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Chapter Glossary

(CBOD)	Clamp Band Opening Device
(CDS)	CubeSat Design Specification
(CSLI)	CubeSat Launch Initiative
(DPAF)	Dual Payload Attach Fittings
(EAGLE)	ESPA Augmented Geostationary Laboratory Experiment
(EELV)	Evolved Expendable Launch Vehicle
(ENRCSD)	Nanoracks External CubeSat Deployer
(ESA)	European Space Agency
(ESPA)	EELV Secondary Payload Adapter
(GEO)	Geostationary Equatorial Orbit
(HEO)	Highly Elliptical Orbit
(ISS)	International Space Station
(J-SSOD)	JEM Small Satellite Orbital Deployer
(JAXA)	Japan Aerospace Exploration Agency
(JEM)	Japanese Experimental Module
(JEMRMS)	Japanese Experimental Module Remote Manipulator System
(M-OMV)	Minotaur Orbital Maneuvering Vehicle
(MEO)	Medium Earth Orbit
(MLB)	Motorized Light Bands
(MPAF)	Multi Payload Attach Fittings
(MPEP)	Multi-Purpose Experiment Platform
(NOAA)	National Oceanic and Atmospheric Administration
(NRCSD)	Nanoracks ISS CubeSat Deployer
(OMV)	Orbital Maneuvering Vehicle
(PCBM)	Cygnus Passive Common Berthing Mechanism
(SL-OMV)	Small Launch Orbital Maneuvering Vehicle
(SSMS)	Small Spacecraft Mission Service
(SSOD)	Small Satellite Orbital Deployer
(TRL)	Technology Readiness Level



10.0 Integration, Launch, and Deployment

10.1 Introduction

Of the more than 1,849 total Spacecraft launched in 2021, more than 1,700 were SmallSats with a mass less than 600kg. SmallSats represent more than 82% of all spacecraft launched from 2012-2021, and 16% of the total mass launched. In 2021, the SmallSat revolution was in full swing, accounting for more than 94% of all spacecraft launched. With more SmallSat and CubeSat constellations currently being planned, the demand for launch of SmallSats is expected to continually rise (1).

Since launch vehicle capability usually exceeds primary customer requirements, there is typically mass, volume, and other performance margins to consider for the inclusion of a secondary small spacecraft. Small spacecraft have an opportunity to use this surplus capacity for a potentially more cost-effective ride to space. A large market of adapters and dispensers has been created to compactly house multiple small spacecraft on existing launchers. These technologies provide a structural attachment to the launcher as well as deployment mechanisms. This method, known as “rideshare,” is still the main way of putting small spacecraft into orbit. The terms ‘rideshare’ and ‘hosted payload’ are sometimes used interchangeably, however there are distinct and subtle differences; hosted payload services offer space for a payload on a shared platform to a predetermined orbit, while rideshare services provide space for a dedicated spacecraft integrated onto the launch vehicle or separation system. For more information on hosted payloads, readers are encouraged to review the Complete Spacecraft Platforms chapter of this report.

As both SmallSat and CubeSat adapters and dispensers have become more developed, rideshares have taken on more popularity as a means to access space. Additionally, nanosatellite form factors are increasing in dimensions and mass, which require larger dispensers to accommodate these larger CubeSat sizes. Although not a new idea, using orbital maneuvering systems to deliver small spacecraft to intended orbits is another emerging technology. Several commercial companies are developing orbital tugs to be launched with launch vehicles to an approximate orbit, which then propel themselves with their on-board propulsion system to another orbit where they will deploy or serve as an integral part of their hosted small spacecraft.

Expanding future capabilities of small satellites will demand dedicated launchers. Flying the spacecraft as a dedicated payload may be the best method of ascent for missions that need a very specific orbit, near complete capability of available launcher performance, interplanetary trajectories, precisely timed rendezvous, or special environmental considerations. Technology developers and hard sciences can take advantage of the quick iteration time and low capital cost of small spacecraft to yield new and exciting advances in space capabilities and scientific understanding. The emergence of very small launch vehicles has altered the landscape by providing dedicated rides for small spacecraft to specific destinations on more flexible timelines.

NASA’s Launch Services program developed a new Indefinite Delivery/Indefinite Quantity (IDIQ) mechanism in Q1 2022: the Venture Class Acquisition of Dedicated and Rideshare (VADR) launch services. The principal purpose of the VADR IDIQ contract is to accommodate very low complexity CubeSats (up to more complex Class D missions) and provide FAA licensed launch services capable of delivering payloads to a variety of orbits. This contract mechanism provides a broad range of commercial launch services for traditional and dedicated rideshare options. The commercial approach uses a lower level of mission assurance for higher risk tolerant payloads, serving as an ideal platform for technical development that is contributing to NASA’s science and research development efforts. The 2022 Heliophysics Small Explorers Announcement of Opportunity and Mission of Opportunity are the first NASA AO’s to use this contract structure for upcoming launches. The VADR IDIQ contract provides a new mechanism for traditional and dedicated rideshare launches for risk-tolerant payloads. While the initial 13 companies have been



selected, a special on-ramp provision allows new launch services and capabilities to be proposed. (2).

