Chapter Contents

Chapter Glossary

(COTS)	Commercial-off-the-Shelf
(EELV)	Evolved Expendable Launch Vehicle
(ESPA)	EELV Secondary Payload Adapter
(GEO)	Geostationary Equatorial Orbit
(I&T)	Integration and Test
(kg)	Kilogram
(LEO)	Low Earth Orbit
(MEO)	Medium Earth Orbit
(MTBF)	Mean Time Between Failures
(NASA)	National Aeronautics and Space Administration
(SHF)	Super High Frequency
(SmallSat)	Small Satellite
(SPA)	Secondary Payload Adapter
(STMD)	Space Technology Mission Directorate
(UHF)	Ultra High Frequency
(UK)	United Kingdom
(Unk)	Unknown
(USA)	United States of America
(VLEO)	Very Low Earth Orbit
(VHF)	Very High Frequency
(W)	Watts
(xGEO)	Beyond Geostationary Equatorial Orbit

2.0 Complete Spacecraft Platforms

2.1 Introduction

The SmallSat market provides a variety of mission-enabling components. Along with a large variety of new and proven components, companies are offering entire spacecraft bus solutions. Spacecraft bus refers to the side of the mission flight segment that provides essential services to the payload. This chapter addresses the state of the art in the small spacecraft bus offerings and provides the reader with a programmatic overview for small spacecraft mission development.

There are 2 distinct types of SmallSat market options in terms of complete spacecraft platforms. One option is not superior to the other and selection may depend on the needs of each individual mission.

- **Hosted payloads** – Also known as "satellite-as-a-service," integrates multiple payloads from different and independent customers into the same platform with some form of resource sharing (cost, autonomy, concept of operations, etc.). Hosted payload configurations and performance vary by provider. Two examples of hosted payloads are:
    - Service provider brokers multiple independent customer payloads into a single spacecraft bus (no primary payload)
    - Service provider intends to launch their own satellite with its own primary goals but have unused resources and allows secondary payloads to be added
- **Dedicated spacecraft bus** – the entirety of the spacecraft bus is at the disposal of a single customer or mission

This chapter organizes the state-of-the-art small spacecraft platforms into these two main categories. The dedicated small spacecraft bus section is further divided by PocketQube, CubeSat, and ESPA-Class offerings. Each subsection contains a summary table with a non-exhaustive list of commercially available small spacecraft platforms.

1. Hosted Payloads (2.2.1)
2. Dedicated Spacecraft Bus (2.2.2)
    a. PocketQubes (2.2.2.1)
    b. CubeSats (2.2.2.2)
    c. ESPA-Class (2.2.2.3)

Following Section 2.2 is a brief explanation on systems engineering considerations that introduces newcomers to the design selection process and highlights specific resources for mission development. On the Horizon is a section that describes upcoming technology considered low maturity and revolutionary in small spacecraft platform with the potential to advance the state-of-the-art.

The list of organizations/companies in this chapter is not all-encompassing and does not constitute an endorsement from NASA. The information is for awareness and guidance only. The performance advertised may differ from actual performance since the information has not been independently verified by the State-of-the-Art document staff and relies on information provided directly from the manufacturers or available public information.

Section 2.6 includes a list of providers with contact information and the source used to complete the tables. It is recommended to contact the organizations/companies directly for further clarification and application to your specific needs.

2.2 State-of-the-Art – Spacecraft Platforms

2.2.1 Hosted Payloads

Hosted payloads, also referred as "satellite-as-a-service," "hitchhiking" or "piggybacking," is increasing in popularity due to its cost savings. The idea is to share the spacecraft bus platform with other payloads and still achieve mission success. The terms of the agreement are negotiated in advance with the provider to ensure necessary on-orbit time, power, pointing and data volume (among other resources) are adequate for the mission.

Figure 2.1: Representation of NASA's FASTSAT minisatellite. Credit: NASA.

Configurations of a hosted payload platform are typically scalable, and several spacecraft platform vendors provide hosted payload services. Larger spacecraft bus hosted options offer deployable capability/mechanisms for smaller nanosatellite missions. NASA's Fast, Affordable, Science and Technology Satellite (FASTSAT) is an example of a minisatellite that hosted smaller science and technology flight missions. It carried several low-TRL experiments and deployed NanoSail-D. See figure 2.1 for an illustration of FASTSAT. Figure 2.2 is from Loft Orbital Hosted Payload Services.

Hosted payload services are becoming more appealing for academic and government scientific missions. This option provides a cost-effective and timely solution to those missions going to the same destination.

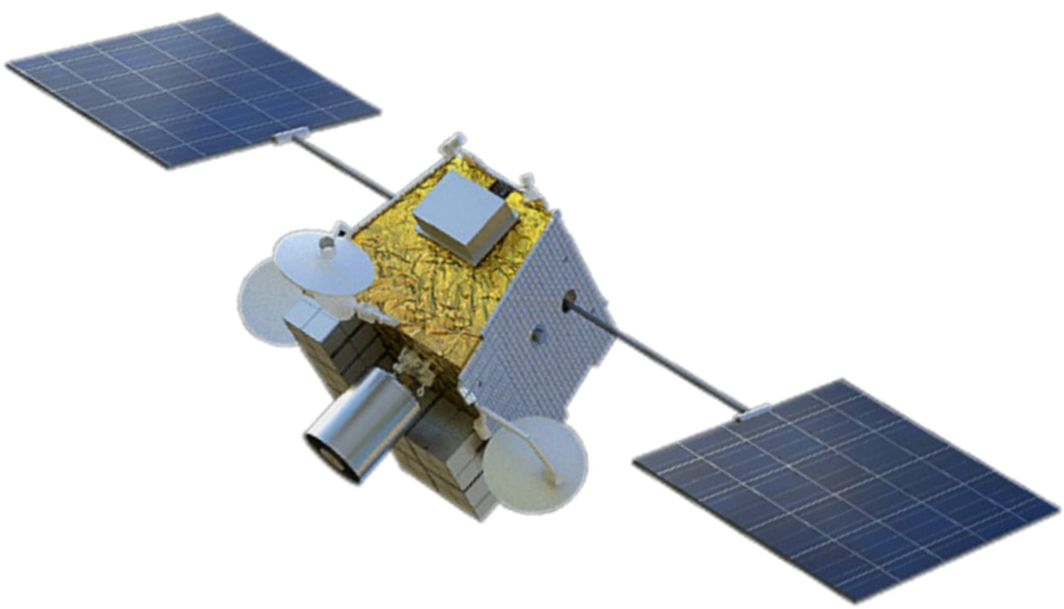

Figure 2.2: A rendering of a generic Longbow-class Loft Orbital satellite. Credit: Loft Orbital.

