# CubeSats Survey: Capabilities and Applications with a Glance on the Iraqi Satellite Program Activities

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## Abstract

CubeSats started as educational tools and have evolved to a standard platform for technology demonstration and scientific instrumentation in about 10 years. Using Commercial-off-the-shelf (COTS) components and some miniaturization technologies led to many scientific value missions. Furthermore, advantages of reducing the cost and development time compared with larger satellites, and the possibility of launching a large number of CubeSats with a single rocket launch, have led to new mission architectures consisting of very large constellations or clusters of CubeSats. These new architectures combine between the temporal resolution of Geostationary Earth Orbit (GEO) missions and the spatial resolution of Low Earth Orbit (LEO) missions, thus breaking a traditional trade-off in earth observation mission design. This paper shows the current capabilities of CubeSats in the field of Earth observation missions, also; it introduces the applications, capabilities and limitations of CubeSats in various fields during the past, present and near future with a glance on the experience of Iraq in small cubic satellites .

**Keywords**: CubeSats Applications, Conestelation and Earth Observation

# مسح الأقمار الصناعية المكعبة: الامكانيات والتطبيقات مع لمحة عن نشاطات العراق في برنامج الأقمار الصناعية

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## الخلاصـــة

في اقل من عشر سنوات، تطورت الاقمار الصناعية المكعبة من مجرد كونها ادوات تعليمية الى منصات قياسية لبرهنة التكنولوجيا وتفعيل العلوم. ان استخدام مبدا "مكونات القطع الجاهزة الموجودة على الرف" وما استطاعت اليه بعض التكنولوجيا من الوصول اليه من حيث امكانية تصغير احجام المكونات المادية، قد ادى الى وجود حالات متعددة لمهمة القمر الصناعي وبقيمة علمية موثوقة. علاوة عما سبق، فان التحسين في كلفة التطوير وزمن التطوير نسبة الى الاقمار الصناعية الكبيرة قد ادى الى توفير امكانية حمل عدد كبير من الاقمار الصناعية الصغيرة المكعبة ضمن الصاروخ الواحد واعطى زخماً لوجود مهمات تعتمد مبدا "التجمعات" او "الكوكبة" من الاقمار الصناعية الصغيرة. ان تلك المعماريات توعد بدمج مهام دقة المدار الارضي الثابت مع مهام الدقة المكانية للمدار الارضي الواطئ، مما يؤدي الى نشوء اتجاه جديد في تصاميم المهمة المخصصة لمراقبة الارض. توضح هذه الورقة القدرات الحالية للأقمار المكعبة في مجال مهام مراقبة الأرض، أيضًا، وهي تقدم تطبيقات وقدرات وقيود الاقمار المكعبة في مختلف المجالات خلال الماضي والحاضر والمستقبل القريب مع لمحة عن تجربة العراق في نشاط برنامج الأقمار الصناعية.

**الكلمات المفتاحية**: تطبيقات الاقمار الصناعية الصغيرة المكعبة، كوكبة من الأقمار الصناعية ومراقبة الارض.

## Introduction

Space activity started in 1957 with the launch of Sputnik 1 weighing 80 Kg, can be considered as the beginning of new generation of technology. A series of space missions followed sputnik 1 and every mission costs a relevant high budget. The rapid development in technology and, the need for low-cost limitation produced a new generation of small satellites. The small satellites, like Nano and Pico, provide cheaper alternatives to bigger satellites by reducing the requirements. The CubeSat project started in 1999 at Stanford University, Space System development Lab. Another goal was for educational purpose to give the students a chance to design satellite and get experience in this field (Addaim, *et a*l., 2010). Professor Jordi Puig-Suari at California Poly technique (Cal Poly) State University and Professor Bob Twiggs at Stanford University were created the concept of the (CubeSat Standard). The dimension of standard 1U is 10x10x10 $cm^3$ and its standard weight is 1.33kg. From power consumption point of view, it is recommended to keep the 1U to within a few Watts with maximum usable data rate up to 1Mbps. The basic budget for 1U satellite in terms of its (Design, Assembly, Test and Launch) is 50000 – 200000 $ (Puig-Suari, *et al*., 2001).