The information described below is not intended to be exhaustive but provides an overview of current state-of-the-art technologies and their development status for a particular small spacecraft subsystem. It should be noted that Technology Readiness Level (TRL) designations may vary with changes specific to payload, mission requirements, reliability considerations, and/or the environment in which performance was demonstrated. Readers are highly encouraged to reach out to companies for further information regarding the performance and TRL of described technology. There is no intention of mentioning certain companies and omitting others based on their technologies or relationship with NASA.

10.2 State-of-the-Art – Launch Integration Role

Launch options for a SmallSat include dedicated launch, traditional rideshare launch, or multi-mission launch, as described in the launch section below. Regardless of the approach, however, integration with the launch vehicle is a complex and critical portion of the mission. The launch integration effort for a primary spacecraft typically includes the launch service provider, the spacecraft manufacturer, the spacecraft customer, the launch range operator, and sometimes a launch service integration contractor (3). When launching on either a multi-mission or rideshare launch, the launch integration becomes even more complex.

When flying as a rideshare payload on a launch, it is generally the primary spacecraft customer who decides whether secondary spacecraft will share a ride with the primary spacecraft and, if so, how, and when the secondary spacecraft are dispensed. This is not always the case, however, as there are occasions where the launch vehicle contractor or a third-party integration company can determine rideshare possibilities. More flexibility may be available to secondary spacecraft that are funded through such a program, although the mission schedule is normally still determined by the primary spacecraft.

There are several options for identifying and booking a ride for a SmallSat. For rideshare and multi-mission launches, the spacecraft customer may choose to use a launch broker or aggregator to facilitate the manifesting, or work directly with the launch service provider. A launch broker matches a spacecraft with a launch opportunity, whereas an aggregator provides additional services related to manifesting. In the event of a dedicated launch, the spacecraft customer generally does not use a launch broker or aggregator. In both cases, however, key aspects for integration must be managed and a launch integrator can assist or coordinate those activities for the spacecraft customer.

Whether a spacecraft customer chooses to use a launch integrator or not, certification of flight is a key spacecraft responsibility. Requirements for radio frequency licensing, National Oceanic and Atmospheric Administration (NOAA) remote sensing licensing, and laser usage approval are all the responsibility of the spacecraft operator to obtain (4) (5). The launch integrator or the launch service provider will require proof of licensure before launching the satellite. They will also require additional analyses and supporting data prior to launch. This may include safety documentation, orbital debris information, materials and venting data, and spacecraft specific models (6).

For rideshare and multi-mission launches, many satellites are subject to a “do no harm” requirement to protect the primary satellite or other satellites on a multi-mission launch. A list of “do no harm” requirements are imposed on the rideshare satellite by the launch provider, launch integrator, or primary mission owner. These requirements vary by launch provider and launch integrator, but usually include restrictions on transmitters, post separation mechanical deployments, and hazardous materials. A comprehensive list of typical “do no harm” requirements is provided in TOR-2016-02946 Rev A (7).



10.2.1 Launch Brokers and Services Providers

A launch broker for small satellites is an individual or organization which matches a spacecraft with a launch opportunity, usually as a rideshare satellite or a multi-mission manifest spacecraft. Typically, a launch broker does not provide any additional launch integration services beyond coordinating the relationship between the spacecraft manufacturer or customer and the launch service provider. Their purpose is to fill excess capacity on a launch, and they can also bolster negotiations between the launch provider and payload for scheduling, integration, safety testing, and cost (39).

Further services can include working with the satellite customer and the launch vehicle provider to ensure that the customer's spacecraft is compatible with the launch vehicle's mission, and by performing analyses and physical integration. This service can also provide the integration hardware, such as CubeSat dispenser, separation system, or other hardware as described below, or this hardware may be provided by either the spacecraft customer or the launch services provider. It should be noted that there is no universally accepted definition of "launch broker" and the term can be used interchangeably with "launch aggregator" and "launch integrator."

10.3 Launch Paradigms

The SmallSat market has grown considerably over the past decade experiencing a 23% compound annual growth rate from 2009 to 2018 (10). This growth continues unabated. From 2013 to 2017 there was an average of about 140 SmallSats (less than 200 kg) launched per year. From 2017 to 2021 this number jumped to around 1700 SmallSats per year, and more than 550 SmallSats were launched in 2022. In Q2 2022, SmallSats represented 96% of spacecraft launched and 51% of the total upmass. Of these spacecraft, 200-600 kg were the most numerous type of spacecraft launched (accounting for more than 65% of total launches), while micro, nano, pico, and femto spacecraft were the next most launched spacecraft (1).

This increase in small satellite demand has caused a shift in the launch vehicle market, as well as with many companies creating or advertising launch platforms centered around small satellites. This section will detail three types of launch methods for SmallSats and the current state of these markets. While other chapters in this report cite specific companies providing "state-of-the-art" technologies, this section will provide an overview of the different types of launches available for SmallSats rather than highlighting specific companies.

