SMALL SATELLITE MARKET INTELLIGENCE

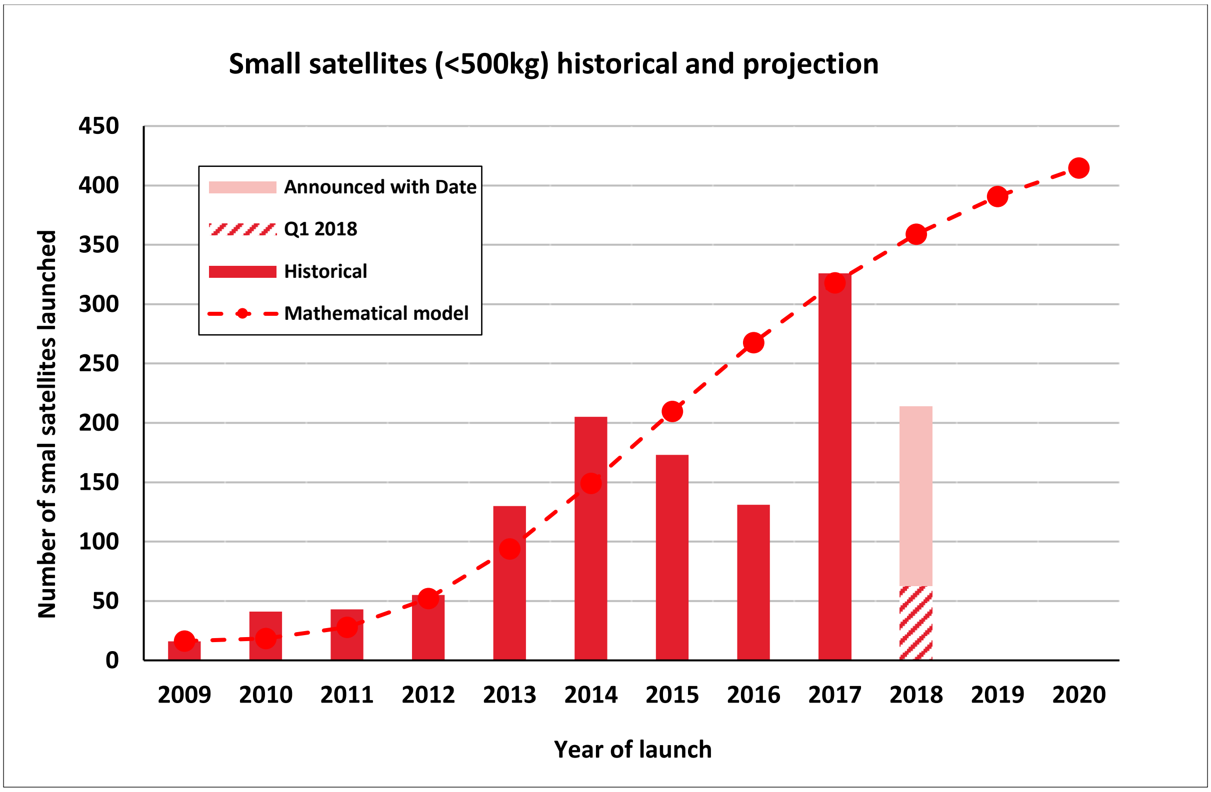
Q1 2018

This issue of the Satellite Applications Catapult's quarterly Small Satellite Market Intelligence report provides an update of the small satellites launched in Q1 2018 (1st January to 31st March 2018). This edition also includes a closer look at small satellite propulsion systems, and their adoption by upcoming satellite missions and constellations.

SMALL SATELLITES FACTS AND FORECASTS

OVERVIEW:

63 small satellites were launched in Q1 2018, more than in all of 2012 (the 2012 total had already been exceeded by February 2nd). March and February saw fewer launches carrying fewer small satellites than January, which saw 31 small satellites launched on a PSLV as well as 3 other launches carrying small satellites including the first flights of Rocket Lab's Electron small launcher and the SS-520, a Japanese small launcher and the world's smallest orbital vehicle.