Table 2-1: Hosted Payload Providers
(The fields indicate maximum capability, organizations may offer multiple options including smaller capabilities within the Hosted Payloads category)

Organization	Max Volume	Max Mass (kg)	Peak Power (W)	3-σ Pointing Control/ Knowledge	Destination	US Office
Artemis Space Technologies UK	0.58 m^3	500	1,500	0.01°/0.01°	LEO, MEO, GEO, Lunar and Deep Space	No
Astranis Space Technologies Corp. USA	0.02 m^3	10	300	<0.1°/ <0.09°	GEO	Yes
Axelspace Japan	0.2 m^3	30	184	<0.05°/ <0.04°	LEO	No
Berlin Space Technologies Germany	1 m^3	200	3,000	<0.017°/< 0.017°	LEO	Yes
Bradford Space USA	0.38 m^3	220	1,500	1.5°/ 0.006°	LEO, GEO, GTO, Cislunar, Lunar, Deep Space	Yes
C3S Electronics Development Hungary	16.5U	18.5	155	0.2°/ 0.2°	LEO, MEO	No
EnduroSat Bulgaria	10U	20	60	0.1°/ 0.05°	LEO	Yes
General Atomics EMS USA	0.46 m^3	200	450	0.03°/ 0.02°	LEO	Yes
German Orbital Systems Germany	4U	8	50	<1°/< 1°	LEO	No
Gran Systems Taiwan	6U	9	25	5°/ 5°	LEO, Lunar	No
Hemeria France	0.1 m^3	35	250	0.03°/0.01°	LEO, GTO, GEO	No
Innova Space Argentina	0.5U	0.5	4	<15°/< 15°	LEO	Yes
In-Space Missions UK	Unk	Unk	Unk	Unk	LEO	Unk
Loft Orbital USA	0.44 m^3	85	>1,000	<0.035°/<0.03°	LEO	Yes
Momentus USA	1 m^3	350	3,000	0.05°/ 0.05°	LEO	Yes
Muon Space USA	60U	30	200	0.03°/ 0.012°	LEO	Yes
NanoAvionics Lithuania	0.7 m^3	150	378	0.15°/ 0.03°	LEO	Yes
NearSpace Launch USA	8U	16	160	0.5°/ 0.2°	LEO	Yes
Northrop Grumman USA	0.37 m^3	50	420	<4°/<1°	LEO	Yes
NovaWurks USA	1 m^3	150	1000	0.002°/0.0004°	LEO, GEO, xGEO	Yes
NPC SPACEMIND Italy	12U	24	100	<0.1°/<0.1°	LEO, MEO	No
OHB LuxSpace Luxembourg	0.3 m3	90	600	<0.022°/ 0.01°	LEO	No

Open Cosmos UK	12U	18	160	0.03°/0.02°	LEO	No
Orbital Astronautics UK	0.163 m^3	100	5,000	<0.05°/<0.01°	LEO, MEO, GEO, Deep Space	No
Orion Space Solutions USA	14U	45	400	<1°/<1°	LEO, GEO, Lunar	Yes
Quantum Space USA	0.5 m^3	100	400	0.006°/0.006°	LEO, GEO, Cislunar, Lunar, Deep Space	Yes
Redwire USA	0.94 m^3	104	500	0.005°/0.0017°	LEO, MEO, GEO and Deep Space	Yes
SatRev Poland	3U	3	25	1°/0.6°	LEO	No
Sierra Space USA	0.48 m^3	250	500	0.001°/ <0.001°	LEO, MEO, GEO	Yes
SITAEL Italy	0.54 m^3	100	1,000	0.018°/ 0.010°	LEO	No
Space Inventor Denmark	24U	50	400	<0.008°/ <0.008°	LEO, GEO, MEO	No
Spacemanic Czech Republic	12U	18	500	0.1°/ 0.05°	LEO, MEO, GEO, Lunar	No
Spire Global USA	12U	32	300	0.1°/ 0.05°	LEO	Yes
Xplore USA	0.125 m^3	55	210	0.17°/ 0.018°	VLEO, LEO, Cislunar	Yes
York Space Systems USA	-	300	1,500	0.008°/ 0.004°	LEO, GEO, Lunar	Yes

2.2.2 Dedicated Spacecraft Bus

The market has grown considerably over the last 5 years with complete spacecraft bus solutions including I&T and operations options. The addition of I&T and operations gives missions flexibility in implementation, allowing the mission to focus on unique or challenging aspects of the project as needed. Mission implementation solutions are shown in table 2-2. A complete vendor solution can allow the mission organization to focus primarily on payload development, however this may not be appropriate for all missions. For example, an organization may decide to perform their own mission operations if the vendor offerings do not meet the requirements for the project.

Table 2-2: Mission Implementation Flexibility

Option	Product or Service		
	Spacecraft Bus	System-Level Integration and Testing	Operations
1	Vendor	Vendor	Vendor
2	Vendor	Vendor	Mission Organization
3	Vendor	Mission Organization	Mission Organization
4	Mission Organization	Mission Organization	Mission Organization

2.2.2.1 PocketQubes

PocketQubes refer to small satellites that conform to a form factor of 5 cm cubes. PocketQubes use a standard deployer and follow a unit nomenclature of P. In this case 1P refers to a single 5 cm cube (see figure 2.3). Consequently, 2P refers to 2 of these single units. A typical PocketQube deployer can deploy up to a 3P satellite but larger deployers may allow additional capability. PocketQube providers have developed spacecraft busses to simplify mission implementation; a list of providers is included in this section; table 2-3 provides available commercial PocketQube products. Figure 2.4 is an example of a PocketQube deployer at Alba Orbital.

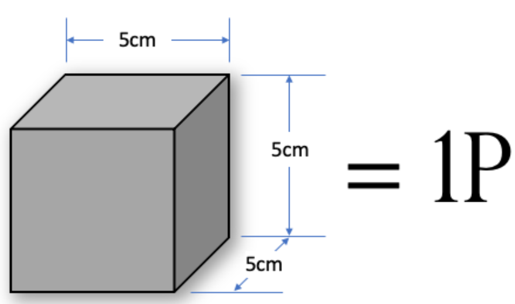

Figure 2.3: PocketQube Dimensions.

Figure 2.4: Alba Orbital Integration of PocketQubes into the Deployers. Credit: Alba Orbital.

Organization	Peak Power (W)	3-σ Pointing Control/ Knowledge	Comm Options	Intended Destination	Maturity	US Office
Alba Orbital UK	15	5°/2°	UHF, S	LEO	Flown LEO	Yes
Citadel Space Systems UK	20	Unk	UHF, S	Unk	Unk	Unk
DIYSATELLITE Argentina	9	<5°/<5°	VHF, UHF, SHF	LEO, GEO, Lunar	Flown LEO	No
FOSSA Systems Spain	10	<5°/<5°	UHF, S	LEO	Flown LEO	No
Innova Space Argentina	3.9	N/A - Magnetic Passive	UHF	LEO	Flown LEO	Yes
Quub, Inc. USA	26	5°/2°	UHF, S	LEO, Lunar	Flown LEO	Yes

Table 2-3: PocketQubes Market Solutions
(The fields indicate maximum capability, organizations may offer multiple options including smaller capabilities within the PocketQube category)

2.2.2.1 CubeSats

CubeSats refer to small satellites that conform to a form factor of 10 cm cubes. The CubeSat standard was created by California Polytechnic State University, San Luis Obispo, and Stanford University's Space Systems Development Lab in 1999 to facilitate access to space for university students. When launch providers started adopting this standard as a secondary payload service it enabled increased, low-cost opportunities for space access. Many organizations are currently using the standard including academia, private industry, and government. For more information on the history of CubeSats, the reader is encouraged to review the Introduction of this report.

CubeSat sizes follow a unit nomenclature in which 1 unit or 1U refers to a single 10 cm cube (see figure 2.5). Consequently, 2U refers to 2 of these single units, 3U is a set of 3 single units, and so forth. CubeSat providers have developed spacecraft busses to accommodate missions from 1U to 27U satellites. This section provides a list of providers separated by satellite size: 0.25U-3U, 6U, 12U and 16U+ in tables 2-4, 2-5, 2-6, and 2-7.

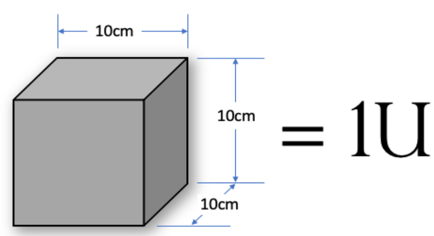

Figure 2.5 - CubeSat Dimensions.