10.3.1 Dedicated Launches

In the context of this report, dedicated launches for SmallSats are those that use launch vehicles which are generally meant to be used to launch satellites with a mass less than 180 kg. This does not mean that the maximum mass to orbit is 180 kg or less, however. For the purposes of this report, dedicated launchers will have a maximum payload of 1000 kg, as many launch vehicles being marketed for SmallSats have masses to orbit that are higher than 180 kg. The primary orbit for this type of launch is low-Earth orbit, with very few companies currently targeting highly elliptical orbit (HEO), medium-Earth orbit (MEO), or geostationary equatorial orbit (GEO). As reported in October 2019, there were 148 small launch vehicles with a maximum capability of less than 1000 kg to low-Earth orbit being tracked as current and future launch vehicles, however only eight from that list were successfully flown (11).

Dedicated launches for SmallSats have many advantages. A SmallSat on a dedicated launch controls the mission requirements in whole--what they need, when they want to launch, and where they want to go. They generally have a readiness "go / no-go" call on launch day in case something goes wrong with their satellite pre-launch. They can also request special launch



accommodations, such as a nitrogen purge or late battery charge, that are generally not available to a rideshare launch (this may be as a standard service or with an additional cost as mission-unique). The downside to a dedicated launch is that they are generally more expensive than a rideshare launch.

10.3.2 Traditional Rideshare Launches

Until recently, there were only a few launchers that allowed small spacecraft to ride as primary spacecraft. The majority of small spacecraft are carried to orbit as secondary spacecraft, using the excess launch capability of larger rockets. Standard ridesharing consists of a primary mission with surplus mass, volume, and performance margins which are used by another spacecraft. Secondary spacecraft are also called auxiliary spacecraft or piggyback spacecraft. For educational small spacecraft, several initiatives have helped provide these opportunities. NASA's CubeSat launch initiative (CSLI) for example, has provided rides to a significant number of schools, non-profit organizations, and NASA centers. As of October 2022, the program launched 148 CubeSats, and continues to select CubeSats for launch (12). The European Space Agency (ESA) "Fly Your Satellite" program is a similar program which provides launch opportunities to university CubeSat teams from ESA Member States, Canada, and Slovenia (13).

From the secondary spacecraft designers' perspective, rideshare arrangements provide far more options for immediate launch with demonstrated launch vehicles. Since almost any large launcher can fit a small payload within its mass and volume margins, there is no shortage of options for craft that want to fly as a secondary spacecraft. On the other hand, there are downsides of hitching a ride. The launch date and trajectory are determined by the primary spacecraft, and the smaller craft must take what is available. In some cases, they need to be delivered to the launch provider and be integrated on the adapter weeks before the actual launch date. Generally, the secondary spacecraft are given permission to be deployed once the primary spacecraft successfully separates from the launch vehicle, but there are instances where the rideshare spacecraft separate prior to the primary satellite (14).

Multi-mission manifest launches are those that exclusively use launch vehicles to launch multiple SmallSats. These launches have shown the ability to hold and deploy dozens of satellites to multiple altitudes, though these orbits tend not to be vastly different. These types of launches are growing in popularity with many launch vehicle providers offering regular launches to the same altitude at regular intervals throughout the calendar year. While challenging, the logistics of these missions are managed by various integrators throughout the market, many of which are new to industry but are forging a new path in rideshare. Multi-mission manifest launches provide the opportunity to place large numbers of satellites into orbit on a single launch. Multi-mission manifest missions accounted for over 1500 SmallSats launched in 2021.

10.4 Deployment Methods

The method by which SmallSats are deployed into orbit is a critical part of the launch process. The choice of deployment method depends on the form factor of the satellite. This section will discuss the deployment of CubeSats, which generally use CubeSat dispensers, and the deployment of free-flying SmallSats.

10.4.1 CubeSat Dispensers

The CubeSat form factor is a very common standard for spacecraft up to approximately 24 kg (12U CubeSat) but can also be extended to approximately 54 kg in a 27U configuration (33). The most updated CubeSat Design Specification document is found at <http://www.cubesat.org>, a website maintained and operated by California Polytechnic State University, San Luis Obispo, the creators of the CubeSat form factor.

The CubeSat form lends itself to container-based integration systems, or dispensers, which serve as an interface between the CubeSat and the launch vehicle. It's a rectangular box with a hinged door and spring mechanism. Once the door is commanded to open, the spring deploys the CubeSat. Many companies currently manufacture dispensers for the CubeSat form factor which follow one of two constraint systems: the rail-type dispenser, and the tab-type dispenser. Due to the large number of dispenser manufacturers, the different companies are not listed here. Instead, a brief overview of the two types of dispensers is provided.

A rail-type dispenser (figure 10.1) supports CubeSats that have rails which extend the length of the CubeSat on four parallel edges. The rails on the CubeSat prevent it from rotating while inside the dispenser. After the dispenser door has been commanded to open, the rails slide along guides inside the dispenser and the CubeSat is deployed. As such, it is important that any rail-based CubeSat follow the current development specifications to ensure compliance. This type of dispenser is the most widely manufactured configuration, with more than fifteen manufacturers worldwide.