This research shows the current capabilities of CubeSats in the field of Earth observation missions. Also, the research introduces the applications, capabilities and limitations of CubeSats in various fields in the past, present and near future focusing on earth observations applications. The CubeSats constellation concepts and their applications were also studied.

## Materials and Methods

The CubeSat consists of two basic parts, Payload determined by the satellite mission and Platform bus. The platform is made up of several subsystems. Figure (1) shows an example of 1U CubeSat chassis and Figure (2) shows an example of the CubeSat subsystems.

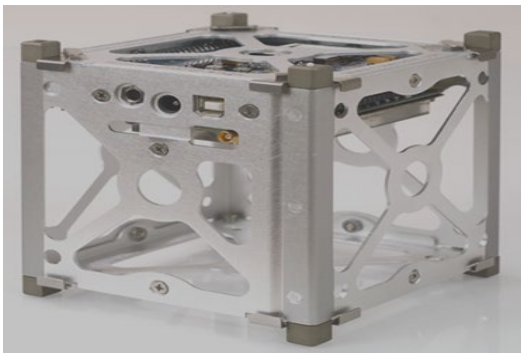
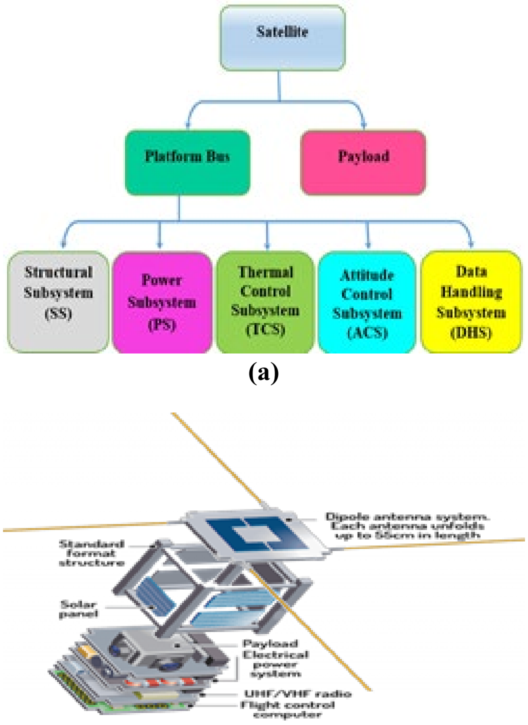


**Figure (1) Chassis of 1U CubeSat**



**(a)**

**(b)**

**Figure (2) CubeSat Subsystem (a) Typical (b) Assembled**

The main target for any CubeSat program is focusing towards education or capability demonstration while the secondary objective is related to science or to experimental verification. In addition, in some cases, researchers have been using constellations of CubeSats for continuous time tasks. Due to the above facts and limitations, the CubeSats should give a reasonable answer to the questions (Puig-Suari, *et al*., 2001):

1- Can CubeSats do world-class Earth science?

2- What missions can CubeSats do rather than education and student's experiments in universities?

3- What are the capabilities of CubeSats that have already been demonstrated? And what are the capabilities that are currently under development?

4- What are the limitations that prevent high performance of CubeSats in Earth Science? And which scientific applications are most affected by these limitations.

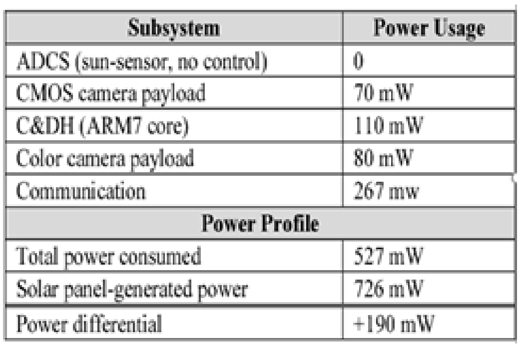
## Results and Discussion

The rapid revolutionary in micro/ nanosatellites with CubeSat concept has increased due to the development of miniaturized as well as lightweight electronic components and advanced manufacturing technologies subjected to limitations in terms of various configuration, power consumption, satellite mission, cost and size. As a result, many facts related to CubeSat technology can be presented in the following:

### A- Power Consumption

Since the CubeSats are quickly developing deployable satellites, this will restrict it to be simple, low-cost and efficient compromise between the solar panels' size, available power budget and stored energy limiting the functionality and data processing capabilities. As a good estimation, the available power for 1U CubeSat would be 1W (Marinan, *et al.*, 2013). Table (1) shows the power profile for the CubeSat. Therefore, high energy payloads such as imaging (Radar or Scatter) requires much power levels (Marinan, *et al.*, 2013).

