REST Journal on Emerging trends in Modelling and Manufacturing

Vol: 9(2), June 2023

REST Publisher; ISSN: 2455-4537 (Online)

Website: https://restpublisher.com/journals/jemm/

DOI: https://doi.org/10.46632/jemm/9/2/1

Design And Development of A CubeSat for Atmospheric Research

***S. Rohan, Sam K Saju, Sradha syam, Shabna**

Aeroin SpaceTech Pvt.Ltd, Tamil Nadu, India.

*Corresponding Author Email: rohan.aeroin@gmail.com

Abstract: *The paper "Design and Development of CubeSat for Atmospheric Research" presents the development and design of a CubeSat for studying the Earth's atmosphere. CubeSats are miniature satellites that offer a cost-effective option for conducting scientific research in space. The paper discusses the selection of sensors, communication systems, and other subsystems necessary for the successful execution of the mission. The study shows the viability and possible uses of CubeSat missions for atmospheric research, such as tracking weather patterns and examining climate change's consequences.*
Keywords: *CubeSat, Atmospheric research, Miniature satellites, Sensors, Communication systems, Subsystems, Weather patterns, Climate change.*

1. INTRODUCTION

The study of Earth's atmosphere is essential for understanding climate change, weather patterns, and air quality. However, acquiring data on atmospheric variables like temperature, pressure, and composition requires specialized devices that are costly. CubeSats, which are small satellites weighing less than 1.33 kg, offer a more affordable option for scientific research in space. While CubeSats were initially created for educational purposes, their potential for scientific study has only recently been explored. The paper discusses the design and development of a CubeSat for atmospheric research, which will yield valuable information on atmospheric variables. The research will showcase the usefulness of CubeSats for studying the atmosphere and open more possibilities for future CubeSat missions in this field.

2. LITERATURE REVIEW

N. Saeed Et.al (2020) They mentioned about how CubeSats` special features, such as their small size, low power consumption, and limited computing power, affect their communication capabilities. They emphasise the main difficulties that CubeSat communications face, including bandwidth limitations, power restrictions, and interference from other systems. X. Yu Et.al (2014) A comprehensive design for a CubeSat-based asteroid exploration mission is presented by the authors. They demonstrate the effectiveness of the CubeSat design for an asteroid exploration mission by presenting the results of calculations and experiments. Shiroma Et.al (2011) They also go over the various CubeSat parts, including the power supply, communication system, and onboard sensors, as well as the difficulties in creating these parts for CubeSats.The following section of the paper highlights some current and planned CubeSat missions in a variety of industries, such as Earth observation, space weather research, and technological demonstration. For instance, the authors explore the usage of CubeSats for monitoring and tracking wildfires as well as missions to study the impact of space weather on the ionosphere of Earth. Hernandez Et.al (2015) The CubeSat`s power system is an essential part of the design, and this paper describes how to choose the best power regulation technology. The study describes how battery bus topology with maximum power point tracking was designed to take into account the temperature impacts on solar cells caused by the low Earth orbit environment. In order to select the best power source design, the study offers preliminary calculations based on the space mission analysis and design model, and it estimates the total output power to be 13.45W at zero incidence. A. Edpuganti Et.al(2022) This article tries to present a thorough analysis of all established and newly developed EPS CubeSat architectures. The article also suggests prospective areas for additional investigation and development of the CubeSat EPS. The paper emphasises how crucial it is to choose the appropriate EPS architecture for a CubeSat mission based on the mission`s goals, the environment, and other mission-specific constraints.

3. DESIGN OF CUBESAT FOR COMMUNICATION

The main objective of the designed cubesat mainly is for telecommunication. RF (Radio Frequency) stands out as the most established and effective choice for long-distance transmission of information and command exchange within the telecommunication subsystem.