Multiple companies have developed deployers for CubeSats with different dimensions and external volume allocations. Contact your sponsoring organization and/or launch provider for specifics on which deployer is used in your mission. Many CubeSat deployers exist in the market but the primary 2 interfaces follow the classic corner rails or the tabs (clamped and unclamped), as seen in figure 2.6. Most spacecraft bus providers in this chapter can adapt to different interfaces. Please refer to the Launch, Integration, and Deployment chapter for further information on SmallSat deployers. Figure 2.7 includes images of CubeSat missions that have

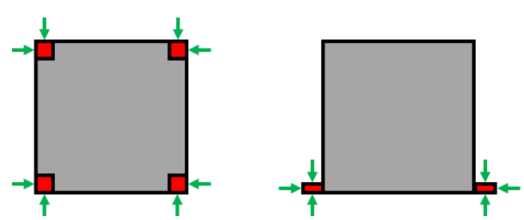

Figure 2.6: Rails vs. Tabs Restraint System Cross-Section.

been successfully flown in space, figure 2.8 provides examples of CubeSat deployers' location on a rocket, and figure 2.9 provides examples for 6U and 16U satellites from Spire Global.

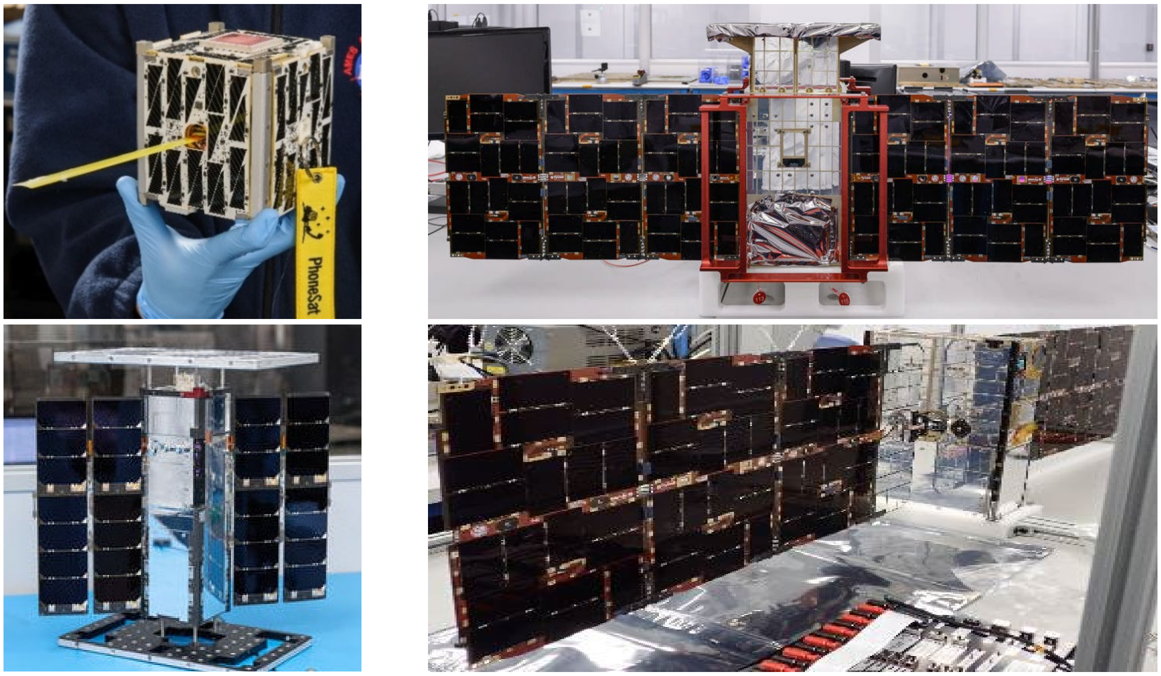

Figure 2.7: Examples of flown CubeSats. (Top left) 1U PhoneSat spacecraft, (top right) 12U CAPSTONE spacecraft, (lower left) 3U CLICK spacecraft, (lower right) 6U PTD-3 spacecraft. Credits: NASA and Terrain Orbital.

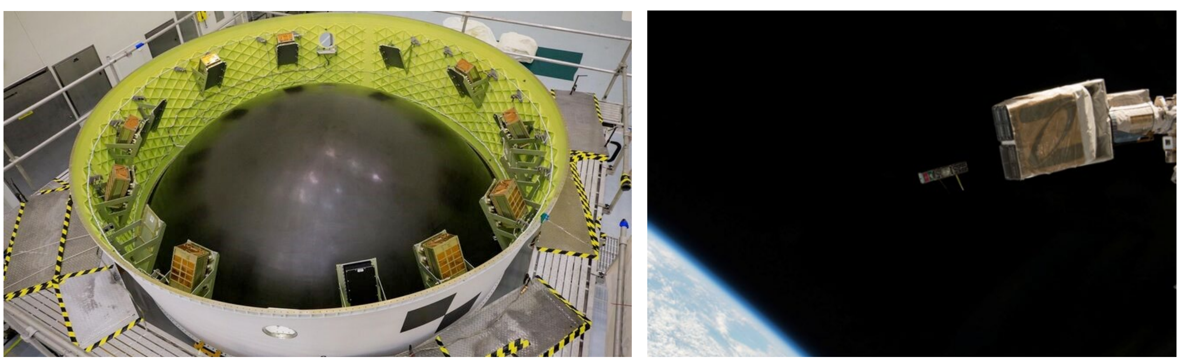

Figure 2.8: (left) Location of Artemis CubeSat deployers in between the Orion Crew Vehicle and the Interim Cryogenic Propulsion Stage (ICPS); (right) NASA Nodes mission deployment from ISS. Credit: NASA.

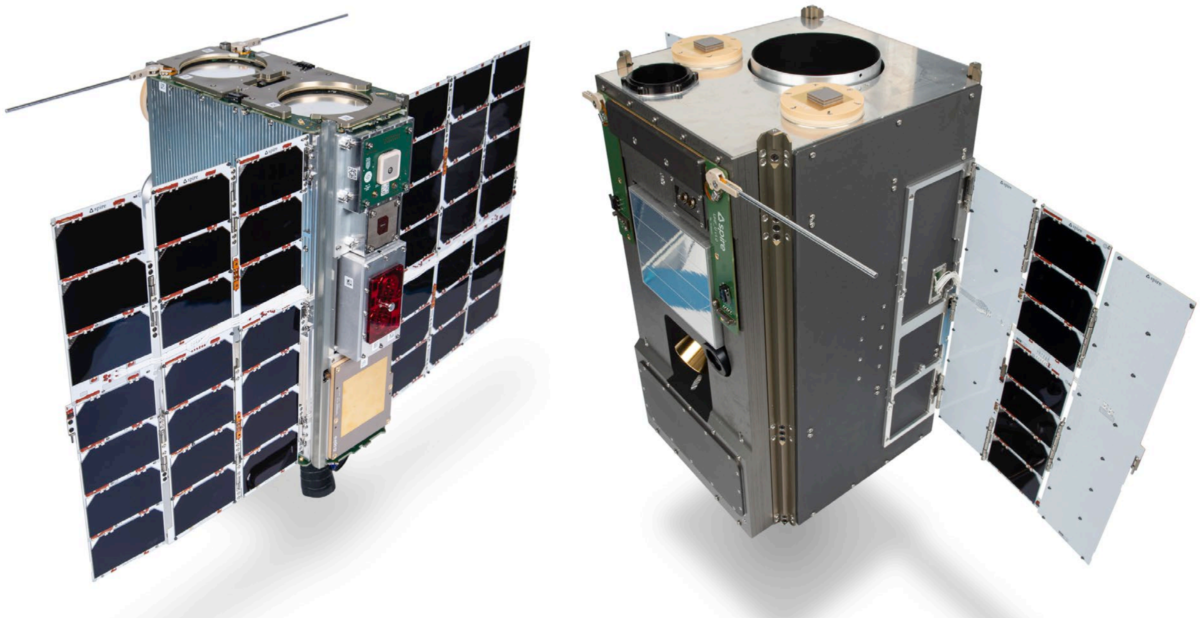

Figure 2.9: Examples of a 6U and 16U CubeSat. Credit: Spire Global.

