Virgin Galactic's facility in Long Beach, California.

Developments in dedicated small satellite launch vehicles

The advent of small satellites has prompted significant changes within the launch market. While initially most small satellites were launched as secondary payloads or from shuttles to the International Space Station (ISS), a new niche market specialising in dedicated small satellite launch capabilities is emerging, transforming what was once the domain of a select few companies to a much more highly-populated market. A large number of new market entrants is embracing the small satellite era with a range of dedicated launch technologies with the opinion that satellite operators would prefer such a service to the secondary payload model.

To date, the vast majority of small satellites have been launched as secondary payloads, piggybacking off of larger satellite launches, or shuttles to the International Space Station (ISS). Most of the major launch service providers now offer secondary payload launches as an option on many of their rockets, although a small number have refused to participate.

Secondary payload launch mechanisms are truly a worldwide phenomenon. Japan Manned Space Systems Corporation (JAMSS) provides small satellite launch services from the ISS and as secondary payloads with launch vehicles like Mitsubishi Heavy Industries' (MHI) H-IIA, using deployment opportunities provided by Japan Aerospace Exploration Agency (JAXA).

Arianespace is another major launch service operator that provides piggyback payload launches. In April 2016, in addition to its main payload of the European Space Agency's (ESA) 2,146kg Sentinel-1B satellite, the Soyuz launcher successfully deployed three 1kg Cubesats for the ESA's 'Fly Your Satellite!' programme, and the CNES' 300kg Microscope, France's satellite developed to verify the equivalency principle for inertial and gravitational mass as stated by Albert Einstein.

The Indian Space Research Organisation (ISRO) has also been launching small satellites as secondary payloads for several years. In December 2015, it launched the 625kg Singapore Technologies Electronics Limited (ST Electronics) TeLEOS-1, Singapore's first commercial Earth observation satellite, along with five small satellites as secondary

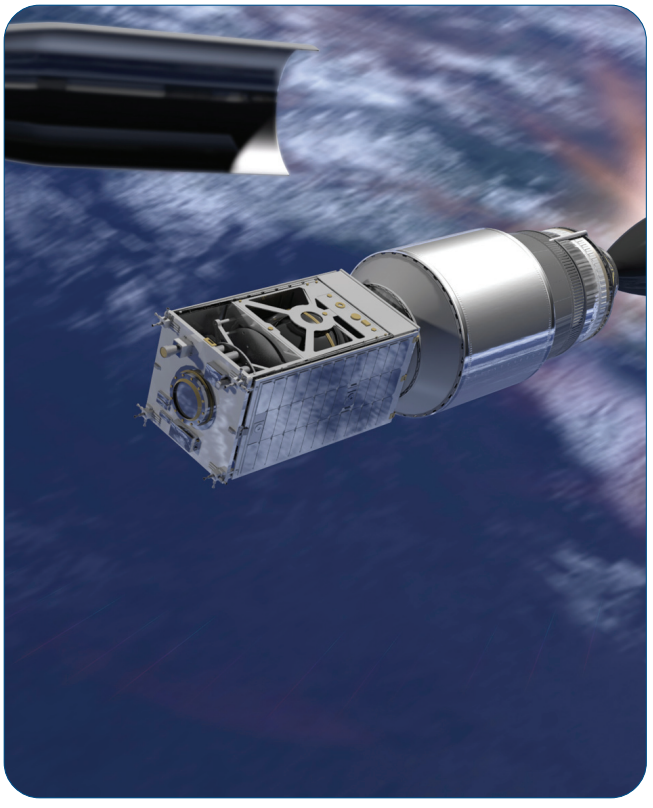
payloads, into a 550km near equatorial orbit (NEqO) with a Polar Satellite Launch Vehicle (PSLV-C29). The ISRO has another noteworthy secondary payload launch scheduled for November 2016, for the first two 10kg small satellites of PlantiQ's 12-satellite constellation.

Piggyback launches come with a number of caveats, including launch date, deployment location, deployment mechanism compatibility and payload restrictions. While piggybacking might work well for proof-of-concept satellites with experimental payloads, or small entities that are prepared to wait to launch a single satellite, for larger commercial entities that require precise launch dates or that plan to launch a series of small satellites with their own specifications, specialist, cost-effective commercial launch opportunities are required.