**Table (1) Subsystem Power Profile**



| Subsystem | Power Usage |
|---|---|
| ADCS (sun-sensor, no control) | 0 |
| CMOS camera payload | 70 mW |
| C&DH (ARM7 core) | 110 mW |
| Color camera payload | 80 mW |
| Communication | 267 mw |
| **Power Profile** | |
| Total power consumed | 527 mW |
| Solar panel-generated power | 726 mW |
| Power differential | +190 mW |

### B- Geolocation

Over the past decade, RF-sensing satellite systems have been developed and deployed to sense a larger swath width of the Earth at any one time, subject to frequency and ground emitter RF power constraints. The maritime Automatic Identification System (AIS) data are used to track ships and to derive meteorological information. This becomes important in the case of multiple CubeSats. In which, the ability to precisely align the individual measurements may heavily affect the quality of the out coming data (Brauun, *et al.*, 2001).

Table (2) shows a practical case between the CubeSat altitude verses attitude uncertainty/control.

**Table (2) Cube-satellite Altitude with Attitude Uncertainty and Control**

| Case | Remark |
|---|---|
| Orbit Altitude | 500 km |
| Attitude determination uncertainty of 2°. | Spatial uncertainty on ground is 17.5 km |
| Future accuracies for estimated to 0.02°. | Uncertainty on ground is 175 m. |
| With 0.5° attitude control accuracy. | Spatial uncertainty on ground is 4.5 km |

## C- Communications

CubeSats are low-cost and small satellites which were initially designed by students during educational process, but are now launched to conduct space research and for commercial use (Selva, *et al.*, 2011).

Downlink powers for typical CubeSats range from 0.1W to 1W with data rate that has a maximum value of 512 kbps which can be considered as a limiting factor that can be evaluated by the available link power budget, rather than by the available electronics on board the satellite. Table (3) below shows the limitations between the imaging types versus the image size and access duration (Selva, *et al.*, 2011).

**Table (3) limitations between the Imaging Type Versus the Image Size and Access Duration.**

| Item | VGA Camera | Hyper Spectral Imager |
|---|---|---|
| Image Size | 2.34 Mbits | 256 Mbits |
| Average Access Duration (5min) | A Data Rate of 0.5M bps Yields 64 Images | 0.58 Cubes for the Hyper Spectral Sensor |

To improve the limited downlink capabilities, the ground station networking must be improved to achieve longer accumulated access time per orbit and therefore increased download capabilities. In addition, these efforts have only limited capabilities in increasing the total amount of data down linked in the order of one magnitude and come at the price of reduced scientific duty cycle (Brauun, *et al.*, 2001).

## D-Avionics and On-board Data Handling

Although CubeSats are subjected to space radiation, moderate or high data processing capabilities can be reached by using the COTS microcontrollers manufactured from space qualified components (Selva, *et al.*, 2011). The satellite OBC (On Board Computer) is a computer that processes the various information and the data that is transmitted to the satellite, or the information and the data that is received from the payload or other onboard subsystems. Of course, the OBC controls the payload and the spacecraft performs the following operations (Selva, *et al.*, 2011).

1- Telecommand (TC)

Receives, decodes, validates and routes the commands data to other Satellite subsystems or to the payload.

2-Telemetry (TM)

Gathers, processes, stores and transmits health mission data (Payload data) and spacecraft telemetry data to the Ground Station.

The OBC should have; high functional integration, reliability, low expenses with maximized fault-tolerance. Since the physical upgrade of satellite electronics is impossible after launch, there is a need for self-repair and upgrade capabilities. The Processor is a general-purpose chip that is used to create a multi-function computer or device requiring multiple chips to handle various tasks (Selva, *et al.*, 2011).