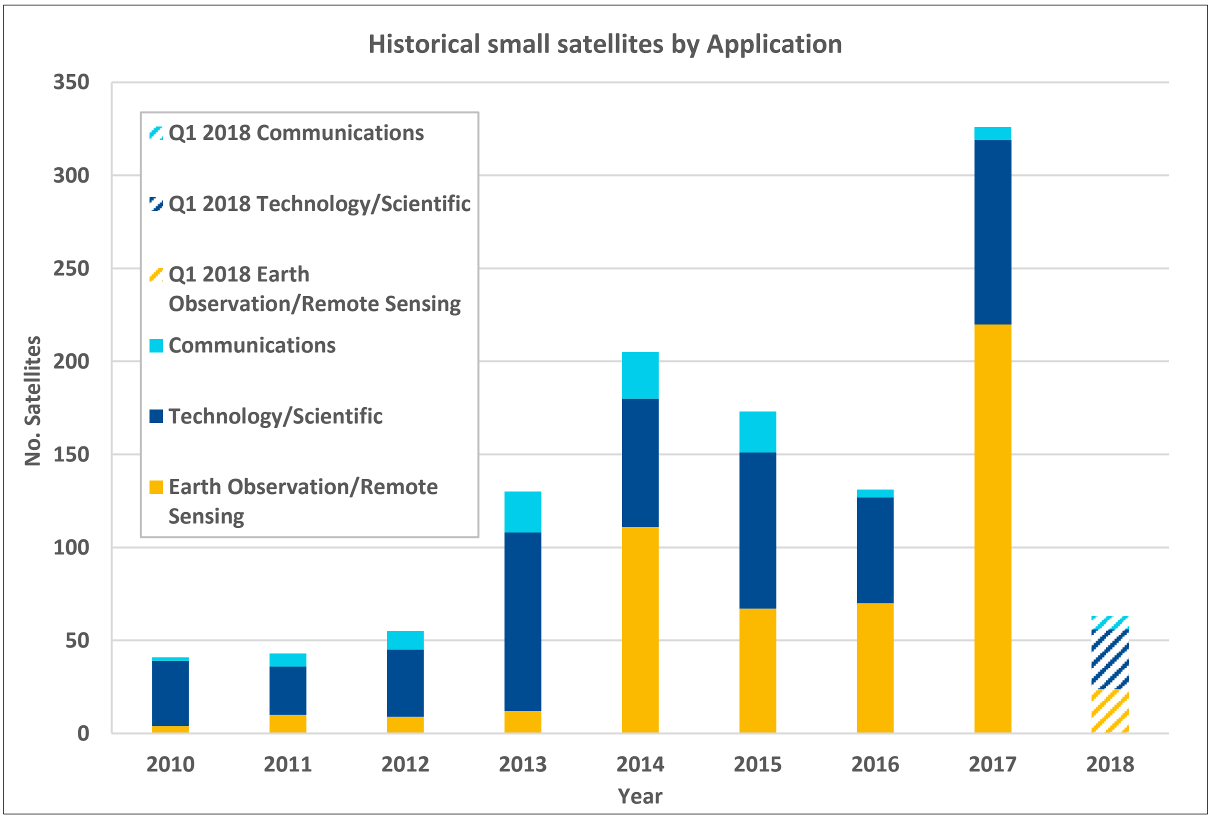


The mathematical model line in the graph above (simulating an accelerating market uptake from low levels in 2009 followed by a levelling off) approximates the historical growth of small satellites. Launch failures in 2015, with knock-on effects on 2016, can explain the offset between actual launches and the model. Although the announced satellites for the rest of 2018 so far appear to be falling short of the modelled growth curve, further launch announcements and confirmations of uncertain launches and manifests will likely take the total number of satellites launched in 2018 well above the current number announced.

With the growing use of small launchers providing ‘responsive’ access to space, satellite manifests and launch dates are increasingly being announced only shortly before launch, and due to this the current metric of “announced with date” is more likely to underestimate the total number of satellites launched than it previously was.

A number of interesting launches are expected to occur later in 2018: the first commercial launch of the Falcon Heavy in June (carrying ~30 small satellites), the first commercial launch of Virgin Orbit’s Launcher One, continuing launches of the Electron, and the first OneWeb satellites launched in August.

APPLICATION:

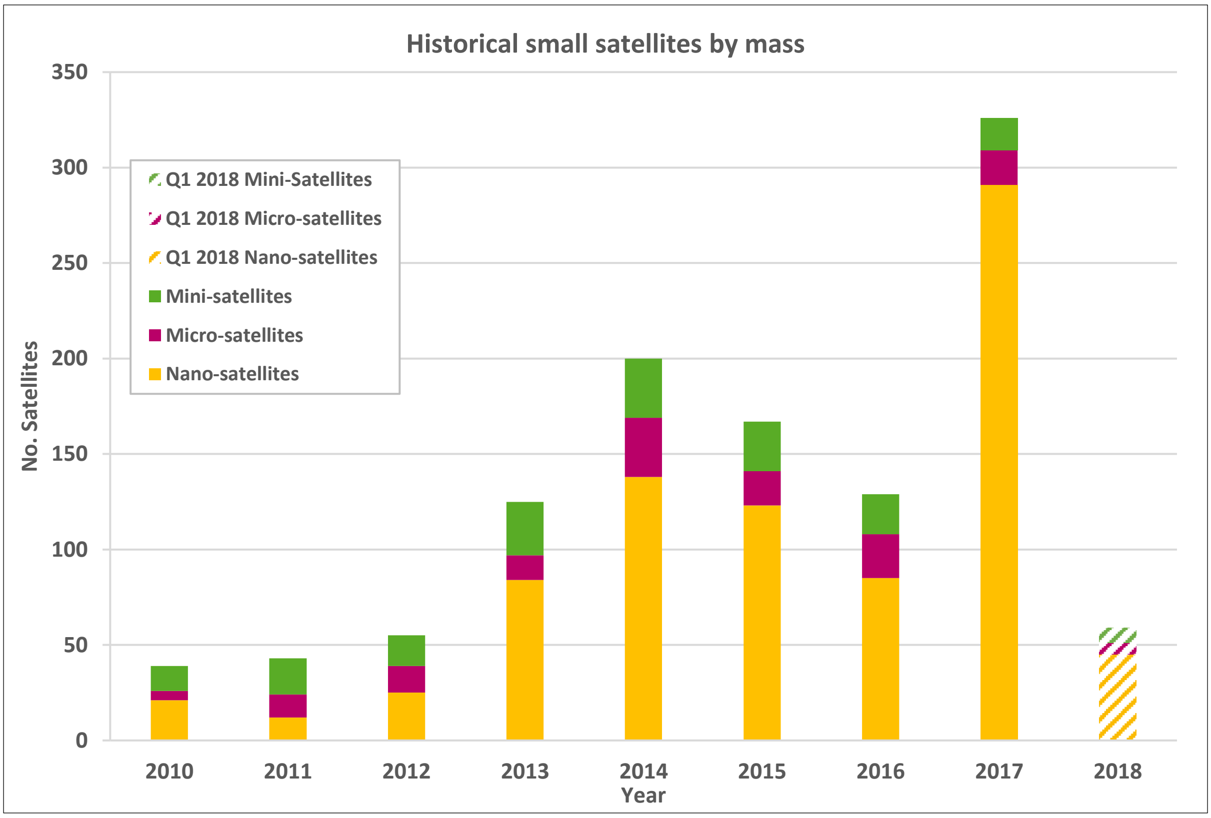


Applications are defined by the primary objective of the mission with the following groupings:

