satellites could undertake functions similar to that of a large satellite in a more cost-effective manner.

The mission life for large satellites is normally more than 10 years (for small satellites less than three years). Hence, most of the functional large satellites are found operating on a decadal old sensor technology. Since the life, cost and launching frequency of the small satellites vary from the large satellites, they could gain from various latest technological innovations and developments. It is obvious from the following table that small satellites are cost-effective investments.

Table 1: Estimated Manufacturing Cost of Satellites Per Kg[3]

	Mass (kg)	Altitude (km) Orbit Period	Project Lifetime	Total Cost (M US$)	Cost/Mass (k US$/kg)
Mini	100 - 500	1000 – 5000 (2 – 3 hrs)	4 - 7 yrs	10-150	200
Micro	10 – 100	500 – 2000 (1.6 - 2 hrs)	2 - 5 yrs	1-30	400

2 See "Miniaturized satellite", May 2006, at http://whatis.techtarget.com/definition/miniaturized-satellite (Accessed November 14, 2015)

3 Tony Azzarelli, "International Regulations for Nano/Pico Satellites", PPT Presentation at ITU Workshop on the Efficient Use of the Spectrum/Orbit Resource, Limassol, Cyprus, April14-16, 2014, at http://www.itu.int/en/ITU-R/space/workshops/cyprus-2014/Pages/Programme.aspx

Nano	1 - 10	300 – 800 (1.4 – 1.7 hrs)	2 - 3 yrs	0.1-10	800
Pico	0.1 – 1	200 - 400 (1.4 – 1.5 hrs)	1 - 2 yrs	0.05-2	1600
Femto	< 100 g	200 – 400 (1.4 – 1.5 hrs)	1 yrs	< 0.05	3200

Why Small Satellites?

Interest in small satellites has leapfrogged during the last few years. As per some estimates[4], over the past decade, roughly US$ 2.5 billion has been invested in small satellites and nearly half of that amount has come into play during last one to two years. Also, one of the private operators has announced that they have a plan of putting a constellation of 648 (launching to begin in 2018) small satellites with an estimated cost of US$ 2 billion (not accounted for in the US$ 2.5 billion estimate cited above).

Following graph depicts the actual and projected per year launches of small satellites.[5] There is a significant increase expected during next five years in the number of launches.

The above graph is based on information drawn from various sources.

Now, the question is why is there a sudden rush for small satellites? Broadly, following could be the key reasons:

1. For any nation-state, achievements made by their scientific community in space technology are a matter of pride. A sense of nationalism is associated with such achievements. Many states which are not in a position to develop independent space programmes are found looking for ways to get satellites launched from other agencies. Such investments have several purposes: first, to get exclusive benefits from the satellite which has been designed and launched for country-specific requirements; second, such investments provide a boost for the development of space sciences in the country; third, it enhances the prestige of the country both internationally and domestically; and fourth, investments in small satellites is a cost-effective option and the state gains much with lesser investments.

[4] Clay Dillow, "Here's why small satellites are so big right now", *Fortune*, August 04, 2015, at http://fortune.com/2015/08/04/small-satellites-newspace/ (Accessed December 30, 2015)

[5] "Nano/Microsatellite Market Assessment 2014", *SpaceWorks Enterprises, Inc. (SEI)*, Atlanta, February 2014, at http://www.sei.aero/eng/papers/uploads/archive/SpaceWorks_Nano_Microsatellite_Market_Assessment_January_2014.pdf and "Nanosatellite database by Erik", athttp://www.nanosats.eu/ (Accessed November 24, 2015)

2. The requirement for high-resolution earth imaging is increasing because of states finding such information useful for precise management of their land, water and forest resources. Also, with increasing danger from natural disasters, space-based inputs for forewarning as well as post-disaster management are extremely useful. Various private business houses are also keen to have real time inputs from the satellites prior to undertaking new business ventures.