Another problem with piggyback launches is that, should the launch fail, the losses can be pretty significant. In November 2015, the Supr Strypi rocket launch, which had already been delayed several times, failed in the first stage of flight. The payload, a collection of small satellites for the US Department of Defense's (DoD) ORS-4 mission, which aims to develop a low-cost low Earth orbit (LEO) satellite constellation at short notice, and the University of Hawaii's 55kg hyperspectral imaging and aeronautical kinematic analysis satellite HiakaSat, was lost.

Moving to the future: Dedicated small satellite launch vehicles

Responding to the growing demand for specialised small satellite launch services, there are currently around 20 companies developing dedicated small satellite launch vehicle projects, including established companies like Orbital ATK, Lockheed Martin and Virgin Galactic, and new market entrants such as CubeCab, Generation Orbit and zero2infinity. Potential payloads vary from 4-760kg, projected prices range from US$0.18-12m, and deployment methods include air, land and balloon.



Virgin Galactic is developing LauncherOne

Firefly Space Systems is one of those start-ups, established with the aim of providing low-cost, high-performance small satellite launch capabilities through the use of mass-produced, state-of-the-art rockets. Unlike traditional launch rockets, which use a bell nozzle, the Firefly á rocket features an aerospike, which provides greater efficiency across the ranges of pressures during the rocket's entire flight. Firefly á also uses a fully pressure-fed propulsion cycle for increased efficiency, and an all-carbon fibre structure to reduce the mass. Firefly á will be able to launch a 400kg payload to a 400km equatorial orbit, or a 200kg payload to a 500km sun synchronous orbit (SSO).

Rocket Lab is another of the new market entrants. Similar to Firefly, Rocket Lab aims to make small satellite launches more cost-effective with a proprietary rocket design that features an innovative new electric propulsion cycle that uses electric motors to drive its turbopumps. The Electron rocket is also the first oxygen/hydrocarbon engine to use 3D printing for all its primary components. Electron will deliver a 150kg payload to a 500km SSO, and can also provide customised launch services, including a range of SSO altitudes in circular or elliptical orbits at 45-98° inclinations. The company is making good progress towards its goals; in December 2015, construction started at its launch site in New Zealand, while in 2016, its engine and second stage propulsion were approved for flight. Once commercial operations start, around 100 launches each year are planned.

NASA invests in the future with its Launch Services Program

In October 2015, NASA's Launch Services Program (LSP) awarded Venture Class Launch Services (VCLS) contracts to provide small satellites with access to affordable launch services via Firefly Space Systems (US$5.5m), Rocket Lab USA (US$6.9m) and Virgin Galactic (US$4.7m).

Small satellites are playing an increasingly-larger role at NASA as they provide a low-cost platform for NASA missions, including space exploration, Earth observation, fundamental Earth and space science, and developing precursor science instruments like cutting-edge laser communications, satellite-to-satellite communications and autonomous movement capabilities. The VCLS contracts will demonstrate a dedicated launch capability for smaller payloads that NASA anticipates it will require on a recurring basis for future missions.

"LSP is attempting to foster commercial launch services dedicated to transporting smaller payloads into orbit as an alternative to the rideshare approach and to promote the continued development of the US commercial space transportation industry," said Jim Norman, Director of Launch Services at NASA. "VCLS is intended to help open the door for future dedicated opportunities to launch CubeSats and other small satellites and science missions."

Virgin Galactic's LauncherOne to offer custom small satellite launch services

Virgin Galactic is developing LauncherOne, a launch vehicle dedicated to the small satellite market, designed to be affordable, reliable, flexible and responsive. A number of commercial and government customers have already been signed up to the future service for satellite applications ranging from deep space exploration, Earth observation, meteorology, and broadband connectivity.