Table 2-4: 0.25U-3U Market Solutions (The fields indicate maximum capability, organizations may offer multiple options including smaller capabilities within the 0.25U-3U category)						
Organization	**Peak Power (W)**	**3-σ Pointing Control/ Knowledge**	**Comm Options**	**Intended Destination**	**Maturity**	**US Office**
AAC Clyde Space Sweden	90	<0.1°/<0.01°	VHF, UHF, S, X	LEO	Flown LEO	Yes
Alén Space Spain	180	0.2°/0.1°	VHF, UHF, S	LEO	Flown LEO	No
Artemis Space Technologies UK	50	0.01°/0.01°	UHF, S, X, Ka, Ku	Designed for LEO	Flown LEO	No
Blue Canyon Technologies USA	27	0.003°/0.003°	L, S, X	LEO, GEO, Deep Space	Flown LEO Qualified GEO and Deep Space	Yes
C3S Electronics Hungary	35	0.2°/0.2°	UHF, S	LEO, MEO	Flown LEO	No
EnduroSat Bulgaria	30	<1°/<0.6°	UHF, S, X	LEO	Flown LEO	Yes
General Atomics EMS USA	10	0.28°/0.08°	UHF	LEO, MEO, GEO, xGEO	Under Development	Yes
German Orbital Systems Germany	24	<1°/<1°	UHF, S	LEO	Flown LEO	No
GomSpace Denmark	35	2.5°/2°	S	LEO	Flown LEO	Yes
Gran Systems Taiwan	25	5°/ 5°	VHF, UHF	LEO	Flown LEO	No
GUMUSH AeroSpace Turkey	80	<1°/ <0.005°	VHF, UHF, S, X	LEO	Flown LEO	No
Hex20 Australia	25	0.003°/ 0.003°	UHF, S	LEO, MEO, GEO, Lunar	Flown LEO	No
IMT Italy	>5	10°/5°	VHF, UHF	LEO	Under Development	No
Innova Space Argentina	7.5	<15°/<15°	UHF	LEO	Flown LEO	Yes
ISISPACE The Netherlands	50	<15°/<15°	VHF, UHF, S	LEO	Flown LEO	No
NanoAvionics Lithuania	175	13.20°/12.93°	UHF, S, X	LEO	Flown LEO	Yes
NearSpace Launch USA	80	0.5°/0.2°	L, UHF, S, X	VLEO, LEO	Flown LEO	Yes
NPC SPACEMIND Italy	51.6	<0.1°/<0.1°	UHF, S, X, Ka	LEO, MEO, GEO, Lunar	Flown LEO and MEO	No
Open Cosmos UK	160	2.4°/0.67°	UHF, S	LEO	Flown LEO	No

Orbital Astronautics [UK]	400	0.1°/ 0.01°	S, X, K, Ka, Optical	LEO, MEO	Flown LEO	No
Orion Space Solutions [USA]	8	1°/1°	L, S, X	LEO	Qualified LEO	Yes
Pumpkin Space Systems [USA]	200	0.05°/<0.05°	UHF, S, X, Ka	LEO	Flown LEO	Yes
Quub, Inc. [USA]	44	5°/2°	UHF, S	LEO, Lunar	Flown LEO	Yes
SatRev [Poland]	36	1°/0.6°	UHF, S	LEO	Flown LEO	No
SkyLabs [Slovenia]	100	0.3°/0.06°	VHF, UHF, S	LEO, MEO	Flown LEO and MEO	No
Space Flight Laboratory [Canada]	93	0.009°/0.004°	UHF, S, X, Ka	LEO, GEO, Lunar	Flown LEO Qualified GEO and Lunar	No
Space Inventor [Denmark]	100	0.01° / 0.01°	VHF, UHF, S, X, L	LEO	Flown LEO	No
Spacemanic [Czech Republic]	30	0.1°/0.05°	VHF, UHF, S	LEO, GEO, Lunar	Flown LEO Qualified GEO	No
Spire Global [USA]	35	0.1°/0.05°	UHF, L, S, X, Ka, Ku	LEO	Flown LEO	Yes

Organization	Peak Power (W)	3-σ Pointing Control/ Knowledge	Comm Options	Intended Destination	Maturity	US Office
Table 2-5: 6U Market Solutions (The fields indicate maximum capability, organizations may offer multiple options including smaller capabilities within the 6U category)						
AAC Clyde Space Sweden	150	<0.1°/<0.01°	VHF, UHF, S, X	LEO	Flown LEO	Yes
Alén Space Spain	180	0.2°/0.1°	VHF, UHF, S	LEO	Flown LEO	No
Argotec Italy	100	<0.03°/<0.01°	UHF, S, X, K	LEO, GEO, Lunar, Deep Space	Flown Deep Space Flown Lunar	Yes
Artemis Space Technologies UK	100	0.01°/0.01°	UHF, S, X, Ka, Ku, Optical	LEO, MEO, GEO, Lunar, Deep Space	Flown LEO Qualified MEO, GEO, Lunar, and Deep Space	No
Astro Digital USA	240	<0.1°/<0.05°	UHF, S, X, Ka	LEO	Flown LEO	Yes
Blue Canyon Technologies USA	108	0.003°/0.003°	L, S, X	LEO, GEO, Deep Space	Flown LEO and Lunar Qualified GEO and Deep Space	Yes
C3S Electronics Development Hungary	165	<0.2°/<0.2°	UHF, S	LEO, MEO	Under Development	No
EnduroSat Bulgaria	60	<0.021°/<0.021°	UHF, S, X	LEO	Flown LEO	Yes
General Atomics EMS USA	10	0.28°/0.08°	UHF, S	LEO	Flown LEO	Yes
German Orbital Systems Germany	72	<1°/<1°	UHF, S, X	LEO	Flown LEO	No
GomSpace Denmark	102	0.07°/0.056°	S, X	LEO, Deep Space	Flown LEO Qualified Deep Space	Yes
Hex20 Australia	45	0.003°/0.003°	UHF, S, X	LEO, MEO, GEO, Lunar	Flown LEO	No
IMT Italy	115	0.1°/0.1°	VHF, UHF, S, C, X	LEO	Under Development	No
ISISPACE The Netherlands	100	<0.3°/<0.3°	UHF, S, X	LEO, Lunar	Flown LEO Qualified for Lunar	No
Millennium Space Systems USA	100	<0.03°/<0.014°	UHF, S	LEO	Flown LEO	Yes