The Microcontrollers are typically designed by using the Complementary Metal Oxide Semiconductor (CMOS) technology and therefore, less power is required during fabrication process. The most commercially available controllers for OBC purposes- can use the suitable one from (8–33) MHz and (16–32) bit category. Work memory (RAM) is used for runtime storage of the executed OBC functions.

Two types of RAMS are available; Static RAM (SRAM) and Dynamic RAM (DRAM). In most cases DRAM is Synchronous: in such cases it is called SDRAM, which differs from DRAM because DRAM needs to be periodically refreshed requiring extra circuitry, but it offers higher memory. CubeSats have an on-board memory starting from 32 kB up to 8 MB, and when using additional flash memory up to 8GB (Brauun, *et al.*, 2001).

### E-Attitude Determination and Control Determination

By Using miniaturized sun sensors in combination with magnetometers an accuracy of less than 2º can be achieved for attitude determination. There is a little dependency on star trackers because of their low performance (Farahat, 2013).

### F- Control

Using passive and/or active magnetic control a pointing accuracy better than 5º in attitude control can be achieved and when using reaction wheels the achieved overall control accuracies are better than 2º. Accuracies in order of 1º and below are readily available for attitude determination and control module (Farahat, 2013).

### G- Mass and Dimensions

For a 1U CubeSat, the total mass must be below 1.33 kg and the dimension is $10 \times 10 \times 10$ cm$^3$. 1U, 2U and 3U configurations using 1, 2, and 3 CubeSat units have already been launched, 6U and bigger configurations have been proposed. The most limiting constraints on the payload are the dimension constraints because the payload performance depends strongly on its dimension (10 cm), which corresponds to 3 GHz (C-band).

### H- Thermal Control

The temperatures of the CubeSats components must be regulated and kept within a certain range in order to work in optimal function as well as survival. A variety of techniques are used to regulate the temperatures throughout a spacecraft. Miniaturized thermal management systems were required to ensure thermal control requirements (Gilmore, 2002). Heat sinks and optical tape on the outer structure are used to perform the Passive thermal control of CubeSats in order to keep the structure temperature approximately between -15 °C to 40 °C for sun synchronous orbits. The effectiveness of passive cooling by radiators is limited in which the radiated power is linearly dependent on the surface area facing cold space.

## Applications of CubeSats

Modern life applications such as TV-Internet set, broadcasting, Internet, radar and climate change monitoring are highly dependent on the revolution of the Satellite technology. CubeSat's applications have been distinguished to be as educational platform, experimental tool, store and forward communications, sensing sensors and in space access (Selva, *et al.*, 2011). In addition to the previous applications, CubeSats are currently still being improved and adapted through the using of the (COTS) for using more specific and advanced applications (Gilmore, 2002).

### A- Earth and Climate Observation

The United States of America has been adopted the meteorological satellite since 1960s to monitor the weather and climate of the Earth, especially clouds. Other phenomenon like: fires, effects of pollution, auroras, sand and dust storms, snow cover, ice mapping, boundaries of ocean currents, energy flows, etc., are other types of environmental information collected using such satellites

(Munteanu, 2008). For better understanding of the weather, natural disasters, pollutions, and water, it is required to measure earth characteristics by means of the earth observation techniques (Munteanu, 2009). An earth observation satellite within its orbit will scan the image of the earth surface and map the focused area, allowing to efficiently measure the soil characteristics using radar technique (Marinan, *et al*., 2013). The need for picosatellites such as CubeSats was quickly realized with a dedicated mission such as Carbon Dioxide measurements and GNSS radio occultation plus the Hyperspectral Microwave Atmospheric Sounding measurements have been taken from (MICROMAS) CubeSat and sharing the results involving clouds and aerosol by NASA's Cloud CubeSat (Selva, *et al*, 2012).