3. Space-faring states are found making significant investments in space sciences for various purposes: building up space stations, organising human visits to space, management of space debris, undertaking visits to asteroids and other planets, developing space tourism, etc. There is a need to test various technologies which could have utility for such ongoing and future projects. Small satellites (normally in Lower Earth Orbit or LEO) offer cost-effective opportunity to undertake various technology testing experiments in space.

4. Small satellites have significant strategic utility including possible counter-space capabilities. However, there is a need to have a short launch service schedule which could make it possible to use them for specific tactical purposes when need arises.

5. Spatial expansion of Internet services is possible if space-based Internet becomes a reality. New business models are emerging factoring small satellites as a tool to provide such facilities. Major investments are expected in the near future in this sector.

Small Satellite Launch Systems

Barring few early years of development in the field of satellites and launch vehicles, small satellites are mostly found being launched as secondary payloads. Also, on occasions, such satellites do get launched from International Space Station (ISS) depending on the nature of specific missions. Aspace-plane too could launch such satellites. However, in all such cases, these satellites get launched only as subset to the main activity. In fact, at times, launch agency is required (read compelled) to launch secondary payload in the form of small satellites as 'piggyback' to utilise the full capacity of the launch vehicle.

Over the years, there have been some targeted efforts to develop specific launch vehicles for the small satellites. Currently, in view of the increasing importance of small satellites, various agencies are found making renewed attempts to develop and operationalise small satellite launch systems. Following tables[6] provide information about the past, present and proposed small satellite launch systems:

[6] Lucien Rapp, Victor Dos Santos Paulino and Adriana Martin, "Satellite Miniaturization: Are New Space Entrants About To Threaten Existing Space Industry?",*Space Institute for Research on Innovative Uses of Satellites (SIRUS)*, July 2015, at http://chaire-sirius.eu/wp-content/uploads/2015/07/Note-SIRIUS-Satellite-Miniaturization.pdf and "Comparison of Orbital

Table 2: Operational and Experimental Light Launch Vehicles for Orbital and Sub-orbital Launch (LEO, MEO and GEO)

Table 2(a): Launchers which began operations during 1990-2000

Vehicle	Origin	Manufacturer	Payload Capacity		First Launch	Last Launch	Launches
			Mass to LEO (Kg)	Mass to Other Orbits (Kg)			
Shavit 1/ 2	Israel	IAE	160		1988	2014	9
Pegasus	USA	Orbital	443		1990	2013	42
Start-1	Russia	MITT	532	350 SSO	1993	2006	5
Volna	Russia	Makeyev	100		1995	2010	6
Shilt	Russia	Makeyev	280-420		1998	2006	2
Minotaur I	USA	Orbital	580		2000	2013	10

Above table indicates that the United States (US) has done more than fifty small satellite launches by using their two specially developed small satellite launch vehicles. Other states like Israel and Russia have undertaken limited launches. In the last three decades, no serious attempts have been made to develop an exclusive small satellite launch system. This indirectly indicates that the global focus during the period was more towards development of big satellites and hence heavy satellite launch systems.

Launch Systems", Wikipedia, at https://en.wikipedia.org/wiki/Comparison_of_orbital_launch_systems (Accessed on December 14, 2015)

Table 2(b): Launchers which began operations in 21st century

Vehicle	Origin	Manufacturer	Payload Capacity		First Launch	Last Launch	Launches
			Mass to LEO (Kg)	Mass to Other Orbits (Kg)			
Safir	Iran	Iranian Space Agency	100		2008	2015	4
Unha	North Korea	KCST	100		2009		*3*
KSLV/NARO-1	South Korea	KARI &NPO Energomash	100		2009	2013	3(1)
Kuaizhou	China	CALT	400		2013	2014	2
Minotaur V	USA	Orbital		640 to GTO 447 to TLI	2013		1
Long March 11	China	CALT	700		2015		1

Above table indicates that in the last few years, countries like China and the US have been making investments towards developing small satellite launch systems. The vehicles developed by Iran and North & South Korea should not be strictly viewed from the 'prism' of attempt towards developing small satellite launchers. These states have joined the community of space-faring states only during the last few years. Their attempts for many years have been to indigenously develop a rocket which could place a satellite into an orbit. The first step in that direction is to develop a vehicle which could successfully launch minimum weight satellites into the space. Hence, their initial launches have been in the category of small satellites.