- Communications: the objective of the mission is to transmit or receive signals to/from a user terminal or gateway;
- Technology/Scientific: the objective of the mission is to gather knowledge to better understand physical phenomena or to test the functionality of a payload or equipment;
- Earth Observation/Remote sensing: the objective of the mission is to provide imagery or data relating to the Earth or its atmosphere.

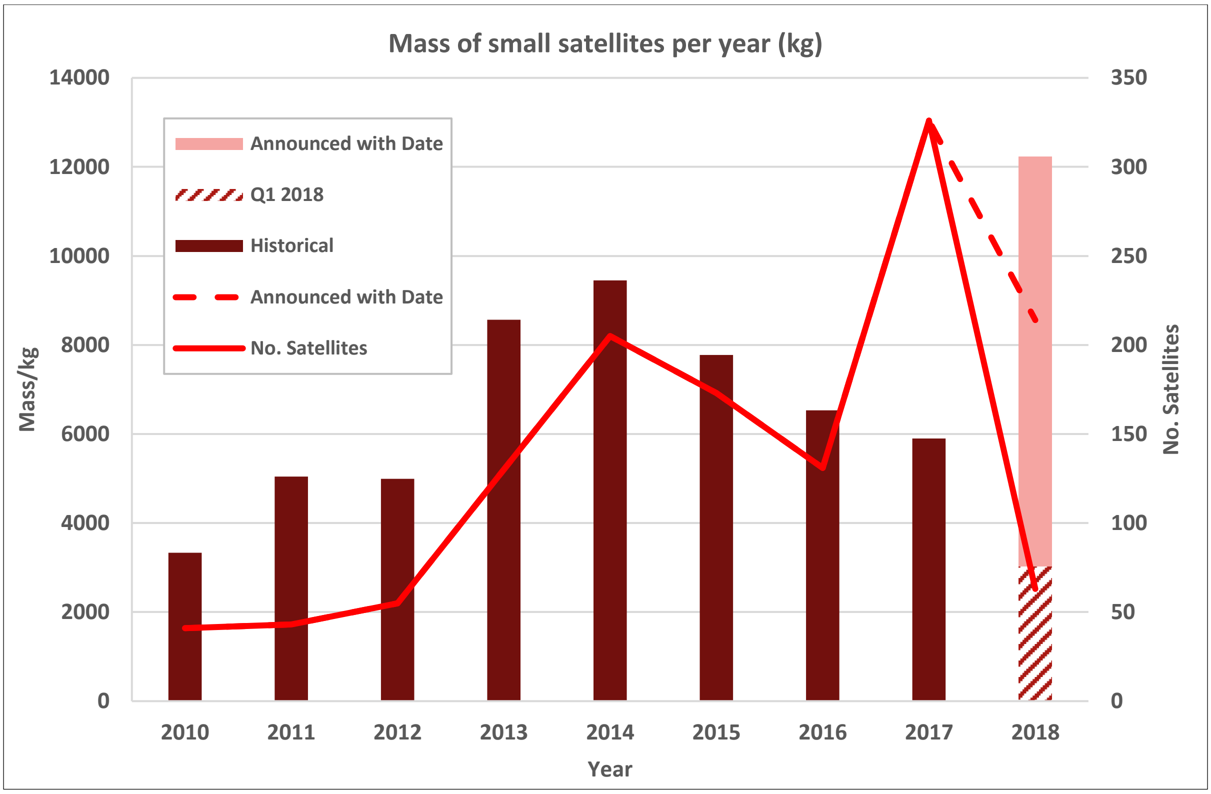
With Planet's constellation reaching completion, their overriding presence in the launch statistics is decreasing. As such, Earth observation and remote sensing have ceased to be the main drivers for small satellite launches with only 38% of the satellites launched in Q1 being primarily for this purpose. The dominant application in Q1 2018 was the Technology/Scientific category. At 51% of small satellites, these are largely university projects, and almost entirely non-commercial in nature. The Catapult continues to expect significant growth in communications small satellites in 2018 and for them to start to dominate in 2019 as a number of IoT and broadband small satellite constellations begin launching, it is likely that this application will take over as the primary driver of small satellite launches. The February launch of the two test satellites from SpaceX's Starlink constellation, Kepler Communications' first IoT satellite, and the manifested OneWeb satellites mark the beginning of this future trend.

SIZE OF SATELLITES:



Nano-satellites continue to represent most small satellites launched; 71% of the total this quarter, although this is down from nearly 90% in 2017. The 6U format has increased in popularity, 14 were launched in all of 2017 (5% of satellites in the CubeSat format) while 7 (16% of satellites in the CubeSat format) were launched in Q1 2018. This quarter has also seen the launch of four pico-satellites (<1kg), of which none were launched in 2017. Furthermore, Twiggs Space Labs announced plans to launch 63 picosatellites on an Antares launch later this year.