Architecture

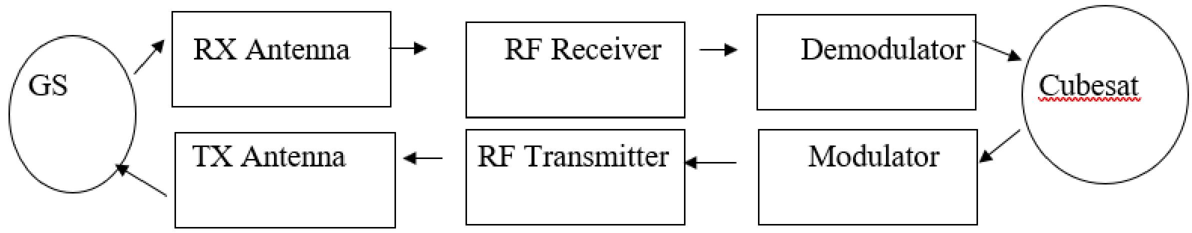

FIGURE 1. Architecture

TABLE 1. Key Concepts

Step	Information Required
Identify Requirements	Identify Requirements
Frequencies	Amateur, Experimental or commercial
Design Specification	Transmission /Reception
Select Data Protocol	Method for error correction in specified format.

TABLE 2. About Radio Hardware (TX/RX)

Connectors for interface (Coaxial cables)
Circuits – (amplifier, filter, mixer etc)
(Demodulator or Modulator)
AS - DS conversion Circuit
Connectors for Interfaces

TABLE 3. Major Charateristics

	Items	Product Values
Transmission	Freq.Range	430 – 440 [MHz]
Transmission	Power	Cont.Wave : 0.15W, Freq.Modulation: 0.85W
Transmission	Freq.Stablility	±2.5 ppm
Transmission	Modulation	Audio frequency shift keying, Gaussian Minimum shift keying
Reception	Freq.Range	145Mhz
	Power Consumption	0.2- 0.5 W
	Dimensions	80 × 50 × 12 [mm]
	Mass	50 g

4. POWER GENERATION OF CUBESAT

A 1U cubesat, measuring 10x10x10 cm, has a maximum weight of 1 kg and is considered a large picot-sat. On the other hand, a 3U cubesat (30x10x10 cm) falls under the definition of a Nano-sat. In the past, small satellites accounted for approximately 20% of all satellite launches. Although small satellites are less complex than their larger counterparts, they have limited capabilities. Typically, small satellite missions have straightforward and less intricate objectives. However, advancements in technology have led to increased capabilities of small satellites, while still maintaining their affordability. Funding for small satellite projects usually requires completing the design and construction within a timeframe of 1-3 years. The power system of a satellite is vital for generating, storing, distributing, and managing its electrical power. Photovoltaic arrays, typically positioned on the spacecraft's exterior, are employed to generate energy.

TABLE 4. Design Of Power Systems

Design Elements	Needs	Necessaries
Power Supply	Requirements for payload	Battery and Solar Array
Distribution of power	Running of CubeSat	Electric Works
Duration	Depends upon Orbit	Battery
Voltage	CubeSat running	Electric Works

TABLE 5. About the Cubesat sensors and Gyroscopes

Name	About	Origin	Staus
Sun Sensors			
ss-411	Best seller Micro DSS	Sinclair Interplanetary	9
DSS	Active Pixel Sensors	TNO	7
Gyroscopes			
Micro-FORCE-1	Single axis gyroscope foe small satellites	Northrop Grumman	9
VSGA	3- axis gyroscopes	AES	7

TABLE 6. About Cubsat solar array

Type	About	Accuracy/Efficiency
Solar array/cell	Improved TASC	27%
Solar array/cell	Next Triple Junction	29.5%
Solar array/cell	Triple Junction Solar array 2G28 / 3G30	28 – 30%

TABLE 7. About Materials

Array	Si-Silicon	GaAs- Gallium Arsenide	3 layer junction GaAs
Theo-Efficiency	28.5%	23%	41+%

5. LAUNCH AND DEPLOYMENT OF CUBESAT

The deployment of CubeSats has transformed space exploration and opened up numerous possibilities for scientific and technological discoveries. CubeSats are standardized and cost-effective small satellites that are ideal for a wide range of missions. To launch a CubeSat, the mission must be planned, defining the objectives, requirements, desired orbit, and mission timeline. After that, the CubeSat is designed and constructed by selecting the appropriate components and subsystems, such as the power system, communications system, and attitude control system, using standardized CubeSat components that are available from various suppliers. Once the CubeSat is constructed, it is integrated with the chosen launch vehicle and subjected to tests to ensure its readiness for launch, including environmental testing to ensure it can withstand harsh launch and space conditions. [] The CubeSat is integrated into a cubesat dispenser or specialized deployment system, which will deploy the CubeSat into orbit. The CubeSat is then launched into space along with the primary payload on the selected launch vehicle. CubeSats can be launched from various locations, such as ground-based launch sites and international space stations. Once the CubeSat is deployed into orbit, its onboard systems are activated, and it starts to collect data or carry out other mission objectives. The CubeSat's communication system is utilized to transmit data back to Earth, where it can be analyzed to achieve the mission objectives. The mission operations team communicates with the CubeSat using ground-based antennas and ensures that the CubeSat is performing as expected.