Presently, as per the available information, no proposals are in place from Israel and Russia to undertake any major investment in the field of small satellite launches in the near future. Following are the proposals for the US vehicle *Orbiter*:

- October 2016, launch for Cyclone Global Navigation Satellite System (CYGNSS) payload from Cape Canaveral
- June 2017, launch for Ionospheric Connection Explorer (ICON) payload from Kwajalein Atoll

Tables 2(a) and 2(b) indicate that China is the only new entrant (state actor) in small satellite launcher field. Few private agencies are also found making investments for developing small satellite launch vehicles. However, the process is facing some challenges owing to which states and private agencies are taking time towards developing such vehicles. At the same time, dependence on regular launch vehicles is also limiting the use of small satellites to their fullest potential. Some such challenges include:

1. Launch Cost: Presently, launching small satellites into LEO costs more if small satellite launch vehicles are used. If such satellites are launched in a piggyback mode, then there is relative cost saving. For example, the US$ 125 million *Atlas V* vehicle (capacity 9,000 Kg payload) delivers load in LEO at the rate of US$ 14,000 per Kg and the US$ 25 million *Taurus* vehicle (capacity 1,300 Kg payload, such vehicles are used to put many small satellites in space in a single launch) delivers load in LEO at a rate of US$ 19,000 per Kg.[7] Naturally, sending small satellites as a secondary payload is a cost-effective option.

2. Orbit Limitations: If small satellites are launched as secondary payloads, then opportunities for such launches are limited by the lack of control on the launch schedule and destination orbit of the vehicle. Constraints on volume and pressure of stored propellant, nominally to protect the primary payload and requirement of antenna systems for primary payload, at times restricts small satellite payload to manoeuvre into more suitable or favourable mission orbits.[8] Many a time, the primary load gets launched as a part of some specific mission, say a special sub-orbital or deep space missions. Such payload needs to be placed in a specified orbit and need to have pre-programmed orbital velocity. For such missions limited launch windows are available. Hence, secondary payload is forced to 'obey' the rules meant for primary payload and gets placed in the orbit by undertaking some compromises.

3. Scheduling Issues: A launching state requires some minimum time for preparation. Launch scheduling is dictated by logistical, technical and meteorological requirements. Life spans of big satellites are around 10 to 15 years while for small satellites are normally two to four years. Hence, small satellite missions require quick turnaround which is not achievable when their launching is tied up with other payloads.

Above points indicate that launching small satellites by using a launcher specifically-designed for the purpose may be desirable, but it is not the best option under the present circumstances. In order to make small satellite launch systems efficient, efforts are being made at two levels: making the existing systems (Vertical Launchers) more competitive, and building upon other launch options like the air launch systems.

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7 See Annual Space Launch Reports/Logs from 2010 to 2015, at http://www.spacelaunchreport.com/ and Jonathan Coopersmith "Affordable Access to Space", *Issues in Science and Technology*, 29 (1), Fall 2012, at http://issues.org/29-1/jonathan/ (Accessed January 05, 2016)

8 N.H. Crisp, K. Smith andP.Hollingsworth, "Launch and deployment of distributed small satellite systems", *Acta Astronautica*, 114, September-October 2015, pp. 65–78.