Satellite classification	Satellite sub - classification	Associated wet mass range
Small Satellite < 500 kg	Mini-satellite	100 kg - 500 kg
	Micro-satellite	10 kg – 100 kg
	Nano-satellite	1 kg – 10 kg



The total mass[1] of small satellites launched in Q1 was more than half of that launched in all of 2017. The high average mass (more than double that of 2017) of small satellites in 2018 means that despite little increase in total number of satellites launched, 2018 is likely to see a record mass of small satellites launched. The increase in mass stems from the drop in the proportion of Planet satellites launched and a rise in more massive communications satellites (60% of the mass launched in Q1 was made up by four mini-satellites: two SpaceX MicroSats and two Roskosmos Kanopus-V satellites).

The average mass of satellites launched in 2018 is expected to increase past Q1, as larger satellites such as OneWeb's, Russian Gonets-M, and Taiwanese Formosats are launched.

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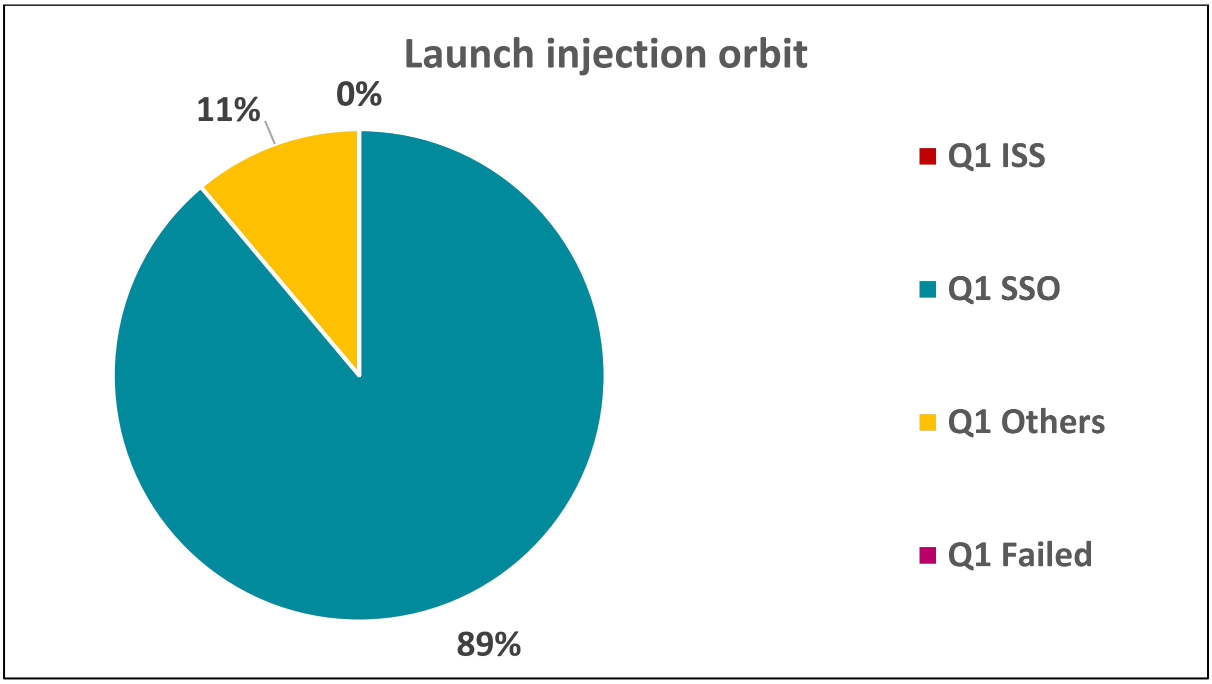
[1] For CubeSats of unpublished mass, it was assumed that they massed 1.3kg per unit, leading to an uncertainty of ±1% in the total mass featured in the graph

ORBIT:

Q1 2018 saw 89% of small satellites launched to Sun Synchronous Orbits, with none launched to the ISS in this quarter. The remaining 11% were split between dedicated small launchers (Electron and the Japanese SS-520), or rideshares with unique applications (PODSAT as a modular GEO satellite demonstrator, or Weina 1A, a Chinese nano-satellite of unconfirmed application launched with a trio of remote sensing satellites).



LAUNCH FAILURES:

No satellites were lost to launch failures in Q1 2018. The reason for the failure of nine of the small satellites aboard the Fregat stage launched in July 2017 was disclosed[2] to Astro Digital (whose satellites were unresponsive). Glavkosmos provided Astro Digital with documents detailing the failure of a thruster on the Fregat stage which damaged the satellites so that the company could prove to insurers that it was blameless. Roscomos (parent of Glavkosmos) continues to demand repayment from Dauria Aerospace for the two satellites built for Roscosmos that were also unresponsive.

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[2] "Insurance firm paid Astro Digital's claim for lost cubesats, sources said", SpaceNews, 09/03/2018

TECHNOLOGY INSIGHT: SMALL SATELLITE PROPULSION

A growing number of organisations are developing propulsion technologies suitable for use on small satellites. Previously small satellites have been largely unable to propel themselves, with only attitude-stabilisation available, as well as some discussion of differential drag techniques. Engineering efforts are succeeding in reducing the size of electric thrusters, and developing small chemical or cold thrusters that could easily be added to small satellite buses and conceivably fit inside single CubeSat units. The rest of this report will investigate the additional capabilities and the value that propulsion modules can add to small satellites.