6. TYPES OF LAUNCH VEHICLES USED FOR CUBESATS

Launch vehicles play a crucial role in CubeSat missions, with several factors to consider when selecting the appropriate vehicle, such as payload mass and volume, launch site location, launch schedule, cost, and availability. CubeSats are often launched as secondary payloads, alongside larger satellites or on the same rocket as another primary payload. There are various launch vehicles available, each with its own advantages and disadvantages. One such launch vehicle is the Pegasus rocket, which is air-launched from a carrier aircraft and can be launched from various locations due to not requiring a traditional launch pad. However, it can only launch a few CubeSats at a time due to limited payload capacity. Another option is the Minotaur rocket, a repurposed intercontinental ballistic missile known for its reliability and low cost. However, it is also limited in its payload capacity and not suitable for larger CubeSats. The Falcon 9 rocket is a popular choice due to its high payload capacity and versatility, capable of launching multiple CubeSats on a single mission. Its reusable first stage also adds to its appeal, although it can be more expensive than other launch vehicles. The Soyuz rocket, a Russian rocket known for its low cost and reliability, can launch multiple and larger CubeSats but is limited in launch site locations. Lastly, the Electron rocket is a newer launch vehicle designed for small satellite missions, including CubeSats. Known for its low cost and fast turnaround time, it is limited in payload capacity and launch site locations. Considering the specific needs of a CubeSat mission, the appropriate launch vehicle must be selected based on its strengths and weaknesses.

7. INTEGRATION OF CUBESATS INTO LAUNCH VEHICLES

The integration of CubeSats into launch vehicles has brought a significant change in the space industry by making space missions more affordable for organizations. CubeSats are standardized, small-sized satellites that can be built and launched at a lower cost compared to traditional satellites. However, the successful launch of a CubeSat depends on how well it is integrated into the launch vehicle. The process of integration varies depending on the launch vehicle and CubeSat, but it typically involves mechanical and electrical integration, protective fairing, and testing and verification. Mechanical integration involves attaching the CubeSat to the launch vehicle using a separation system that is designed to release the CubeSat from the launch vehicle once it reaches orbit. The separation system must be tested to ensure that it will function correctly and release the CubeSat at the appropriate time. Electrical integration is the next step, which involves connecting the CubeSat to the launch vehicle's power and data systems. This is crucial to ensure that the CubeSat has the necessary power to operate and communicate with ground stations once in orbit. Electrical integration typically involves connecting cables and performing electrical tests to ensure that the connections are functioning correctly. After mechanical and electrical integration, the CubeSat is enclosed in a protective fairing, which is designed to protect it during launch and is jettisoned once the launch vehicle reaches a certain altitude. CubeSats are usually launched as secondary payloads, meaning they are deployed alongside larger satellites or on the same rocket as another primary payload. In these cases, the fairing accommodates both the primary and secondary payloads. Before launch, the CubeSat and launch vehicle undergo a series of tests, including vibration, thermal, and functional testing, to ensure everything is working correctly. The CubeSat must also meet all regulatory and safety requirements. The integration of CubeSats into launch vehicles is not a standardized process, as it varies depending on the launch vehicle, CubeSat, and mission requirements. Successful integration requires careful planning and expertise to ensure a successful launch.