NanoAvionics Lithuania	175	0.18°/0.12°	UHF, S, X	LEO	Flown LEO	Yes
NearSpace Launch USA	160	0.5°/0.2°	L, UHF, S, X	LEO	Flown LEO	Yes
NPC SPACEMIND Italy	85.2	<0.1°/<0.1°	UHF, S, X, Ka	LEO, MEO, GEO, Lunar	Flown LEO	No
Open Cosmos UK	160	0.02°/0.01°	UHF, S, X	LEO	Flown LEO	No
Orbital Astronautics UK	1,000	0.1°/0.01°	S, X, K, Ka, Optical	LEO, MEO	Flown LEO	No
Orion Space Solutions USA	15	1°/1°	L, S, X	LEO	Flown LEO	Yes
Pumpkin Space USA	200	0.05°/<0.05°	UHF, S, X, Ka	LEO, Lunar	Flown LEO Qualified Lunar	Yes
Quub, Inc. USA	50	5°/2°	UHF, S, Ku	LEO, Lunar	Under Development	Yes
SatRev Poland	36	1°/0.6°	UHF, S	LEO	Qualified LEO	No
SkyLabs Slovenia	200	0.3°/0.06°	VHF, UHF, S	LEO, MEO	Flown LEO and MEO	No
Space Dynamics Lab USA	80	0.021°/0.021°	UHF, S, X, Ka	LEO, GEO, GTO, Cislunar, Deep Space	Qualified LEO and GEO	Yes
Space Flight Laboratory Canada	240	0.009°/0.004°	UHF, S, X, Ka	LEO, GEO, Lunar	Flown LEO Qualified GEO and Lunar	No
Space Inventor Denmark	200	<0.008°/<0.008°	VHF, UHF, S, X	LEO	Flown LEO	No
Spacemanic Czech Republic	500	0.1°/0.05°	VHF, UHF, S	LEO, GEO, Lunar	Flown LEO Qualified GEO	No
Spire Global USA	200	0.1°/0.05°	UHF, L, S, X. Ka, Ku	LEO	Flown LEO	Yes
Terran Orbital USA	180	0.008°/0.007°	UHF, S, X, C	LEO, GEO, Deep Space	Flown LEO and Lunar Qualified GEO and Deep Space	Yes

Table 2-6: 12U Market Solutions (The fields indicate maximum capability, organizations may offer multiple options including smaller capabilities within the 12U category)						
Organization	**Peak Power (W)**	**3-σ Pointing Control/ Knowledge**	**Comm Options**	**Intended Destination**	**Maturity**	**US Office**
AAC Clyde Space Sweden	400	<0.01°/<0.0075°	VHF, UHF, S, X, K, Ka, Ku, Optical	LEO	Qualified LEO	Yes
Argotec Italy	180	<0.03°/<0.01°	UHF, S, X, K	LEO, GEO, Lunar, Deep Space, DRO	Under Development	Yes
Artemis Space Technologies UK	150	0.01°/0.01°	UHF, S, X, Ka, Ku, Optical	LEO, MEO, GEO, Lunar, Deep Space	Flown LEO Qualified GEO, MEO, Lunar, and Deep Space	No
Blue Canyon Technologies USA	108	0.0025°/0.0025°	L, S, X	LEO, GEO, Deep Space	Flown LEO and GEO Qualified Deep Space	Yes
C3S Electronics Development Hungary	165	<0.2°/<0.2°	UHF, S	LEO, MEO	Under Development	No
EnduroSat Bulgaria	70	0.1°/0.05°	UHF, S, X, K	LEO	Flown LEO	Yes
General Atomics EMS USA	115	0.3°/0.024°	UHF, S	LEO	Qualified LEO	Yes
GomSpace Denmark	102	0.07°/0.056°	S, X	LEO	Qualified LEO	Yes
Hex20 Australia	110	0.003°/0.003°	UHF, X	LEO, MEO, GEO, Lunar	Flown LEO	No
ISISPACE The Netherlands	190	<0.03°/<0.03°	UHF, S, X, Ka	LEO	Under Development	No
NanoAvionics Lithuania	175	0.18°/0.09°	UHF, S, X	LEO	Flown LEO	Yes
NearSpace Launch USA	500	0.5°/0.2°	L, UHF, S, X	LEO, MEO	Under Development	Yes
NPC SPACEMIND Italy	96	<0.1°/<0.1°	UHF, S, X, Ka	LEO, MEO, GEO, Lunar	Flown LEO	No
Open Cosmos UK	160	0.031°/0.027°	UHF, S, X	LEO	Flown LEO	No
Orbital Astronautics UK	1,000	0.05°/0.01°	S, X, K, Ka, Optical	LEO, MEO, GEO	Flown LEO	No
Orion Space Solutions USA	40	<1°/<1°	L, S, X, Ka	LEO, GEO	Qualified LEO and GEO	Yes
Pumpkin Space USA	400	0.05°/<0.05°	UHF, S, X, Ka	LEO, Lunar	Qualified LEO	Yes
SkyLabs Slovenia	500	0.3°/0.06°	VHF, UHF, S	LEO, MEO	Flown LEO and MEO	No

Space Dynamics Lab USA	80	0.021°/0.021°	UHF, S, X, Ka	LEO, GEO, GTO, Cislunar, Deep Space	Flown LEO Qualified GTO and GEO	Yes
Space Flight Laboratory Canada	322	0.009°/0.004°	UHF, S, X, Ka	LEO, GEO, Lunar	Flown LEO Qualified GEO and Lunar	No
Space Information Laboratories USA	180	0.008°/0.008°	S, X, Ka	LEO, GEO, Lunar	Under Development	Yes
Space Inventor Denmark	200	<0.008°/<0.008°	VHF, UHF, S, X	LEO	Flown LEO	No
Spacemanic Czech Republic	500	0.1°/0.05°	VHF, UHF, S, X	LEO, GEO, Lunar	Flown LEO Qualified GEO	No
Spire Global USA	300	0.1°/0.05°	UHF, L, S, X, Ka, Ku	LEO	Qualified LEO	Yes
Terran Orbital USA	180	0.008°/0.007°	UHF, S, X, C	LEO, GEO, Lunar, Deep Space	Flown LEO and Lunar Qualified GEO and Deep Space	Yes

Table 2-7: 16U+ Market Solutions

(The fields indicate maximum capability, organizations may offer multiple options including smaller capabilities within the 16U+ category)

Organization	Format	Peak Power (W)	3-σ Pointing Control/ Knowledge	Comm Options	Intended Destination	Maturity	US Office
AAC Clyde Space Sweden	16U	400	<0.01°/<0.0075°	VHF, UHF, S, X, K, Ka, Ku, Optical	LEO	Qualified LEO	Yes
Argotec Italy	16U+	250	<0.07°/<0.03°	UHF, S, X, K	GEO, Lunar, Mars, Deep Space	Under Development	Yes
Artemis Space Technologies UK	16U	200	0.01°/0.01°	UHF, S, X, Ka, Ku, Optical	LEO, MEO, GEO, Lunar, Deep Space	Flown LEO Qualified GEO, MEO, Lunar, and Deep Space	No
Astro Digital USA	16U+	500	<0.05°/<0.01°	UHF, S, X, Ku, Ka, V, W, Optical	LEO	Flown LEO	Yes
Blue Canyon Technologies USA	16U	108	0.0025°/0.0025°	L, S, X	LEO, GEO, Deep Space	Qualified LEO, GEO and Deep Space	Yes
C3S Electronics Hungary	16U+	165	<0.2°/<0.2°	UHF, S	LEO, MEO	Under Development	No
EnduroSat Bulgaria	16U	80	0.1°/0.05°	UHF, S, X, K	LEO	Qualified LEO	Yes
German Orbital Systems Germany	16U	164	<1°/<1°	UHF, S, X	LEO	Qualified LEO	No
GomSpace Denmark	16U	150	0.07°/0.056°	S, X	LEO	Qualified LEO	Yes
Hex20 Australia	27U	150	0.003°/0.003°	UHF, S, X	LEO, MEO, GEO, Lunar	Flown LEO	No
ISISPACE The Netherlands	16U	190	<0.03°/<0.03°	UHF, S, X, Ka	LEO	Under Development	No
NanoAvionics Lithuania	16U	175	0.18°/0.09°	UHF, S, X	LEO	Flown LEO	Yes
Nara Space Korea	16U	232	0.006°/0.006°	S, X	LEO	Qualified LEO	No
NPC SPACEMIND Italy	16U	120	<0.1°/<0.1°	UHF, S, X, Ka	LEO, MEO, GEO, Lunar	Under Development	No
Open Cosmos UK	16U	160	0.031°/0.027°	UHF, S, X	LEO	Flown LEO	No
Orbital Astronautics UK	16U, 27U	1,000	0.05°/0.01°	S, X, K, Ka, Optical	LEO, GEO, Lunar	Qualified LEO	No
Orion Space Solutions USA	16U+	400	<1°/<1°	L, S, X, Ka, Optical	LEO, GEO, Lunar	Qualified LEO, GEO and Lunar	Yes