BENEFITS TO SMALL SATELLITES

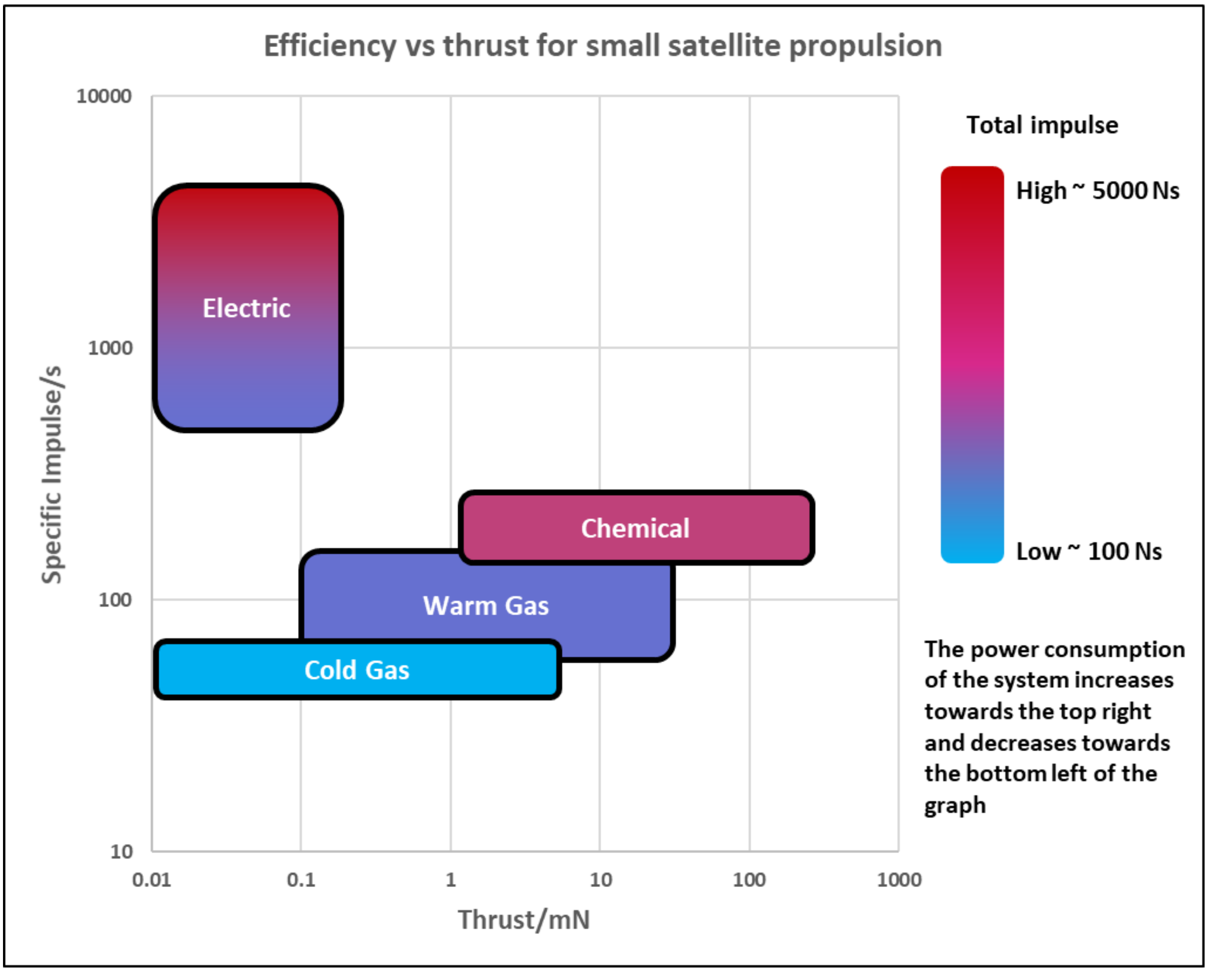
The current prevalence of rideshares in the launch market for small satellites means that the orbits that an operator can put their small satellites into is limited. For constellation applications this can limit the effectiveness of individual satellites, as their orbits cannot necessarily be equally phased. Satellites with propulsion can phase themselves equally across a plane, even if released together.

For small satellites beyond LEO, propulsion systems are of greater importance. Great stress is being placed on the ability of mega-constellations to be able to safely and consistently deorbit themselves, and geostationary orbit slots are valuable and carefully protected. For geostationary applications of small satellites (for instance the Astranis constellation) it will be necessary for them to be equipped with propulsion systems for orbit raising, station keeping, and decommissioning. Astranis is seeking to investigate both chemical and electric solutions for their constellation, although, it is likely that the longer lifetimes of geostationary satellites will make electric propulsion the more attractive option (mirroring the large satellite world, where electric geostationary satellites are growing in popularity).

Station keeping is not limited to geostationary satellites, large constellations can operate more efficiently if drift of their satellites can be prevented and propulsion for satellites in very low orbits can significantly increase their lifetimes from months to years by counteracting atmospheric drag. The necessary trade-off is that the propulsion system will require volume and power, which will reduce payload capacity unless a larger satellite is built at a higher cost. This trade-off means that propulsion systems are likely to be more attractive to operators of small satellites of higher mass, where the penalty for a propulsion system will be less of the total mass of the satellite.