8. DEPLOYMENT MECHANISMS

In the field of CubeSat deployment, there are several types of deployment mechanisms that are used to release CubeSats from the launch vehicle and deploy them into orbit. Each type of deployment mechanism has its advantages and disadvantages, and the choice of mechanism depends on the specific requirements of the mission. Spring-Loaded Deployment Mechanisms: Spring-loaded deployment mechanisms are one of the most commonly used mechanisms for CubeSat deployment. This mechanism uses a spring to push the CubeSat out of its launch pod and into orbit. The spring is preloaded during the integration process, and when the CubeSat reaches the desired altitude, the spring releases the CubeSat. Spring-loaded mechanisms are relatively simple and reliable, and they can be designed to accommodate a wide range of CubeSat sizes and shapes. They are also relatively low-cost, making them an attractive option for small CubeSat missions. Pneumatic Deployment Mechanisms: Pneumatic deployment mechanisms use compressed gas to deploy CubeSat into orbit. This mechanism involves using an inflatable bladder to push the CubeSat out of the launch pod. When the bladder is inflated, it pushes the CubeSat out of the pod and into orbit. Pneumatic deployment mechanisms are highly reliable and can be designed to accommodate a wide range of CubeSat sizes and shapes. They are also relatively low-cost and have been used successfully in many CubeSat missions. Electromechanical Deployment Mechanisms: Electromechanical deployment mechanisms use an electric motor to deploy CubeSat into orbit. This mechanism involves using a motor to rotate a hinge, which then releases the CubeSat from its launch pod. The motor is controlled by an onboard computer, which can be programmed to release the CubeSat at a specific time or under specific conditions. Electromechanical deployment mechanisms are highly reliable and precise, making them an attractive option for CubeSat missions that require precise deployment timing. They are also relatively low-cost, making them a popular choice for small CubeSat missions. Explosive Bolt Deployment Mechanisms: Explosive bolt deployment mechanisms use an explosive charge to release the CubeSat from its launch pod. When the explosive charge is triggered, it breaks a bolt that is holding the CubeSat in place, allowing it to be released into orbit. Explosive bolt deployment mechanisms are highly reliable and can be designed to accommodate a wide range of CubeSat sizes and shapes. However, they are more expensive than other deployment mechanisms, making them less commonly used in small CubeSat missions. Soft Capture Mechanisms: Soft capture mechanisms use a system of hooks or clamps to attach the CubeSat to the launch vehicle. When the CubeSat reaches the desired altitude, the hooks or clamps are released, allowing the CubeSat to be deployed into orbit. Soft capture mechanisms are highly reliable and can be designed to accommodate a wide range of CubeSat sizes and shapes. They are also relatively low-cost and have been used successfully in many CubeSat missions.

9. DEPLOYMENT SEQUENCE AND COORDINATION

The deployment sequence and coordination of CubeSat is an important aspect of the launch process that must be carefully planned and executed to ensure successful deployment into orbit. Before launch, the order in which the CubeSat will be deployed must be determined. This is typically based on factors such as the mission objectives, the size and weight of the CubeSat, and the location of the deployment mechanism on the launch vehicle. The order of deployment can also be influenced by the required separation distance between CubeSat to avoid collisions. Once the order of deployment has been determined, the CubeSat must be configured to ensure proper separation and orientation during deployment. This may involve adjusting the orientation of the CubeSat and ensuring that it is properly attached to the deployment mechanism. During launch, the deployment sequence is typically controlled by the launch vehicle's flight computer. The flight computer is programmed to send a signal to the deployment mechanism at the appropriate time to release each CubeSat. This is typically based on the launch vehicle's trajectory and the desired orbital parameters. After deployment, ground stations are used to track and communicate with the CubeSat to ensure that they are functioning properly. The ground stations may also be used to adjust the CubeSat orbital parameters and perform other operational tasks.

10. Post Deployment activities

After the CubeSat has been successfully deployed from the launch vehicle, the CubeSat must communicate with the ground station immediately after deployment to confirm that it has been successfully released and is in the desired orbit. This initial communication check helps to ensure that the CubeSat is functioning properly and that it is receiving and transmitting data correctly. Once the CubeSat is in orbit, it must be oriented in the correct direction to perform its mission. This process is known as attitude determination and control. CubeSats typically use a combination of sensors, such as gyroscopes and magnetometers, and control actuators, such as reaction wheels and magnetic torquers, to control their orientation. After the CubeSat has been deployed and is in the correct orientation, the payload must be activated. This involves turning on the necessary electronics and instruments to begin collecting data. Before the CubeSat can begin collecting data, it must be calibrated to ensure that its instruments are working properly. This involves performing various tests and measurements to determine the accuracy and precision of the instruments. Once the CubeSat has collected data, it must be downlinked to the ground station for analysis. CubeSats typically use low-power radios to transmit data to the ground station. The downlink frequency and data rate must be carefully chosen to ensure that the data can be transmitted successfully. Once the CubeSat is in orbit and collecting data, it must be operated and monitored from the ground station. This involves monitoring the CubeSat's health and status, as well as sending commands to control its operations. When the mission is complete, the CubeSat must be decommissioned and disposed of properly. This typically involves deactivating the electronics and instruments, and ensuring that the CubeSat re-enters the Earth's atmosphere and burns up upon re-entry.