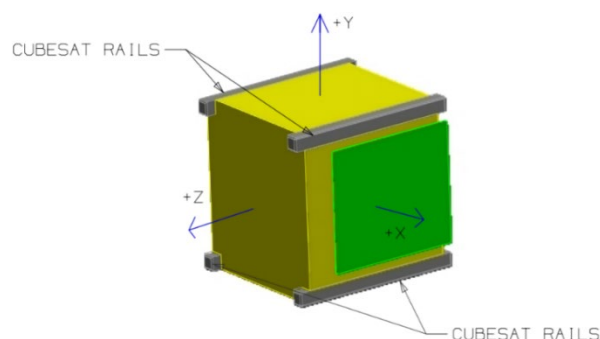


Figure 10.1: The Rail-type CubeSat. Credit: CalPoly's CubeSat Program.

A tab-type dispenser (figure 10.2) supports CubeSats with tabs which run the length of the CubeSat on two parallel edges. Typically, the dispenser grips the tabs to hold the CubeSat in place, only releasing it after the door has been commanded to open. In the past, this type of dispenser was not widely manufactured as Planetary Systems Corporation (recently acquired by Rocket Lab USA) held the patent for the design. Recently however, more developers are beginning to develop their own tab-based designs for CubeSat dispensers. There are some tab-based dispensers that do not grip the tabs. Rather, they provide a slot to accommodate the tab, which slides freely within the slot. While use of tab-type dispensers is growing, they remain a minority among dispensers purchased and used by developers.

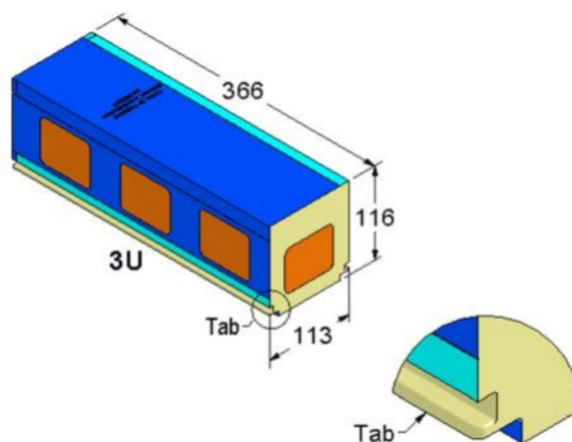


Figure 10.2: The Tab-type CubeSat. Credit: Planetary Systems Corporation.

While CubeSats can generally pick their dispenser type (rail vs. tabbed), the choice of the actual dispenser is not always a decision made by the CubeSat. In many cases, the launch vehicle provider or launch aggregator/integrator has already determined which dispensers will be installed on the launch vehicle. As each dispenser manufacturer has slightly different volumes and requirements, it is beneficial for the CubeSat to design for as wide a range of dispensers as possible to maximize launch opportunities.

Additionally, some dispenser manufacturers offer accommodations which may violate the “do no harm” requirements set forth by the launch vehicle or launch integrator, such as inhibits on

deployables and transmitters. Therefore, it is beneficial for the CubeSat to evaluate “do no harm” recommendations from a variety of organizations, as these requirements can vary from flight to flight on the same LV based on the risk posture of the primary payload and/or the mission “owner” (7).

10.4.2 SmallSat Separation Systems

Small satellites which do not meet the form factor of a CubeSat, or will not be using a CubeSat dispenser for integration to the launch vehicle, require a different separation mechanism. Separation systems for SmallSats generally follow either a circular pattern or a multi-point (3 or 4 point) pattern. Depending on the launch vehicle, separation systems may already be in place and available to secondary spacecraft. It should be noted that separation systems are often some of the most complicated pieces of hardware involved with launching spacecraft. If a spacecraft is given the option to bring its own separation system to launch, great care should be taken in selection, including the development maturity and flight heritage for any separation system.

Circular separation systems use two rings held together by a clamping mechanism. One ring is attached to the launch vehicle and the other ring is attached to the spacecraft. Once the clamping mechanism is released, the two rings separate and are pushed apart by springs. Each ring then remains with the spacecraft or the launch vehicle. There are two primary types of clamping configurations, the motorized light bands (MLB) and Marman clamps.

The MLB (figure 10.3) is a motorized separation system that ranges from 8 inches to 38 inches in diameter. Smaller MLB systems are used to deploy spacecraft less than 180 kg, while larger variations may be used to separate larger spacecraft or other integration hardware such as orbital maneuvering systems, which are discussed below. The MLB's separation system eliminates the need for pyrotechnic separation, and thus deployment results in lower shock with no post-separation debris.

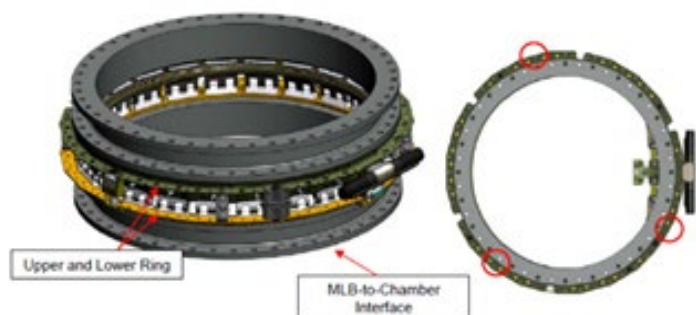


Figure 10.3: MkII Motorized Lightband. Credit: Planetary Systems Corporation.