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Conference Program

October 4

Time	Session
09:00-09:20	Welcome Address
09:20-09:50	Opening Keynote
09:50-11:00	Satellite Operators Panel: An Industry in Transition
11:00-11:30	Morning Refreshments
11:30-12:30	Satellite Broadcast
12:30-14:00	Welcome Luncheon
14:00-14:40	Satellite Users Panel
14:40-15:30	Satellite Manufacturers Panel
15:30-16:00	Refreshments
16:00-16:30	Changing Media World
16:30-17:30	The Rise of HTS in Asia
18:30-20:00	2016 APSCC Awards

October 5

Time	Session
09:00-09:30	Space in Silicon Valley
09:30-10:15	Changing Times & Changing Tech, Where is Satellite on the Curve?
10:15-11:00	Mobility: The Battle for In-flight Connectivity
11:00-11:30	Morning Refreshments
11:30-12:30	The Rise of Smallsats and Big Data
12:30-14:00	Networking Luncheon
14:00-14:45	Satellite Launch Services Panel
14:45-15:30	Constellations - Large & Small
15:30-16:00	Refreshments
16:00-16:30	IoT and Satellites
16:30-17:30	Financing | Risk Management
18:00-20:00	Networking Reception

October 6

Satellite Experts In-Depth Track

Time	Session
09:30-10:30	Delivering Stable Satcom: Voices from Satellite Operators
10:45-11:45	Delivering Stable Satcom: New Technology to Save the Sky
12:00-12:45	Teleport Operation - A Technology Update
12:45-14:00	Conference Luncheon
14:00-15:00	Beating IMT: Policy & Regulation
15:30-16:30	New Tech: Advances in Satellite Design
17:15-19:00	Closing Social Networking Event

Youth Development Workshop

Time	Session
09:00-09:15	Welcome & Workshop Overview
09:15-10:15	Satellite Communication Fundamentals, Systems & Applications
10:30-11:30	Satellite Communications Regulation
11:45-12:45	The Satellite Telecommunications Industry
12:45-14:00	Conference Luncheon
14:00-17:00	Satcoms Workshop: 'A broadband satellite system for Islaysia'
17:00-17:15	Wrap-up
17:15-19:00	Closing Social Networking Event

Unlike traditional satellite launch operations that utilise a rocket and launch-pad, LauncherOne will be carried under the left wing of a dedicated Boeing 747-400 carrier aircraft called Cosmic Girl to around 35,000ft, where upon it will be released to make its rocket-powered flight into orbit. The 73,500lbf LOX/RP-1 rocket engine will fire for around three minutes, followed by the 5,000lbf LOX/RP-1 rocket, which will propel the launcher to orbit through multiple burns of around six minutes. The satellite(s) will then be deployed, and LauncherOne will be de-orbited, while Cosmic Girl returns to land for re-use.

LauncherOne's payload capacity is extremely customisable. Up to 300kg can be launched to 500km SSO, and up to 500kg can be launched to 200km circular 28.5° LEO. One of its key selling points is that LauncherOne will be able to launch a 200kg payload to standard SSO, the most commonly-desired orbit for small satellites, for less than US$10m.

To date, Virgin Galactic has completed launch assessments for the primary launch site of the Mojave Air and Spaceport (MHV) in California and for a variety of locations including the Shuttle Landing Facility (SLF) at the Kennedy Space Center (KSC) in Florida and the NASA Wallops Flight Facility (WFF) in Virginia. The company is prepared to obtain approvals to operate in locations other than Mojave based on customer interest.

The unique concept enables performance benefits in terms of payload capacity, while also allowing launches from untraditional locations and under a variety of weather conditions, which can often delay traditional launches. The first launch is expected to commence in 2017.

DARPA's ALASA programme to reduce launch costs to less than US$1m

The Defense Advanced Research Projects Agency (DARPA), an agency of the US Government responsible for the development of emerging technologies for military applications, was created in 1958 in response to the Soviet Union's Sputnik 1 launch a year earlier. Today, DARPA's Airborne Launch Assist Space Access (ALASA) programme aims to develop a dedicated small satellite launch service that reduces launch costs three-fold compared to current secondary payload military and US commercial costs of US$30,000/lb. ALASA is being designed to launch 100lb satellites into LEO within 24 hours of request, for less than US$1m per launch.