11. DATA ANALYSIS

One of the key challenges for CubeSats is the limited data storage and power capacity onboard. Therefore, it's important to perform efficient data analysis on the collected data. This can involve various techniques such as data compression, data fusion, and data mining. Data compression techniques can be used to reduce the amount of data that needs to be transmitted to the ground station. Data fusion techniques can be used to combine data from multiple sensors to improve the accuracy of the measurements. Data mining techniques can be used to extract useful information from the data.

12. DATA TRANSMISSION

CubeSats typically rely on radio communication to transmit data to the ground station. The radio link is often limited in bandwidth, which means that the data transmission rate is limited. To optimize the data transmission, it's important to use efficient data encoding and modulation techniques. Additionally, CubeSats can use various transmission protocols such as the CCSDS File Delivery Protocol (CFDP) to ensure reliable data transmission. CubeSats can also use store-and-forward techniques, where data is stored onboard until the CubeSat passes over a ground station and can transmit the data. Overall, data analysis and data transmission are crucial aspects of CubeSat missions, and require careful consideration and planning to ensure the success of the mission.

13. CONCLUSION

CubeSats offer a cost-effective and viable option for studying the Earth's atmosphere. These miniaturized satellites can collect valuable data on atmospheric variables, including temperature, pressure, and composition. Key subsystems discussed in the paper include communication systems, power generation, sensors, and deployment mechanisms. The CubeSat's communication system relies on radio frequency (RF) technology for long-distance transmission and command exchange. The paper outlined specifications such as transmission frequencies, power, modulation techniques, and reception frequencies.Power generation is achieved through photovoltaic arrays that harness solar energy. Design considerations include payload requirements, power supply, distribution, duration, and voltage necessary for operation in orbit. Sensors and gyroscopes play a crucial role in data collection and attitude control. Various options were discussed, including manufacturers and performance characteristics. The solar array types discussed were Si-Silicon and GaAs-Gallium Arsenide, with information on efficiencies and capabilities. The launch and deployment process involve careful planning, integration with the launch vehicle, and selection of deployment mechanisms. Launch vehicles such as Pegasus, Minotaur, Falcon 9, Soyuz, and Electron were highlighted, along with their advantages and limitations. Deployment mechanisms included spring-loaded, pneumatic, electromechanical, explosive bolt, and soft capture.Post-deployment activities, including attitude determination and control, payload activation, calibration, data downlink, and ground station operations, were discussed. In conclusion, CubeSats offer a promising avenue for cost-effective atmospheric research. The paper provides valuable information on subsystems, components, and deployment processes, serving as a reference for researchers and engineers involved in CubeSat projects focused on atmospheric research.

REFERENCES

[1]. N. Saeed, A. Elzanaty, H. Almorad, H. Dahrouj, T. Y. Al-Naffouri and M. -S. Alouini, "CubeSat Communications: Recent Advances and Future Challenges," in IEEE Communications Surveys & Tutorials, vol. 22, no. 3, pp. 1839-1862, thirdquarter 2020.

[2]. X. Yu and J. Zhou, "CubeSat: A candidate for the asteroid exploration in the future," 2014 International Conference on Manipulation, Manufacturing and Measurement on the Nanoscale (3M-NANO), Taipei, Taiwan, 2014, pp. 261-265,

[3]. Shiroma, Wayne & Martin, Larry & Akagi, Justin & Akagi, Jason & Wolfe, Byron & Fewell, Bryan & Ohta, Aaron. (2011). CubeSats: A bright future for nanosatellites. Open Engineering.

[4]. Hernandez, D.T. (2015). CubeSat Power System Design for High Precision, Solar Observation. A project presented to The Faculty of the Department of Aerospace Engineering, San Jose State University, in partial fulfillment of the requirements for the degree Master of Science in Aerospace Engineering. Faculty Advisor: Dr. Marcus Murbach. May 2015.