### B- Space Weather Forecasting

CubeSats cluster can play an important role in application called (Space Weather Forecasting), to provide an initial warning of solar system storms. The concept is to forecast the weather of the solar system by establishing a CubeSat with a specific payload and high antenna performance to transmit the data with a high rate to the earth. The rest of the CubeSats will use low performance antennas for communication between each satellite within the earth's orbit (Munteanu, 2008).

### C- Space Research

A new approach called "Nanosatellite Tracking of Ships" program (NTS) using CubeSat is intended to test the satellite in a real space environment by ensuring communication between the receiving part of the Automatic Identification System (AIS) and AIS transmitting part in LEO within a range of 100 Km. Based on this technique, the following tasks can be performed:

- Providing the required awareness of global marine traffic by the collection of the AIS signals in the LEO range.
- Surrounding radio frequency (RF) measurement with noise level identification.
- Platforming for mission qualification.

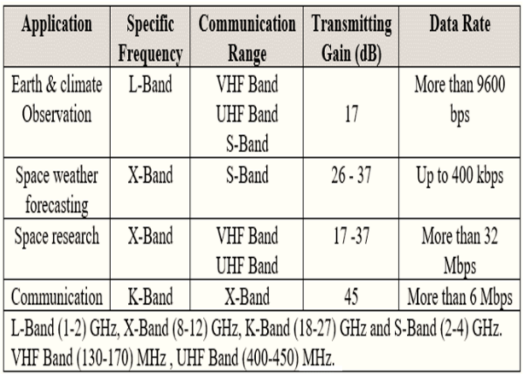
### D- Communications

The most important application of picosatellites is in the communication field. Correct link power budget is highly required to ensure efficient communication between the space earth or space/space communication links (Arvizu, *et al*., 2015). For CubeSats communications, the operating frequency is in the S-band (2.45 GHz) and the signal reception can be accomplished by small antenna receivers via the smaller antennas using compliant to the CubeSat structure (Arvizu, *et al*., 2015). As a promising application, scientists have been studying a new field called "Quantum Communications" to show the possibility of optical communication systems in space between satellite and known earth station (Bentum, *et al*., 2009) The satellite communicates by transmitting a laser in the optical field frequency range to a base station on earth with a Line of Sight (LOS) enabling the link establishment (Bentum, *et al*., 2009).

Thus, tracking and acquisition system should be included in the CubeSats for position determination.

IRIDIUM satellite constellations are an example of communication system that uses frequencies (22.55 GHz to 23.55 GHz) to enable stable route traffic network. The IRIDIUM system utilizes a combination of (FDMA/TDMA) to form a multiplexed signal that is most efficient use of limited spectrum (Shahriar, 2006). As a current trend, the Chinese government for Aerospace Science and Industry Corporation has been declared precision-navigation user terminals in China called "Beidou" with full constellation of 35 satellites will be fitted with chipsets receiving satellite signals not only from China's Beidou constellation, but will receive GPS (for USA), Glonass (for Ruusian) and Galileo (for European Commission systems) (BeiDou, 2012). The BeiDou signals, based on Code Division Multiple Access (CDMA) technology can support three levels of services as: Public service, Licensed service and Restricted service. Table (4) summarizes the applications profile.

**Table (4) Application Profile**



| Application | Specific Frequency | Communication Range | Transmitting Gain (dB) | Data Rate |
|---|---|---|---|---|
| Earth & climate Observation | L-Band | VHF Band<br>UHF Band<br>S-Band | 17 | More than 9600 bps |
| Space weather forecasting | X-Band | S-Band | 26 - 37 | Up to 400 kbps |
| Space research | X-Band | VHF Band<br>UHF Band | 17 -37 | More than 32 Mbps |
| Communication | K-Band | X-Band | 45 | More than 6 Mbps |
| L-Band (1-2) GHz, X-Band (8-12) GHz, K-Band (18-27) GHz and S-Band (2-4) GHz.<br>VHF Band (130-170) MHz , UHF Band (400-450) MHz. | | | | |

## Iraq Space Program; Past and Future Aspects

Iraq has started the space technology program in the year 1989 to build a small satellite depending on the experts of Iraqi engineers and the international standards in this field. The result was building and testing two flight models of this satellite during the period (1989-1990) which was called Al-Tair as shown in Figure (3). The satellite was not launched and the project was terminated because of the Gulf second war in 1991.