Pumpkin Space USA	16U, 27U	400	0.05°/<0.05°	UHF, S, X, Ka	LEO, Lunar	Qualified LEO	Yes
SkyLabs Slovenia	20U+	500	<0.005°/<0.003°	VHF, UHF, S	LEO, MEO	Flown LEO and MEO	No
Space Flight Laboratory Canada	16U	322	0.009°/0.004°	UHF, S, X, Ka	LEO, GEO, Lunar	Flown LEO Qualified GEO and Lunar	No
Space Information Laboratories USA	27U	180	0.008°/0.008°	S, X, Ka	LEO, GEO, Lunar	Under Development	Yes
Space Inventor Denmark	16U	200	<0.008°/<0.008°	VHF, UHF, S, X, L, Ka, Ku, QV	LEO, GEO, MEO	Flown LEO and GEO	No
Spacemanic Czech Republic	16U, 27U	1,000	0.1°/0.05°	VHF, UHF, S, X	LEO, GEO, Lunar	Flown LEO Qualified GEO and Lunar	No
Spire Global USA	16U	300	0.1°/0.05°	UHF, L, S, X, Ka, Ku	LEO	Flown LEO	Yes

2.2.2.2 ESPA-Class

The term ESPA-class refers to the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (SPA) or similar configurations. The ESPA ring typically separates the primary payload with the upper stage of the launch vehicle, permitting additional mounting allocations for secondary payloads. Multiple rings can be stacked without a primary payload on the top to launch multiple payloads.

For this document, the ESPA-class table 2-8 includes options that may not be designed for the ESPA ring, but its mass and volume permit adaptability to rideshare opportunities. The information in this chapter is limited to offerings with mass under 500 kg even though some variants of the ESPA ring can support higher mass. Variants of the ESPA ring include, but are not limited to, ESPA-Heavy and ESPA-Grande. Examples of ESPA Rideshare are provided in figures 2.10 and 2.11, while figure 2.12 shows an example for an ESPA satellite from Muon Space.

Figure 2.10: Example mission configuration using Rideshare Plates. Credit: SpaceX.

Figure 2.11: LandSat-9 ESPA Ring populated with payloads and mass ballasts. Credit: NASA/Randy Beaudoin.

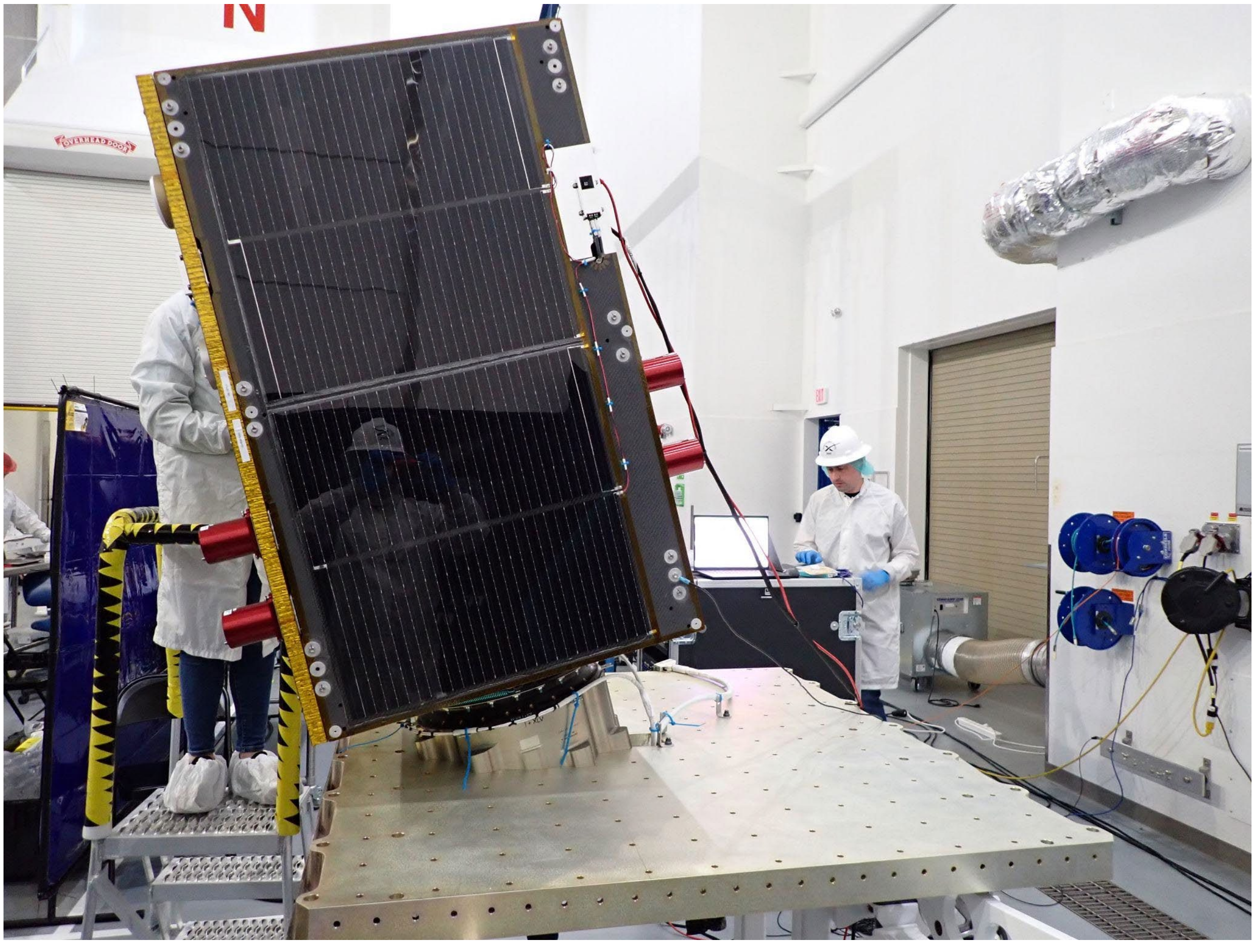

Figure 2.12: ESPA-Class satellite bus from Muon Space during integration at SpaceX facility for Transporter 8 rideshare mission. Credit: Muon Space via ExoLaunch and SpaceX.