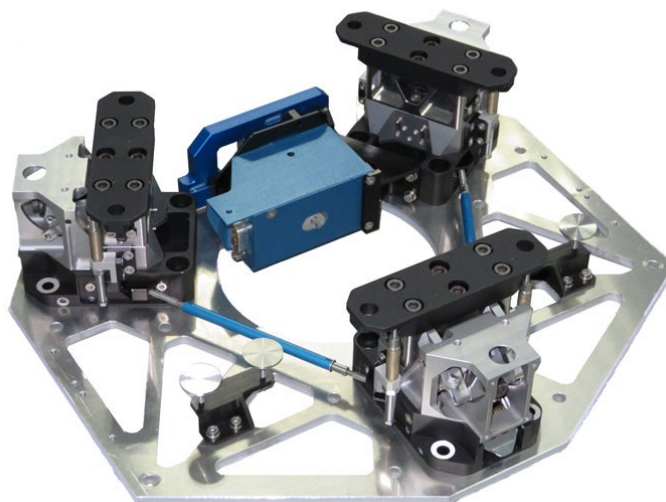
Marman band separation systems use energy stored in a clamp band, often along with springs, to achieve separation. The Marman band is tensioned to hold the spacecraft in place. Some Marman bands use pyrotechnic devices to cut the clamping bolt, however many companies offer a low shock release mechanism which is potentially better for the spacecraft. Sierra Nevada produces a Marman band separation system known as Qwksep, which uses a series of separation springs to help deploy the spacecraft after clamp band release. RUAG Space provides several circular separation systems which use their Clamp Band Opening Device (CBOD) release mechanism to reduce shock impact on the spacecraft (15).

Several companies are now providing multi-point separation systems instead of the circular band. Using a multi-point separation system may result in mass savings over a circular separation system. However, some systems require additional simultaneous signals from the launch vehicle provider to ensure proper release. The RUAG PSM 3/8B is a low-shock separation nut developed to fit the OneWeb satellites (16). It requires additional firing commands from the launch vehicle or a dedicated sequencing system. ISISPACE has also developed the M3S Micro Satellite

Separation System (see figure 10.4) which is designed for satellites up to 100 kg but can be configured for higher masses (17).

10.4.3 Integration Hardware

A main driver for CubeSat utility is their adhesion to a standard that can be integrated into several different launch configurations. The physical hardware that attaches both a containerized and non-containerized small spacecraft and keeps it insulated from a rocket body include deployers, adapters, dispensers, and launchers. The purpose of this hardware is to eject the spacecraft safely into orbit, and most services offer different features, interfaces, connections, and designs for small spacecraft specifications. The exact configuration and standards vary by launch vehicle, and the determination of an appropriate and reliable launch option is part of the qualification launch process (32). With this rise in CubeSat constellation, integration hardware capable of launching multiple SmallSats simultaneously and consecutively is now a standard. This section will highlight some of the existing examples of integration flight support hardware that is applicable to both SmallSats and CubeSats, and the reader is highly encouraged to identify other integration services.



*Figure 10.4: ISISPACE M3S Micro Satellite System.
Credit: ISISPACE.*

Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA)

The ESPA ring (figure 10.5) is a multi-payload adapter for large primary spacecraft originally developed by Moog Space and Defense Group. Six 38 cm (15") circular ports can support six auxiliary payloads up to 257 kg each. It was used for the first time on the Atlas V STP-1 mission in 2007. The ESPA Grande (figure 10.6) uses four 61 cm (24") circular ports which can carry spacecraft up to 450 kg (991 lb) (18). Although developed by Moog, several other companies now offer similar designs in different configurations.



*Figure 10.5: ESPA Ring.
Credit: Moog, Inc.*



*Figure 10.6: ESPA Grande Ring.
Credit: Moog, Inc.*

Small Spacecraft Mission Service (SSMS) Dispenser

ESA has developed the Small Spacecraft Mission Service dispenser for the Vega launch vehicle (figure 10.7). This dispenser comes in a variety of different modular parts which can be configured based on the satellite launch manifest. The modularity of the dispenser provides greater flexibility for accommodating different customers (19).