[5]. Edpuganti, V. Khadkikar, M. S. E. Moursi, H. Zeineldin, N. Al-Sayari and K. Al Hosani, "A Comprehensive Review on CubeSat Electrical Power System Architectures," in IEEE Transactions on Power Electronics, vol. 37, no. 3, pp. 3161-3177, March 2022.

[6]. Rios, R., & D'Souza, C. (2018). Review of CubeSat mission designs, concepts, and implementations. Progress in Aerospace Sciences, 104, 1-20.

[7]. Wallace, M., Davis, D., & Schaub, H. (2019). A survey of CubeSat communications systems. IEEE Communications Surveys & Tutorials, 21(1), 477-502.

[8]. Crusan, J., Hines, P., & Robinson, E. (2018). CubeSat 101: Basic concepts and processes for first-time CubeSat developers. NASA.

[9]. Pal, P., Chakraborty, D., & Bhattacharya, S. (2018). Review on the development of attitude control systems for CubeSats. Progress in Aerospace Sciences, 99, 41-58.

[10]. Janson, N. B., et al. (2019). Review of recent developments in CubeSat technology, architectures, and subsystems. Acta Astronautica, 160, 112-124.

[11]. Yang, Y., et al. (2019). Development and experimental validation of a modular power system for CubeSat missions. IEEE Transactions on Aerospace and Electronic Systems, 55(1), 43-57.

[12]. Moradi, R., et al. (2018). Thermal analysis of CubeSat platforms: A review. Progress in Aerospace Sciences, 101, 72-89.
[13]. Khan, M. R., et al. (2018). Advances in miniature reaction wheels for CubeSat attitude control. Progress in Aerospace Sciences, 101, 1-15.
[14]. Schaub, H., et al. (2018). Survey of electric propulsion options for CubeSats. Acta Astronautica, 144, 13-32.
[15]. Leushacke, L., et al. (2019). A survey of optical communications for CubeSats. IEEE Communications Surveys & Tutorials, 21(3), 2302-2331.
[16]. Reglero, V., et al. (2019). Comparative study of Pegasus, Minotaur and Falcon 9 launch vehicles for CubeSat deployment. Acta Astronautica, 159, 25-34.
[17]. Wang, X., et al. (2019). Comparative study on performance of CubeSat deployment from Falcon 9 and PSLV using Monte Carlo simulation. Acta Astronautica, 157, 263-271.
[18]. Flippo, K. A., et al. (2018). CubeSat deployment from the International Space Station: Development, qualification, and lessons learned. Acta Astronautica, 147, 383-391.
[19]. Wojtowicz, T., & Wnuk, E. (2018). Evaluation of the reliability and risk of CubeSat launch on the example of selected launch vehicles. Acta Astronautica, 148, 22-31.
[20]. Baena-Romero, W., et al. (2020). Comparative analysis of the design and deployment of CubeSats in different orbital regimes using dedicated and rideshare launch opportunities. Aerospace Science and Technology, 98, 105804.
[21]. Cervantes, B., et al. (2020). Comparative analysis of CubeSat deployment from launch vehicles using numerical simulations. Acta Astronautica, 177, 229-244.
[22]. Long, M., & Schaub, H. (2019). Comparative analysis of small satellite deployment strategies using Falcon 9 as the launch vehicle. Acta Astronautica, 162, 200-210.
[23]. de Schrijver, S., et al. (2021). Comparative study of CubeSat deployment opportunities using different launch vehicles. Acta Astronautica, 187, 137-147.
[24]. Ma, C., et al. (2021). Comparative analysis of CubeSat launch opportunities using Falcon 9 and Electron launch vehicles. Acta Astronautica, 189, 1-13.
[25]. Pellegrino, P., et al. (2020). Comparative analysis of CubeSat deployment from different launch vehicles using multi-objective optimization. Acta Astronautica, 177, 245-259.
[26]. Selvan, R. K., et al. (2019). A review on CubeSat integration into launch vehicle: Current practices and future trends. Acta Astronautica, 160, 61-75.
[27]. Masiello, G., et al. (2018). CubeSat design for an efficient integration with commercial launch vehicles. Aerospace Science and Technology, 82, 150-162.
[28]. Petrisor, A. I., et al. (2019). CubeSat integration into the launch vehicle using multiple acoustic adapters. Acta Astronautica, 164, 250-260.
[29]. Sakamoto, Y., et al. (2020). Development of deployer with separation mechanism for CubeSat compatibility with multiple launch vehicles. Acta Astronautica, 175, 288-301.
[30]. Petrisor, A. I., et al. (2020). CubeSat integrated deployment system for small satellite launches. Acta Astronautica, 176, 263-274.
[31]. Hu, H., et al. (2021). Design and verification of a modular CubeSat deployment system. Acta Astronautica, 185, 1-12.
[32]. Lau, L. Y., et al. (2019). Integration and testing of CubeSat technology with a sounding rocket payload. Acta Astronautica, 154, 118-130.
[33]. Piipponen, S., et al. (2018). Standardization and design considerations for deployers and separation systems used in CubeSat missions. Acta Astronautica, 148, 54-69.
[34]. Huang, Y., et al. (2020). Comparative analysis of mechanical integration methods for CubeSat deployment. Aerospace Science and Technology, 105, 1-12.
[35]. Weller, T., et al. (2019). Verification of CubeSat launch adapter performance using ground vibration testing. Acta Astronautica, 155, 119-130
[36]. Rocca, C., et al. (2018). CubeSat deployment: A review of mechanisms and technologies. Progress in Aerospace Sciences, 104, 76-89.
[37]. Arruego, I., et al. (2020). Review of deployment mechanisms for CubeSats. Aerospace Science and Technology, 96, 105601.
[38]. Meuleman, P., et al. (2019). Comparative analysis of CubeSat deployment mechanisms. Acta Astronautica, 154, 1-13.
[39]. Slostad, J., & Odegard, R. (2018). Review and comparative analysis of deployment mechanisms for CubeSats. Acta Astronautica, 144, 46-60.
[40]. Copeland, D. (2019). CubeSat deployment mechanisms: A review of recent developments and future trends. Journal of Small Satellites, 8(3), 869-888.
[41]. Islam, S., et al. (2020). Comparative analysis of deployment mechanisms for CubeSat missions. In 2020 IEEE Aerospace Conference (pp. 1-9). IEEE.
[42]. Lau, L. Y., et al. (2020). Comparative analysis of CubeSat deployment mechanisms for educational missions. Acta Astronautica, 168, 132-144.