Table 2-8: ESPA-Class Market Solutions

(The fields indicate maximum capability; organizations may offer multiple options including smaller capabilities within the ESPA-Class category)

Organization	Peak Power (W)	3-σ Pointing Control/ Knowledge	Comm Options	Intended Destination	Maturity	US Office
Airbus US Space & Defense USA	2,200	0.3°/0.3°	S, Ka, Optical	LEO	Flown LEO	Yes
Argotec Italy	250	<0.005°	UHF, S, X, K	LEO	Under Development	Yes
Artemis Space Technologies UK	1,250	0.01°/0.01°	UHF, S, X, Ka, Ku, Optical	LEO, MEO, GEO, Lunar, Deep Space	Qualified LEO, MEO, GEO, Lunar and Deep Space	No
Astranis Space Technologies Corp. USA	2,500	<0.1°/<0.01°	MIL-Ka, Ka, Ku, Q, V, X	MEO, GEO, Cislunar, Deep Space, Polar, High Inclination	Flown GEO	Yes
Astro Digital USA	2,000	<0.05°/<0.01°	UHF, S, X, Ku, Ka, V, W, Optical	LEO, GEO, Deep Space	Flown LEO	Yes
Ball Aerospace USA	1,000	<0.007°/<0.006°	L, S, X, Ka	LEO, MEO, GEO, Deep Space	Flown LEO	Yes
Berlin Space Technologies Germany	3,000	<0.017°/<0.017°	UHF, S, X	LEO	Flown LEO	Yes
Blue Canyon Technologies USA	1,082	0.0025°/0.0025°	L, S, X	LEO, GEO, Deep Space	Flown LEO and GEO Qualified Deep Space	Yes
Bradford Space USA	1,500	1.5°/0.006°	S, K	LEO, GEO, GTO, Cislunar, Lunar, Deep Space	Under Development	Yes
CesiumAstro USA	4,500	<0.1°/<0.01°	S, L, Ku, Ka, Optical	LEO	Under Development	Yes
EnduroSat Bulgaria	170	0.1°/<0.05°	UHF, S, X, K	LEO	Under Development	Yes
General Atomics EMS USA	450	0.03°/0.02°	S, X	LEO	Qualified LEO	Yes
Hemeria France	250	<0.03°/<0.01°	S, X	LEO, GEO, GTO	Flown LEO Qualified GEO and GTO	No
LeoStella USA	2,000	0.013°/0.009°	UHF, S, X	LEO	Flown LEO	Yes
Lockheed Martin USA	500+	<0.1°/<0.1°	S, X, Ka	LEO, GEO, Lunar, Deep Space	Flown LEO	Yes

					Qualified GEO, Lunar and Deep Space	
Loft Orbital USA	>1,000	<0.035°/<0.03°	S, X, L	LEO	Flown LEO	Yes
Magellan Aerospace Canada	200	0.01°/0.01°	S, X	LEO	Flown LEO	No
Malin Science Space Systems USA	918	<0.015°/<0.015°	UHF, X, Ka	Mars	Under Development	Yes
Millennium Space Systems USA	500	<0.013°/<0.008°	S, X, Ka	LEO, MEO, GEO, Deep Space	Flown LEO and GEO	Yes
Momentus USA	750	0.05°/0.025°	S, Ka, Optical	LEO	Flown LEO	Yes
Muon Space USA	500	0.03°/0.012°	S, X	LEO	Flown LEO	Yes
NanoAvionics Lithuania	660	0.24°/0.09°	UHF, S, X	LEO	Flown LEO	Yes
Northrop Grumman USA	400	<0.01°/<0.008°	S, X, Ka	LEO, GEO, HEO	Flown LEO, GEO, and HEO	Yes
NovaWurks USA	>5,000	0.002°/0.0004°	UHF, S, L, X, Ka, Ku and Optical	LEO, MEO, GEO, GTO, HEO, Lunar and Deep Space	Flown LEO and GTO	Yes
OHB LuxSpace Luxembourg	834	<0.022°/ 0.01°	S, X	LEO	Qualified LEO	No
Open Cosmos UK	2,200	<0.033°/0.03°	S, X	LEO	Under Development	No
Orbital Astronautics UK	5,000	0.05°/0.01°	S, X, K, Ka, Optical	LEO, MEO, GEO, Deep Space	Qualified LEO	No
Quantum Space USA	1,000	0.006°/0.006°	S, X, Ka	LEO, GEO, Cislunar, Lunar, Deep Space	Under Development	Yes
Reflex Aerospace Germany	>300	<0.01°/<0.01°	S, X, Ka, Ku, Optical	LEO	Under Development	No
Redwire USA	600	0.005°/0.0017°	X	LEO	Qualified LEO	Yes
Sierra Space USA	500	0.001°/ <0.001°	UHF, S, X	LEO, MEO, GEO	Flown LEO	Yes
SITAEL Italy	1,000	0.018°/0.010°	S, X, Ka	LEO	Under Development	No
Southwest Research Institute USA	1,550	0.015°/0.002°	S, X, Ka	LEO, GEO	Flown LEO Under Development GEO	Yes
Space Dynamics Lab USA	1,600	0.021°/0.021°	UHF, S, X, Ka, Optical	LEO, GEO, GTO, Cislunar, Deep Space	Flown LEO	Yes

Space Flight Laboratory [Canada]	1,200	0.009°/0.004°	UHF, S, X, Ka	LEO, GEO, Lunar	Flown LEO Qualified GEO and Lunar	No
Space Inventor [Denmark]	400	<0.008°/<0.008°	VHF, UHF, S, X, L, Ka, Ku, QV	LEO, GEO, MEO	Qualified LEO	No
Surrey Satellite Technology Limited [UK]	400	0.01°/0.01°	S, X	LEO	Flown LEO	No
Terran Orbital [USA]	4,000	0.003°/0.002°	UHF, S, X, C	LEO, GEO, Lunar and Deep Space	Under Development	Yes
XPLORE [USA]	950	0.17°/ 0.018°	S, X	VLEO, LEO, Cislunar	Under Development	Yes
York Space Systems [USA]	1,500	0.008°/0.004°	UHF, S, X, Ka, Ku, Optical	LEO, GEO, Lunar	Flown LEO Qualified GEO and Lunar	Yes

2.3 Programmatic and Systems Engineering Considerations

To make an appropriate decision on which design path to take, small satellite mission developers should consider the programmatic and Systems Engineering factors most important to them, such as:

- What are the environments the system will be exposed during development and in flight?
- Are the Concept of Operations well defined and understood?
- How well do the systems meet functional and performance requirements?
- What are the mission's key performance parameters (e.g., mass, volume, power, data link, data budget, pointing) and how much margin do they offer?
- What is the software development environment, and how much flight and ground software can be re-used? Are emulators, simulators, Engineering Development Units (EDUs) and/or flatsats available to aid that development?
- What are the systems'/components' flight heritage, Technology Readiness Level (TRL), and reliability? What is the remaining Research and Development (R&D) level of effort to integrate the system with existing and/or planned systems?
- What is the mission's risk posture? How much development risk and performance risk are acceptable to the mission?
- Is it most important to meet performance requirements, cost, and/or schedule? What is the system's/components' production/lead time, and what are the contractual mechanisms that will be used to procure the systems and ensure timely delivery if delays are encountered?

Design selection can be driven by unique mission constraints, manufacturing lead time, and documented reliability. All of these and many more considerations should be well understood for each trade space option prior to a down-select. Given mission system performance requirements for key performance parameters like mass, volume, power, data link, data budget, and pointing, a functional importance rating and risk-based trade study should be used to screen the many options available. In addition to functional performance, relevant flight heritage or TRL, production lead time, and any available reliability data should be included in the trades. These, as well as cost, could drive the design to be done via COTS or commercial support.

Mission developers may want to take into consideration the following guides to help them in their selection and design process:

- NASA CubeSat 101 Book https://www.nasa.gov/content/cubesat-launch-initiative-resources
- NASA Systems Engineering Handbook https://www.nasa.gov/connect/ebooks/nasa-systems-engineering-handbook
- NASA Small Spacecraft Technology program Guidebook for Technology Development Projects https://www.nasa.gov/sites/default/files/atoms/files/smallsattechdevguidebook_rev-508d1.pdf

2.4 On the Horizon

As spacecraft buses are combinations of the subsystems described in later chapters, it is unlikely there will be any revolutionary changes in this chapter that are not preceded by revolutionary changes in some other chapter. As launch services become less expensive and commonplace with the rise of dedicated SmallSats launches, the market will continue to expand allowing interested universities and researchers to purchase COTS spacecraft platforms as an alternative to developing and integrating SmallSats themselves. Another option is to use numerous turnkey solutions offered by SmallSat vendors who can customize and cater to customer constraints.