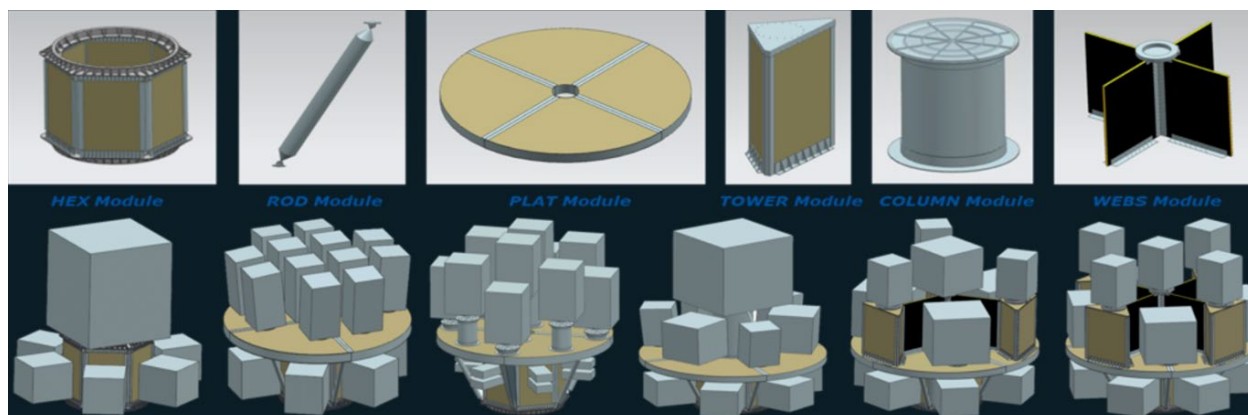


Figure 10.7: The European Space Agency Small Spacecraft Mission Service Dispenser for the Vega Launch Vehicle (19). Credit: European Space Agency.

Dual / Multi Payload Attach Fittings (DPAF / MPAF)

Many launch vehicle providers have existing accommodations for two or more payloads which are sometimes referred to as Dual Payload Attach Fittings (DPAF) or Multi Payload Attach Fittings (MPAF). As these are generally launch vehicle specific, and occasionally mission specific, they are not discussed here.

10.4.4 Orbital Maneuvering / Transfer Vehicles

One of the main disadvantages of riding as a secondary spacecraft (even on a dedicated ride-share mission) is the inability to launch into the desired orbit. The primary spacecraft determines the orbital destination, so the secondary spacecraft orbit usually does not perfectly match the customer's needs. However, by using a space tug, secondary spacecraft can maneuver much closer to their desired orbits. There are many OMVs currently planned for the market however very few if any can point to extensive flight heritage. However, this emerging technology is an area of interest in the near term for both SmallSats and CubeSats.

Propulsive ESPA

The ESPA Ring, discussed above, provides the structure to which SmallSats or CubeSat dispensers are mounted. However, there are several options to add propulsion to the ESPA ring to use it as a space tug.

Moog OMV

Moog Space and Defense has developed the Moog Orbital Maneuvering Vehicle (OMV) line of tugs (figure 10.8) which support different mission types. COMET is the baseline OMV and it can fly with several satellites mounted to it on a multi-manifest mission. Once COMET has separated from the launch vehicle, it can maneuver to reach an orbit that is more desirable for the spacecraft mounted to it. Moog has several variations on the COMET OMV for longer duration or higher-power missions (20). Moog has also developed OMVs for launch vehicles that have spacecraft interfaces smaller than 60 inches, specifically the Minotaur Orbital Maneuvering Vehicle (M-

OMV), which is packaged specifically for the Northrop Grumman Minotaur launch vehicles, and the Small Launch Orbital Maneuvering Vehicle (SL-OMV).

Northrop Grumman ESPASStar

Northrop Grumman's ESPASStar platform (figure 10.9) is similar to the Moog COMET in that it uses an ESPA ring as part of the structure. Additionally, it provides power, pointing, telemetry, command and control for the attached satellites or payloads (21). ESPASStar was developed from the ESPA Augmented Geostationary Laboratory Experiment (EAGLE), which was developed for the Air Force Research Laboratory and was launched in April 2018. Northrop Grumman also recently launched yet another ESPASStar platform during the summer of 2022 on an AtlasV from CCSFS, marking another successful launch and deployment of this platform.

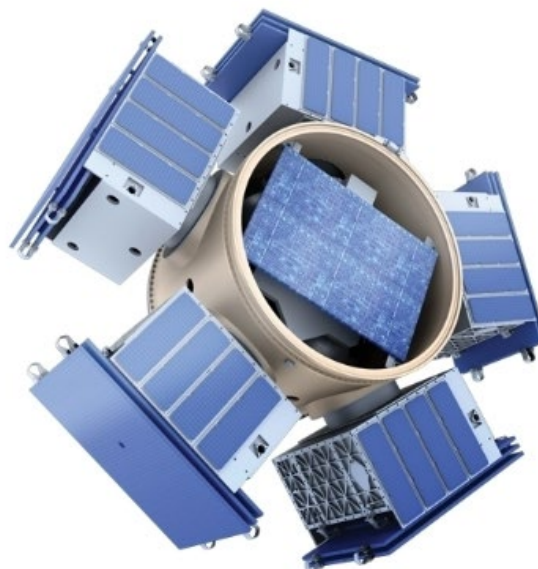


Figure 10.8: Moog OMV. Credit: Moog, Inc.