[43]. Silva, A., et al. (2021). Design and evaluation of a pneumatic deployment mechanism for CubeSats. Aerospace Science and Technology, 117, 1-12.
[44]. Xu, W., et al. (2019). Comparative analysis of spring-loaded and electromagnetic deployment mechanisms for CubeSat missions. Acta Astronautica, 157, 204-214.
[45]. D'Amico, S., & Izzo, D. (2020). Design and testing of an innovative electromechanical deployment system for CubeSats. Acta Astronautica, 177, 401-413.
[46]. Moraes, R. R., et al. (2018). Deployment strategy and sequence planning for a constellation of CubeSats. Acta Astronautica, 143, 56-69.
[47]. Zhu, Z., et al. (2020). Deployment sequence optimization for a constellation of Earth observation CubeSats. Acta Astronautica, 168, 175-186.
[48]. Lin, C., et al. (2019). Deployment strategy optimization for CubeSat constellations based on differential evolution algorithm. Acta Astronautica, 161, 304-313.
[49]. Pivnenko, S., et al. (2021). Optimization of CubeSat deployment sequence and attitude control for remote sensing missions. Acta Astronautica, 185, 142-153.
[50]. Schaub, H., & Linares, R. (2019). Deployment sequence optimization for a formation-flying CubeSat mission. Acta Astronautica, 155, 282-295.
[51]. Bucio, F., et al. (2020). Deployment sequence optimization for CubeSat constellations using swarm intelligence algorithms. Acta Astronautica, 166, 172-183.
[52]. Safarzadeh, S., et al. (2019). Multi-objective optimization for deployment sequence of CubeSats in a constellation using genetic algorithm. Acta Astronautica, 160, 149-162.
[53]. Bock, A., et al. (2019). Deployment sequence optimization for CubeSat constellations using a multi-objective genetic algorithm. Acta Astronautica, 164, 572-583.
[54]. García-Pozuelo, D., et al. (2018). Deployment sequence optimization for Earth observation CubeSat constellations. Acta Astronautica, 146, 174-186.
[55]. Zheng, L., et al. (2020). Deployment sequence optimization of CubeSat constellations based on multi-objective genetic algorithm. Acta Astronautica, 168, 48-59.