SMALL SATELLITE PROPULSION TYPES & COMPANIES

Satellite propulsion systems can be broadly described across four metrics: thrust, specific impulse, total impulse, and power. Thrust is a measure of how much force a propulsion module exerts on a satellite, and thus how fast the satellite accelerates. For small satellites this is best measured in milli-newtons. Specific impulse is the efficiency of the system; it indicates the change in velocity for a given amount of propellant used and is measured in units of seconds. Total impulse measures how much the propulsion system can change the velocity of the satellite across its lifetime. Power is the rate at which the system uses electrical charge. The trade-offs between these values decide how appropriate a propulsion module is for different applications. Considered below are several types of propulsion and how they compare as 1U (a single CubeSat unit of 10x10x10 centimetres) modules. Total impulse, thrust, and power scale with the volume and mass of the system, values for modules larger than 1U are much higher, and specific impulse would be slightly higher in larger modules.



	Electric	**Chemical**	**Warm Gas**	**Cold Gas**
Thrust/mN	0.1	100	20	55
ISP/s	3000	220	180	65
Total impulse/Ns	5000	2000	1000	100
Power/W	40	5	30	2
Dimensions	<1U	1U	<1U	1U
Provider	Enpulsion	NanoAvionics	DSI	VACCO Industries

The figures in this table represent one individual thruster currently available in each category, not the full range of performance each category covers. These thrusters were selected because they are existing technology that reflect the performance currently available from each propulsion category.

Electric propulsion

Electric propulsion relies on the use of electromagnetic fields to accelerate very small quantities of propellant to very high velocities, resulting in systems that trade thrust and acceleration for low propellant consumption. These systems are becoming increasingly popular on satellites as the technologies advance and their performance outstrips older propulsion techniques. Both SpaceX and OneWeb are planning to employ electric propulsion to allow their communications mega constellations to raise their orbits, make corrections and collision avoidance manoeuvres, and deorbit.

The high performance of electric propulsion systems allows them to produce very large changes of velocity, meaning a small satellite could maintain its orbit for a very long time, or make large changes to its initial orbit. A high performance electric thruster could accelerate a satellite by thousands of metres per second. The drawback of an electric thruster is its low thrust compared to other thruster types; the difference in thrust would mean that a satellite employing an electric thruster could take a week to increase its velocity by 1%, where another system might achieve this in hours. Electric thrusters cover a wide performance range due to the variety of techniques different thrusters employ. However, the power consumption of electric propulsion systems is very high compared to other thrusters; 40 W would exceed the power budget of a 3U platform.

Example companies developing or providing small electric propulsion systems[3]:

ThrustMe – A French company developing innovative gridded ion thrusters that are smaller and simpler than existing solutions whilst retaining useful thrust, aiming to produce 1U-sized thruster.

ExoTrail – Another French company producing a miniaturised Hall effect thruster, targeting CubeSats wishing to perform station-keeping or orbit-raising.

Accion Systems – A US company developing electrospray thrusters with high and excellent scalability, as well as batch manufacture of hundreds of units at a time.

Mars Space – UK company developing many different forms of electric thruster, as well as providing consultancy and R&D services.

Neumann Space – An Australian startup developing a novel form of electric propulsion that is versatile in its choice of propellant and exceptionally efficient.

Enpulsion – An Austrian company that provides a 1U electric thruster that is scalable to larger spacecraft and has been employed by ESA missions.

Busek – A US company specialising in electric propulsion and power electronics, offering a wide range of electric thruster types.

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[3] Example companies have been chosen for geographical and technical diversity and sourced from the NewSpace Ventures database and the NASA “Small Spacecraft Technology State of the Art” December 2015 report, this is not a complete list. These companies are listed for example purposes only and are not specifically endorsed by the Catapult.

Chemical propulsion

Chemical propulsion uses energetic chemical reactions of stored propellants. These systems are capable of high thrusts at the cost of rapid depletion of propellants. This category covers many different technologies broadly categorised between liquid, solid, and hybrid fuelled systems. Liquid fuels all flow from tanks into combustion chambers and can be throttled, stopped, and restarted. Sub-categories of liquid propellants are: monopropellant, where one chemical (or a mixture) decomposes over a static catalyst; bipropellant, where two chemicals are ignited together; or hypergolic, where two chemicals spontaneously react on contact with each other. Solid fuels burn in place and cannot be throttled or stopped once lit. Hybrid systems use a liquid flow reacting across a solid, since the liquid flow can be controlled, the system can be throttled, stopped, and started. Much recent research in this area has been on developing "green" propellants – chemicals that can provide efficient propulsion with reduced risk to the environment and to people interacting with the spacecraft. Green chemical propellants are being developed to replace hydrazine, a common chemical hypergolic propellant which is extremely toxic and volatile. Handling hydrazine on the ground in the run-up to launch is difficult, dangerous, and consequently expensive. This research is being done by both commercial organisations and academics. Chemical propulsion allows for high thrust and relatively large velocity changes (hundreds of metres per second), making them suitable for altering the orbits of small satellites. This comes at the cost of low specific impulse, meaning that satellites must carry large fuel reserves that cut into useful payload mass to achieve significant orbit changes. Their power consumption is low, so they will not compete with other subsystems on the satellite for charge, which is at a premium. Lunar Flashlight is an example of a mission enabled by chemical propulsion; the 6U satellite will manoeuvre in lunar orbit using a green monopropellant system.