NanoRacks CubeSats deployed from station. Photo courtesy of NASA

In phase 1, three variable system designs were completed, while in phase 2, Boeing was selected as the prime contractor to produce a low-cost, expendable launch vehicle that could be deployed from a standard aircraft. The vehicle design features a novel propulsion system that will, once fully-developed, use a new monopropellant that combines nitrous oxide and acetylene to create a high-energy mix called NA7, without a separate oxidiser. Such a system would grant increased performance and reliability, be more space-effective, and more affordable than traditional bipropellant systems.

As of November 2015, DARPA had conducted four sub-scale static tests of the propulsion system on test stands, which indicated the need for additional tests to refine the engine design and assess the viability of NA7 as a safe monopropellant. DARPA believes that learning to safely use NA7 could open up ground-breaking capabilities across space and non-space-related fields. To accelerate progress towards this goal, DARPA has ceased development of the ALASA launch vehicle technology demonstrator and is focused on monopropellant safety testing and certification.

In addition, DARPA is reassessing the emerging capabilities of commercial small satellite launch providers, which have made big strides in recent years, and will consider partnership opportunities with providers seeking appropriate payloads for rapid, affordable access to space. DARPA also plans to continue partnering with test ranges on innovative software and hardware for future autonomous flight termination systems and build on the successful ALASA rapid mission planning system.

The software is being designed to be extensible to different launch vehicles, which would remove the need to create proprietary software for each vehicle, dramatically lowering launch costs.

Made In Space and Nanoracks plan 'Stash & Deploy' service

August 2015 saw space manufacturing company Made In Space and satellite launch services provider NanoRacks agree to develop a 'Stash & Deploy' service, which will see the companies use a new commercial 3D printer on the ISS to build and deploy CubeSats in situ. Components that cannot yet be printed will be stockpiled on the ISS for incorporation. With this new service, it will be possible for customers to have custom-designed CubeSats built and launched extremely rapidly.

"This is a fundamental shift for satellite production. In the near future, we envision that satellites will be manufactured quickly and to the customer's exact needs, without being overbuilt to survive launch or have to wait for the next launch," said Andrew Rush, President of Made In Space.

As the CubeSats do not have to withstand the rigorous launch event, they will be built without some of the physical limitations featured in traditional CubeSats. This opens up a world of new options in CubeSat design, including ultra-thin antennas that can more efficiently and more evenly absorb

solar radiation. In addition, the Stash & Deploy service will enable operators to avoid waiting for secondary payload launches. Stash & Deploy is expected to launch in the first half of 2016.

For Made In Space, Stash & Deploy is a stepping stone towards its ultimate goal of building spaceships in space. Another step towards that goal came in November 2015, when NASA awarded Made In Space a two-year US$20m contract to develop Archinaut, a 3D printer-come robotic arm that will operate outside of the ISS, in space. Archinaut will be able to print structures much larger than itself, including, perhaps, massive satellites that enable a new wave of global communications or broadband connectivity services. A demonstration of the project's capabilities is expected in 2017-2018.

A skewed supply-demand balance?

There's been a great deal of development in the field of small satellite launch technology in recent years, which is not expected to abate in the foreseeable future. Indeed, according to several reports, there is an ongoing backlog of small satellites waiting for secondary payload launches. However, several of the dedicated small satellite launch projects have stalled, and not just those belonging to new market entrants, as shown by DARPA.

With the on-set of dedicated small satellite launch services, the providers will also face a challenge beyond technology; market demand. There has been a lot of dispute throughout the industry about what demand for these services actually is, with a significant number of people opining that there will not be enough demand to anywhere near meet the planned supply capabilities. Indeed, around ten years ago, SpaceX announced the Falcon 1, which would carry several hundred kg payloads into LEO for US$6-7m, however, that project was retired due to a reported lack of demand. Granted, the number of small satellites being launched today far exceeds that of ten years ago, but the big question is, 'Is it enough?' ■

A Minotaur I rocket carrying, among other payloads, 11 small cubesat research satellites. Photo courtesy of NASA