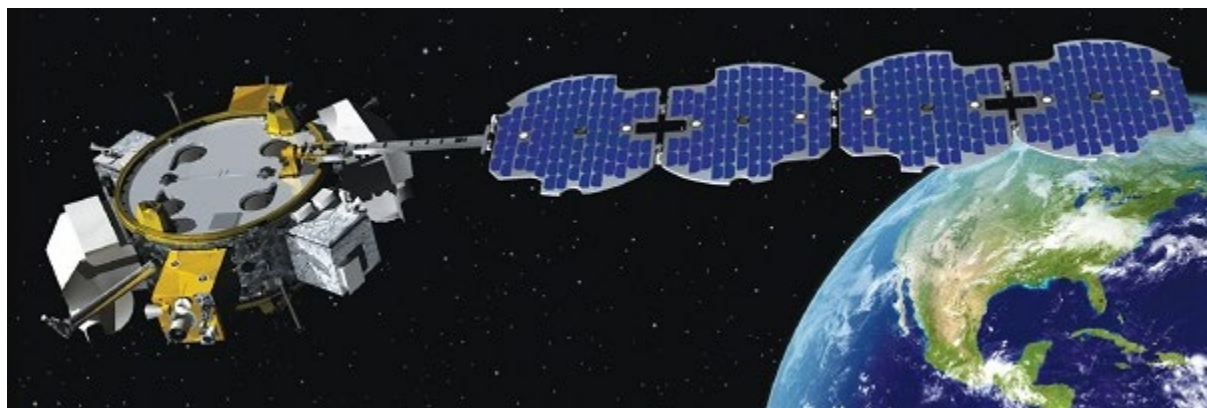


Figure 10.9: Northrop Grumman's ESPASStar Platform. Credit: Northrop Grumman.

Spaceflight Sherpa

In addition to Moog and Northrop Grumman, Spaceflight will also offer a series of orbital transfer vehicles beginning no later than the end of 2022 (22). Spaceflight's platform, the Sherpa, is a SmallSat deployer and space tug that can host payloads. Two of the three next generation Sherpa orbital transfer vehicles are equipped with propulsion, and one is a free flyer. Both the Sherpa-FX2 and LTE1 flew on SpaceX Transporter-2 in June of 2021. The Sherpa AC-1, named for its attitude control capabilities, is a free flying satellite deployer featuring chemical propulsion that flew for the first time in May of 2022 on SpaceX Transporter-5. In addition, an updated version of the Spaceflight Sherpa the LTC-2 was launched in the Fall of 2022 on a SpaceX Transporter mission. There are currently plans for additional launches in the near term as Spaceflight continues to expand the capabilities of their Sherpa platform.

Vigoride

Momentum Space is developing an in-space orbit transfer service for SmallSats, named Vigoride. The maximum payload mass on Vigoride is 750 kg to LEO, and it can be launched from an ESPA

or ESPA Grande ring, from ISS airlocks, or a launch vehicle. It uses water plasma engines to change the orbit prior to releasing payloads at their final orbit (23). Like all OMVs, the Vigoride is capable of changing inclination, altitude, and orbital planes. The first flight for Vigoride occurred in May of 2022, with additional launches planned for the near future.

The orbital maneuvering and transfer vehicles listed here are not an exhaustive list of all those being developed, but they provide an overview of current state-of-the-art technologies and their development status. There was no intention of mentioning certain companies and omitting others based on their technologies.

10.5 International Space Station Options

The International Space Station (ISS) provides several methods for deploying CubeSats and SmallSats. The sections below discuss SmallSat deployment from the ISS as well as deployment above the ISS. The ISS also accommodates hosted payloads for experiments, but those accommodations are outside the scope of this chapter as they are for individual payloads themselves and are not satellites.

10.5.1 Deployment from ISS

The ISS also provides several options for deploying satellites. Generally, the satellites are launched below the ISS to avoid potential contact with the ISS. Below are several options available for launching from the ISS.

Nanoracks ISS CubeSat Deployer (NRCSD)

Nanoracks CubeSat Deployer (NRCSD) (figure 10.10) is a self-contained CubeSat dispenser system that mechanically and electrically isolates CubeSats from the ISS, cargo resupply vehicles, and ISS crew. The NRCSD is a rectangular tube that consists of anodized aluminum plates, base plate assembly, access panels, and deployer doors. The inside walls of the NRCSD are a smooth bore design to minimize and/or preclude hang-up or jamming of CubeSat appendages during deployment, should they become released prematurely.

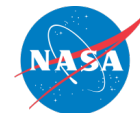
For deployment, the platform is moved outside via the Kibo Module's Airlock and slide table, which allows the Japanese Experimental Module Remote Manipulator System (JEMRMS) to move the dispensers to the correct orientation and provides command and control to the dispensers. Each NRCSD can hold six CubeSat units as large as a 6U (1 x 6U). The NRCSD DoubleWide can accommodate CubeSats up to 12U (2 x 6U) with Nanoracks being able to launch up to 48U per cycle. The CubeSats deploy at a 51.6° inclination, 400 – 420 km orbit 1 to 3 months after berthing at the station.



Figure 10.10: Nanoracks CubeSat Deployer. Credit: Nanoracks.

Nanoracks ISS MicroSatellite Deployment – Kaber Deployer Program

Nanoracks Kaber Microsat Deployer is a reusable system that provides command and control for satellite deployments into orbit from the Japanese Experimental Module Airlock Slide Table of the



ISS. The Kaber supports satellites with a form factor of up to 24U and mass of 82 kg and uses a Nanoracks separation system with circular interface similar to the separation systems discussed above. Satellites are launched to the ISS on a pressurized launch vehicle, mounted to the Kaber deployer, and deployed outside the ISS (24).