Example companies developing or providing small chemical propulsion systems:

Tesseract – A US company providing green bipropellant thrusters from 250g in size to 3.5kg for use individually or as multi-thruster modules.

Perigee Rocket LLC – A South Korean company developing a variety of propulsion systems, avionics, and testing systems.

NanoAvionics – A Lithuanian small satellites platform provider and mission integrator developing miniaturised green propulsion systems for small satellites.

Benchmark Space Systems – A US company developing CubeSat format thrusters that utilise green propellants.

ArianeGroup – European joint venture providing hydrazine thrusters in a variety of sizes with extensive flight heritage.

Aerojet Rocketdyne – US company providing a range of modular hydrazine propulsion units, as well as thrusters in other categories.

Cold & warm gas propulsion

Cold gas propulsion provides thrust by expelling compressed gases. These systems are simple, cheap, and easily miniaturised, but their performance is very poor. For some small satellite applications though, the addition of any manoeuvring capability at a low cost can be very valuable. Performance can be increased by using electrical power to heat the propellant making it more energetic – thrusters of this type are called resistojets. From the above chart (page 7) the low performance of cold gas thrusters can be seen. Their low efficiency means they can only produce a few metres per second of change in velocity. Satellites often need to be very precisely oriented, and this is achieved by using very small turning forces to rotate them very slowly. A thruster that produces too much force will turn a satellite too quickly to precisely aim it. Most chemical thrusters will be unable to produce small enough forces for short enough times to achieve this purpose, but the low thrust and quick action of cold gas thrusters makes them appropriate for controlling the attitude of small satellites, even if they are not able to perform station keeping or orbit raising due to their poor total impulse. Warm gas thrusters have better performance and can be effective for station-keeping, but require significantly more electric power to operate

Example companies developing or providing small gas propulsion systems:

Deep Space Industries – A US asteroid mining company that has developed a steam rocket warm gas propulsion system suitable for use on small satellites.

VACCO Industries – A US company providing a variety of different cold and warm gas propulsion systems as well as components for other propulsion systems.

CU Aerospace – A US company offering cold and warm gas thrusters for CubeSats as well as simulation tools and aerospace materials.

Marotta – US company providing a very small low power cold gas thruster as well as other satellite propulsion components.

Micro Space – A Singaporean company offering cold gas thrusters as well as payloads and satellite buses.

Other

Other manoeuvring methods include solar sails: which require no propellant but are inflexible in their thrust direction; differential drag techniques which use the atmosphere of the Earth but can only reduce orbital velocity rather than increasing it; and tether electrodynamics using the Earth's magnetosphere. These techniques are less useful to small satellite operators than the others listed, as they have serious drawbacks in terms of where they can take a satellite, or in which orbits they can be used. As such they have so far largely been explored in experimental missions by universities and research organisations. Although Planet had spoken of using differential drag techniques to distribute its Flock satellites, it seems unlikely that they extensively employ this technique as it would markedly reduce their satellite lifetimes. The Catapult is unaware of any commercial small satellite missions planning to use solar sails or tethers, although some mention has been made of employing these technologies for end-of-life solutions to ensure rapid deorbiting of defunct satellites.

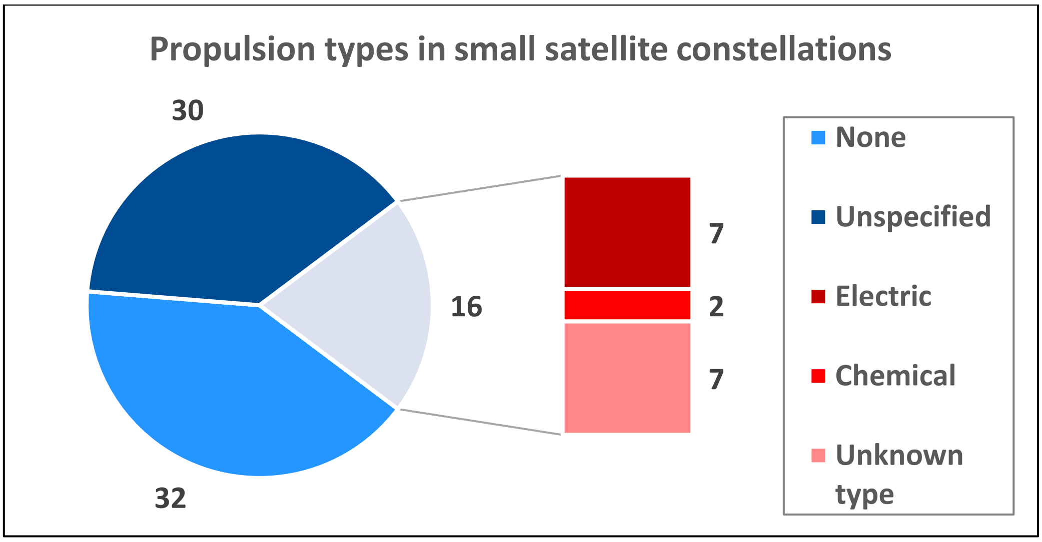
Example companies developing or providing other propulsion methods:

Tethers Unlimited – Developing electromagnetic and momentum-exchange tethers to allow propellantless orbital manoeuvring they also offer a water-electrolysis chemical propulsion system.