SmallSat subsystem technology will continue to mature and gain flight heritage, to produce improved next generation platforms offered by vendors. Platforms with increased performance will spark the interest of newer vendors as they emerge into the market. This was demonstrated in the PocketQube industry: the requirement to satisfy ultra-low mass and volume constraints enabled high-performance capabilities. As the industry grows, there will likely be key technological advancements in SmallSat in-space propulsion, pointing and navigation control, optical communications, radiation tolerance, and radiation hardening. Subsystems described in other chapters in this report include details on radiation testing, but a subsystems' mean time between failures (MTBF) and overall system reliability will become a key design criterion as the sample groups become large enough to be statistically significant.

2.5 Summary

Several vendors have pre-designed fully integrated small spacecraft buses that are space rated and available for purchase. The market ranges from companies that are willing to heavily modify their systems to fit the customer's needs to companies attempting to standardize their system with little to no customization in favor of a better cost proposition. This chapter consolidated a long list of providers with key characteristics to facilitate the research and down-selection process for SmallSat practitioners.

For feedback about this chapter, email: arc-sst-soa@mail.nasa.gov. Please include a business email in case of follow up questions.

2.6 References

The references in this section are provided to facilitate the process in which practitioners can obtain information from the providers. The source indicates how the information provided in this chapter was obtained.

Source definition:

Direct New = organization provided the information through direct communication with the State-of-the-Art team for the current edition of the document.

Direct Old = organization provided the information through direct communication with the State-of-the-Art team on a previous edition of the document, and the team was unable to communicate with the organization to update the current edition of the document.

Website = the team was unable to directly communicate with the organization and limited information was obtained from the organization's website.

Table 2-9: List of Contact Information for Organizations in this Chapter

Organization	Source	Contact Email	Website
AAC Clyde Space	Direct New	enquiries@aac-clydespace.com	www.aac-clyde.space
Airbus US Space & Defense	Direct New	deborah.horn@airbusus.com	www.airbusus.com
Alba Orbital	Direct New	contact@albaorbital.com	www.albaorbital.com
Alen Space	Direct New	sales@alen.space	www.alen.space
Argotec	Direct New	info@argotecgroup.com	www.argotecgroup.com
Artemis Space Technologies	Direct New	info@spaceartemis.com	www.spaceartemis.com
Astranis	Direct New	scott@astranis.com	www.astranis.com
Astro Digital	Direct New	brian@astrodigital.com	www.astrodigital.com

Axelspace	Direct New	Contact Page	www.axelspace.com
Ball Aerospace	Direct New	General Inquiry Form	www.ballaerospace.com
Berlin Space Technologies	Direct New	info@berlin-space-tech.com	www.berlin-space-tech.com
Blue Canyon Technologies	Direct New	info@bluecanyontech.com	www.bluecanyontech.com
Bradford Space	Direct New	info@bradford-space.com	Bradford-Space.com
C3S Electronics Development	Direct Old	info@c3s.hu	www.c3s.hu
CesiumAstro	Direct New	info@cesiumastro.com	www.cesiumastro.com
Citadel Space Systems	Website	contact@citadel.space	Citadel.space
DIYSATELLITE	Direct New	gus@diysatellite.com	www.diysatellite.com
EnduroSat	Direct New	Contact Page	www.endurosat.com
FOSSA Systems	Direct New	contact@fossa.systems	Fossa.systems
General Atomics EMS	Direct New	Chris.white@ga.com	www.ga.com/EMS
German Orbital Systems	Direct New	info@orbitalsystems.de	www.orbitalsystems.de
GomSpace	Direct New	info@gomspace.com	gomspace.com
Gran Systems	Direct New	info@gransystems.com	www.gransystems.com
GUMUSH AeroSpace	Direct New	gumush@gumush.com.tr	www.gumush.com.tr
Hemeria	Direct New	contact@hemeria-group.com	www.hemeria-group.com/en
Hex20	Direct New	lloyd@hex20.com.au	www.hex20.com.au
IMT	Direct New	giovanni.cucinella@imtsrl.it	imtsrl.it
Innova Space	Direct New	info@innova-space.com	innova-space.com/en
In-Space Missions	Website	info@in-space.co.uk	in-space.co.uk
ISISPACE	Direct Old	sales@isispace.nl	www.isispace.nl
LeoStella	Direct New	mike.kaplan@leostella.com	leostella.com
Lockheed Martin	Direct New	timothy.m.linn@lmco.com	-
Loft Orbital	Direct New	gautier@loftorbital.com	www.loftorbital.com
Magellan Aerospace	Direct New	rushi.ghadawala@magellan.aero	www.magellan.aero
Malin Space Science Systems	Direct New	yee@msss.com	www.msss.com
Millennium Space Systems	Direct New	Contact Webpage	www.millennium-space.com
Momentus	Direct New	sales@momentus.space	Momentus.space
Muon Space	Direct New	info@muonspace.com	www.muonspace.com
Nanoavionics	Direct New	info@nanoavionics.com	www.nanoavionics.com
NearSpace Launch	Direct New	nsl@nearspacelaunch.com	www.nearspacelaunch.com
Northrop Grumman	Direct New	John.Dyster@ngc.com	-
NovaWurks	Direct New	info@NovaWurks.com	www.novawurks.com
NPC SPACEMIND	Direct New	info@npcspacemind.com	www.npcspacemind.com
OHB LuxSpace	Direct New	info@luxspace.lu	OHB LuxSpace
Open Cosmos	Direct New	partnerships@open-cosmos.com	open-cosmos.com
Orbital Astronautics	Direct New	hello@orbastro.com	orbastro.com
Orion Space Solutions	Direct New	contact@orionspace.com	orionspace.com
Pumpkin Space Systems	Direct New	sales@pumpkininc.com	www.pumpkinspace.com

Quantum Space	Direct New	sales@quantumspace.us	www.quantumspace.us
Quub, Inc.	Direct New	info@quub.space	quub.space
Reflex Aerospace	Direct New	sales@reflexaerospace.com	www.reflexaerospace.com
Redwire	Direct New	sales@redwirespace.com	www.redwirespace.com
SatRev	Direct New	engage@satrev.space	www.satrev.space
Sierra Space	Direct New	spaceapps@sierraspace.com	www.sierraspace.com
SITAEL	Direct New	sales.space@sitael.com	www.sitael.com
SkyLabs	Direct New	sales@skylabs.si	www.skylabs.si
Southwest Research Institute	Direct New	spacecraft-info@swri.org	-
Space Dynamics Lab	Direct New	info@sdl.usu.edu	www.sdl.usu.edu
Space Flight Laboratory	Direct New	info@utias-sfl.net	www.utias-sfl.net
Space Information Laboratories	Direct New	sales@spaceinformationlabs.com	www.spaceinformationlabs.com
Space Inventor	Direct New	sales@space-inventor.com	space-inventor.com
Spacemanic	Direct New	sales@spacemanic.com	www.spacemanic.com
Spire Global	Direct New	joe.carroll@spire.com	www.spire.com
Surrey Satellite Technology Limited	Direct New	info@sstl.co.uk	www.sstl.co.uk
Terran Orbital	Direct Old	info@terranorbital.com	terranorbital.com
Xplore	Direct New	inquire@xplore.com	www.xplore.com
York Space Systems	Direct New	BD@yorkspacesystems.com	www.yorkspacesystems.com