JEM Small Satellite Orbital Deployer (J-SSOD)

The Japanese Experimental Module (JEM) Small Satellite Orbital Deployer (J-SSOD) is a Japanese Aerospace Exploration Agency (JAXA) developed CubeSat deployer used to launch CubeSats from the ISS. The J-SSOD can launch CubeSats up to the 6U form factor (2x3 configuration). The satellites, with their dispensers, are installed on the Multi-Purpose Experiment Platform prior to Kibo's robotic arm Japanese Experiment Module Remote Manipulator System (JEMRMS) transferring the Multi-Purpose Experiment Platform (MPEP) to the release location. At that point, the CubeSats are deployed (25).

Bishop Nanoracks Airlock Module

A new airlock module, Bishop, was developed for the ISS by Nanoracks, Thales Alenia Space, and Boeing, and is the first commercialized, private module for the space station (30). Bishop provides more than five times the volume of the current Japanese Experimental Module (JEM) airlock, allowing for larger satellites and payload experiments. Bishop can host satellites and payloads, as well as deploy them, based on the needs of the mission. It has been attached to the exterior of the ISS since December 21, 2020 and has been instrumental in deploying CubeSats from the ISS (26).

10.5.2 Deployment Above ISS

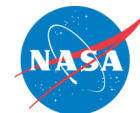
Regular access to the ISS is very attractive for many satellite providers. However, the lower altitude of the ISS means the in-orbit lifetime for the satellite is generally shorter. This section discusses the options that have been developed to deploy CubeSats above the ISS using a cargo resupply module.

Nanoracks Interchangeable CubeSat Launcher (NICL) Previously E-NRCSD

The NICL is a system to deploy CubeSats into orbit above the ISS by using the Northrop Grumman Cygnus ISS Cargo Resupply vehicle. The first mission to use the ENRCSD was on the OA-6 mission in March 2016; the updated E-NRSD design (NICL) will have its first flight on NG-19 currently scheduled for 3/11/2023. Up to 36U of CubeSats in any form factor up to 16U can be deployed above the ISS with each Cygnus mission. CubeSats are installed in the Nanoracks deployer and mounted externally to the Cygnus vehicle before launch. They remain external to the ISS for the duration of time that Cygnus is attached to the station. The deployment altitude is dependent upon the propellant margins remaining in the Cygnus but is typically 465-500 km, meeting a minimum of 45 km above the ISS altitude (27).

SEOPS SlingShot

SEOPS SlingShot is a system to deploy CubeSats into orbit above the ISS using the Northrop Grumman Cygnus ISS Cargo Resupply vehicle. The first mission to use the SlingShot was in 2019. SlingShot can fly up to 72U of CubeSats per Cygnus mission; the largest CubeSat form factor it can fly is 12U. This deployment method differs from the ENRCSD in that the satellites and their dispensers are flown to the ISS as pressurized cargo on a resupply mission. Astronauts remove the satellites and install the dispensers onto the Cygnus Passive Common Berthing Mechanism (PCBM) just prior to Cygnus' departure from the station. Once Cygnus departs the ISS, it raises to an altitude of approximately 500 km and deploys the CubeSats (28). As these CubeSats are hosted in a different location and manner than the ENRCSD CubeSats, it is possible for Cygnus to carry CubeSats in both locations on a single mission.



10.6 On the Horizon

10.6.1 Integration

From a launch broker perspective, several companies have developed online booking systems for launches similar to web-based airline ticket platforms. Some companies, including SpaceX allow one to even provide a credit card payment option for launch services (29). The premise is that you click on your preferred destination and timeline and the website provides you with launch options. As the supply of launches increases, there will most likely be an increase in demand for this type of service.

10.6.2 Launch

As discussed in the launch section above, there are always several new launch vehicles in development. The number continues to grow every year, and how many become realized remains to be seen.

10.6.3 Deployment

There are several emerging capabilities in the area of SmallSat deployment. They consist of CubeSat dispensers, SmallSat separation systems, and orbital maneuvering and transfer vehicles. The technologies listed here are not a comprehensive list.

10.7 Summary

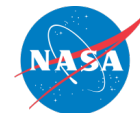
A wide variety of integration and deployment systems exist to provide access to space for small spacecraft. While leveraging excess LV performance will continue to be profitable into the future, dedicated launch vehicles and new integration systems for small spacecraft are becoming popular. Dedicated launch vehicles take advantage of rapid integration and mission design flexibility, enabling small spacecraft to dictate mission parameters. New integration systems will greatly increase the mission envelope of small spacecraft riding as secondary spacecraft. Advanced systems may be used to host secondary spacecraft in-orbit, to increase mission lifetime, expand mission capabilities, and enable orbit maneuvering. In the future, these technologies may yield exciting advances in space capabilities.

The previous few years have shown an increase in the number of available launch vehicles dedicated to small spacecraft. Additionally, the CubeSat Design Specification (CDS) has been revised to include the nanosatellite classification to 12U (31), which has led to the design of dispensers that can be accommodated on a variety of launch vehicles. Regardless of the evolution of the CDS, the dispenser and bus market is symbiotic and seems to be expanding.

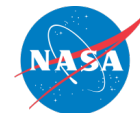
For feedback solicitation, please email: arc-sst-soa@mail.nasa.gov. Please include a business email.

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