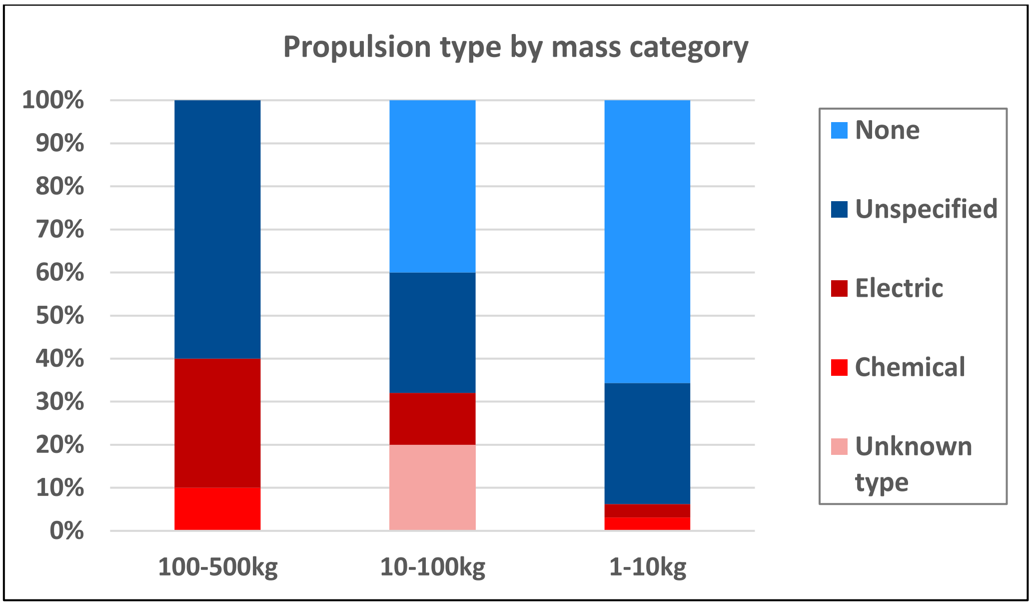
Cranfield Aerospace – Offers drag-sail deployment modules for small satellites to speed up the de-orbiting process at the end of a satellite's life.

CURRENT ADOPTION

Drawing on previous research into the world of small satellite constellations, the Catapult is aware of 16 small satellite constellations who are planning to employ some form of propulsion on their satellites. This is only a small proportion (20%) of the total number of satellite constellations, but this it to be expected, as historically many satellites have not required propulsive capabilities. Given that all of the communications mega-constellations have committed to some form of propulsion, it is likely that this will mean that the majority of small satellites launched in the next decade will include some propulsion capability.



Given that the default is to have no propulsion, it is likely that the vast majority of 'unspecified' constellations in the near future will not use propulsion modules, and have had no reason to specify that they are not. Although as small satellite operators seek to iterate and improve on their designs constellations that are currently without propulsion may switch over and adopt propulsion modules.



Of those constellations planning to use propulsion modules, many more are adopting electric propulsion than chemical. The two likely largest influencing factors in this decision are the improved performance of electric propulsion systems, even when afforded less mass, and rideshare regulatory issues, where small satellites taking rideshares must prove that their satellite is not going to damage the primary or other payloads. This is much easier to do with an electric than chemical propulsion system. The more massive satellites can employ propulsion systems at a lower impact to their useful payload mass, so a greater proportion of them plan to include propulsion modules. In the nanosatellite bracket it may also be that a lack of mature and proven options for satellites of that size is the reason for lower usage (the smallest available propulsion modules tend to be about 1U in size).

GREEN PROPELLANT

A number of propulsion providers are seeking to develop "green propellant" solutions. This means propellants that can be safely handled (low-pressure and non-toxic) but still provide useful performance. Historically, small satellite usage of green propellants has been limited by the lack of interest in giving very small satellites propulsion capabilities in the first place, and by the long heritage of hydrazine compared to recently developed green propellants which designers and engineers are unused to working with. Given that rideshares are extremely common for small satellites, the lower volatility of green propellants is very desirable; there is less risk to the primary payload, making the rideshare safer. This is an important aspect for small satellites seeking propulsion, as it allows them to find rideshares and launches more easily and at lower cost; handling costs for green propellants can be two thirds of the cost for hydrazine ($100,000s cheaper).

Deep Space Industries' Comet resistojet system is a typical example of the type of small satellite propulsion system that is growing in popularity, it is simple and easily integrated as well as being inert. Astro Digital and BlackSky Global have purchased Comet thrusters to use on their Earth observation constellations. Notably, resistojets have very poor performance compared to other propulsion methods, including other green propellants. A number of companies are seeking to develop propellants that will qualify as green but have markedly higher performance than a resistojet.

Enpulsion offers an ion propulsion module in a similar size to the Comet with five times the performance at a lower cost per unit. The primary trade-off between these systems is their thrust, meaning that these satellite operators are choosing high thrust and rapid manoeuvring over longer lifetimes. This is in line with small satellite business models that take short lifetimes for small satellites into account, a short lived small satellite might not have enough time to make full use of an extremely efficient ion thruster.

As green propellant development continues, small satellites are well placed to take advantage of new opportunities due to their lower risk aversion and rapid development cycles, this relationship works in the other direction as well; small satellites can provide flight heritage for propellant systems to reduce risk for more valuable spacecraft.

The Catapult thanks Jonathan McDowell for allowing the use of his data on historical satellite orbital parameters, which can be found on his webpage at http://planet4589.org/.

Contact

The Small Satellite Market Intelligence report is designed as a free data source to share information that is easy to access and use. We welcome feedback on other data points that would be of value to include. You can contact us at:

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