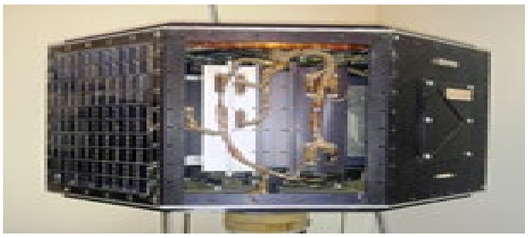
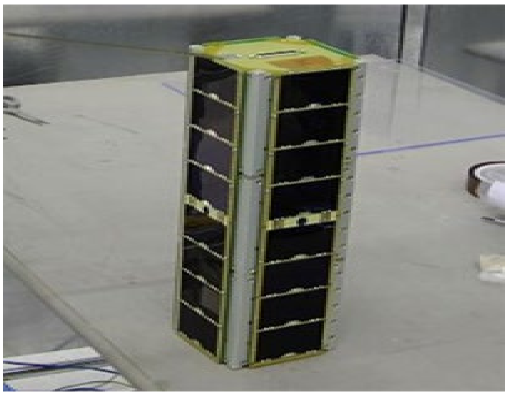
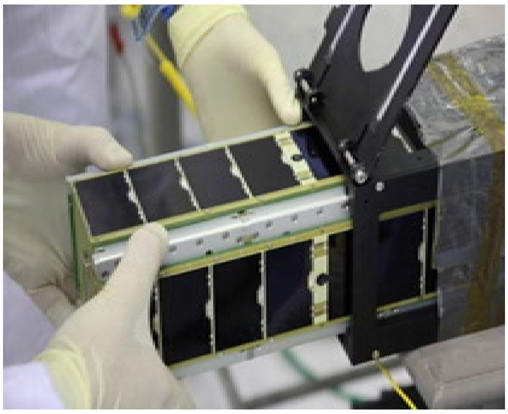


**Figure (3) Al -Tair Satellite**

During (1991-2003), Iraq was under the U.N. embargo sanctions and the emphasis was towards building and developing the complete satellite subsystems individually, in order to keep the staff in touch with this field. After the year 2003, capacity building programs were started throughout contacting National Space Agencies and also through the participation in the national conferences and workshops like KARI, ISNET, BSTI, SUPARCO and UNOOSA. Finally, a memorandum of understanding was signed with the Italian Government in which Iraqi students were sent in a scholarship in the field of Aerospace Engineering. The result was building a 3U CubeSat that was launched on June 19th 2014 @ 19:11 UTC and called "TIGRISAT" as shown in Figure (4), in which the main mission is an educational platform and to study the dust phenomenon over Iraq.



**(a) 3U CubeSat**



**(b) 3U CubeSat in a P-POD**

**Figure (4) Tigrisat CubeSat**

## Examples of Lunched CubeSats

Table (5) shows a summary of the launched CubeSats around the world through the period (2003 – 2014).

## Conclusions

1- CubeSats started as an excellent platform for education and technology demonstration. They can be much more than that: they can be used for Earth science program.

2- Only a small number of CubeSats perform or would perform Earth observation measurements other than space weather. These missions carry optical cameras, photometers, GNSS receivers for the occultation measurements and the millimeter-wave sounders.

3- The reduced mass, power and data rate are the main reasons for the small numbers of missions, and the lack of variety in their payloads. Many of the currently used Earth observation payload technologies like Lidar, High-Resolution Optical Imagers and Hyperspectral Imagers are simply not compatible with these constraints.

4- Technologies compatible with these stringent constraints can be used in CubeSat missions like spectrometers with limited imaging capability, precise accelerometers, and broad band radiometers. These technologies can be used in a variety of measurements including ocean color, ocean mass distribution, glacier mass distribution, vegetation state, and Earth radiation budget amongst others.

5- Constellations of CubeSats added high value when used for the Earth Observing System-of-Systems (EOSS). This is due to:

First, such a system could take care of a fraction of the requirements for the EOSS, thus reducing the burden on larger satellites, and allowing them to focus on the highest performance missions, which CubeSats are incapable of.