Table 3: Air Launch Systems

Programme	Operator	Payload Mass (Kg)	Launch / Propose Launch	Technology	Remarks
Airborne Launch Assist Space Access	DARPA	50 kg	From 2012 till date several pilot projects have been undertaken by Lockheed Martin (L-1011 TriStar, F-15 E Strike Eagle etc)	Air to Orbit Launch(Horizontal Launch System)	Aim is to produce a rocket capable of launching 45 kg satellite (LEO) for less than US$ one million.
XS-1 (Unmanned Space Plane)	DARPA	2500 kg	2017	reusable space plane / booster	Idea is to reuse the spacecraft frequently in LEO (proposed launch rate of 10 missions in just 10 days); cost less than US$ one million per flight
LauncherOne	Virgin Galactic	200 kg	2016	Air to Orbit Launch (Horizontal Launch System)	
Prospector 18	Gravity Spacecraft	20 kg			
Bloostar	zero2infinity S.L.	100 kg 75 kg to SSO	2017	First stage using high altitude balloon and second stage liquid propellant	Low cost launch

It is obvious from the above table that the US defence establishment, along with few private agencies, is also keen on developing air launch systems. Such systems are means of launching rockets at an altitude from a conventional horizontal-takeoff aircraft, to carry satellites to the low earth orbit. Such systems are found relevant owing to the reduced mass, thrust and cost of the rocket. Though the Defence Advanced Research Projects Agency (DARPA) of the US has been testing their air launch system since 2012, but is yet to declare it operational.

The table below presents information about few key agencies developing separate systems for the launch of small satellites. They are also using innovative technologies like 3D printing in order to reduce the turnaround time.

Table 4: Vertical Launch Systems (under making)

Programme	Operator	Payload Capacity Mass(Kg)	Launch / Proposed Launch	Technology	Remarks
Alpha	Firefly	400 kg	2017	2 stage liquid propellant engine	Made with light weight composite carbon material, low cost fuel like kerosene / methane
Electron	Rocket Lab	150 kg	2016	2 stage liquid propellant system	Launch frequency is around 1 launch per week. The first oxygen / hydrocarbon engine to use 3D printing for all primary components.
Soldier-Warfighter Operationally Responsive Deployer for Space	U.S. Army Space & Missile Defence Command	30 kg -50 kg		3 stage Solid / liquid Propellant system	Cost US$1.5 million per vehicle. Nanosat capabilities designed to be directly employed by small unit forces Portable ground processing and launch operations

					• Capable of flying from any coastal site • Capable of operating from austere locations Rapid response time • Ready to fly within 24 hours from garrison storage • Ready to fly within four hours from standby pad

Wrapping Up

Technological advancement in the field of electronic components, nano-technology, sensor technology and material sciences are leading a revolution in overall satellite building capabilities and launch techniques. Small satellites with their distinct features such as short timelines for development, greatly improved computational capabilities, lesser logistical requirements, and capability to operate as an excellent platform for testing, are making small satellites a popular choice amongst the users.

Small satellites are being increasingly projected as the most in-demand choice for militaries, commercial organisations, educational organisations, etc. However, the increase in demand for small satellites is not supported by the best launch options. Various existing small satellite launch options have huge limitations. It is believed that 'proliferation' of small satellites technology is possible only if reliable and cost-effective launch options are made available.

Defence agencies are increasingly looking at small satellites as an important option, essentially for intelligence gathering purposes. Such satellites could also assist in communication and other military-related services. During actual war or in the phase of 'preparation for the war', militaries could require positioning of different categories of small satellites as per the battlefield demand. This is only possible if they have the launch-on-demand technology available. Overall, there is a need to develop exclusive small satellite launch systems for various purposes.

Note: *All tables in this brief are based on information available in open sources. Several websites have been consulted though only major ones have been cited.*

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The Institute for Defence Studies and Analyses (IDSA) is a non-partisan, autonomous body dedicated to objective research and policy relevant studies on all aspects of defence and security. Its mission is to promote national and international security through the generation and dissemination of knowledge on defence and security-related issues.

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