Second, it would help to close some of the expected data gaps in the key measurements for example the (Gravity Measurements).

Third, they would provide unprecedented data products with very high temporal resolution and relatively high spatial resolution, which could potentially create new opportunities for science. Such measurements could be combined with data products from higher performance instruments using disaggregation schemes.

6- In spite of the discrepancy of the Iraqi Satellite Program during the period (1989 – 2013), due to the external circumstance of the second Gulf war and the embargos upon Iraq; such space program struggles to be kept motivated towards a target of an adopted national policy and their applications.

**Table (5) Examples of Launched CubeSats**

| Name | Launch | Date | Type / Organization Mission |
|---|---|---|---|
| QuakeSat | 2003 | 3U Stanford University | Earthquake Detection |
| CUTE-1 (Oscar 55) | 2003 | 1U Tokyo Institute of Technology | Amateur Radio |
| GeneSat-1 | 2006 | 3U NASA/Santa Clara University | Biological Research<br>Technology Demonstration |
| CSTB1 | 2007 | 1U Boeing | Technology Experiment and Demonstration |
| Liberated-1 | 2007 | 1U<br>Sergio Arboleda University | CMOS Camera |
| Cute-1.7 | 2008 | 2U Tokyo Institute of Technology | Separation system Demonstration and Avalanche Photo Diode Sensor Experiment |
| COM PASS-1 | 2008 | 1U FH Aachen | Demonstration of COTS and Taking Photos |
| AAU SAT-2 | 2008 | 1U University of Aalborg, Denmark | ADCS System and Gamma Ray Detector |
| CanX-2 | 2008 | 3U University of Toronto, Canada | Technology Demonstration for Formation Flying |
| SEEDS-2 | 2008 | 1U<br>Nihon University, Japan | Amateur Radio Experiments and Preprogrammed Message Sending |
| PharmaSat | 2009 | 3U NASA/Santa Clara University | Measured the Effect of Antifungal Countermeasurs on Yeast Strains in Microgravity |
| Swiss Cube-1 | 2009 | 1U Ecole Polytechnique FederaldeLausane | Upper Atmospheric Science |
| BeeSat-1 | 2009 | 1U Berlin Institute of Technology | Reaction Wheel Technology Qualification |
| UWE | 2009 | 1U Universitat Wurzburg | ADCS technology demonstration |
| ITUpSAT1 | 2009 | 1U Istanbul Technical University | Imagery, technology |
| NanoSail-D2 | 2010 | 3U NASA Ames Research Center | Technology |
| QbX1 | 2010 | 3U Naval Research Laboratory | Technology demonstration |
| SMDC-ONE | 2010 | 3U US Army SMDC | Communication |
| Explorer-1 | 2011 | 1U Montana Space Grant Consortium | Magnetospheric Research |
| DICE-1 | 2011 | 1.5U Space Dynamics Laboratory | Ionospheric Research |
| RAX-2 | 2011 | 3U University of Michigan | Ionospheric Research |
| Goliat | 2012 | 1U University of Bucharest Romania | Earth Imaging and Space Environment Measuring |
| Raiko | 2012 | 2U Tohoku University/Wakayama University | Ku-Band Communication, Prototype Star Tracker and Deployable Membrane Technology Demonstration |
| CSSWE | 2012 | 3U University of Colorado Boulder/ LASP | Space Weather Research |
| AAUSAT3 | 2013 | 1U University of Aalborg, Denmark | Double AIS System for Tracking Ships in Arctic Regions |
| BeeSat-2 | 2013 | 1U Berlin Institute of Technology | Reaction Wheel Technology Qualification |
| Vermont Lunar | 2013 | 1U Vermont Technical College | Testing Navigation Components to be Used in a Follow up 3U Ion Drive CubeSat to the Moon |
| ESTCube-1 | 2013 | 1U University of Tartu | Space Test of the Electric Solar Wind Sail |
| SkyCube | 2014 | 1U Southern Stars LLC | Crowdfunding, Messaging, Imaging, Balloon Inflation |
| UAPSAT | 2014 | 1U University Alas Peruanas | Technology Demonstration |

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