

CubeSat Survey

Miranda Straub, Ryan Watson, John A. Christian, and Jason N. Gross

Department of Mechanical and Aerospace Engineering
West Virginia University
Morgantown, WV 26505

September 15, 2014

Abstract

In recent years, there has been a significant migration towards small satellite missions due to their reduced cost and development time. Specifically, CubeSats have become increasingly popular not only in university environments, but in government and private industries as well. The standardization of these 10 cm CubeSats has also allowed for rideshare opportunities, thus finding a launch service provider is much simpler, allowing for more frequent access to space. CubeSat standards also allow for commercial off the shelf (COTS) hardware components to be made available at reasonable prices, however there is no standard software as of 2014. NASA Independent Verification and Validation (IV&V) facility has requested a survey of CubeSats to provide additional insight into all previous CubeSat missions. This information will assist them in developing a standard software simulator to be used for all future IV&V CubeSat missions as well as missions at NASA Goddard Space Flight Center (GSFC).

1 Introduction

The CubeSat Project, developed in 1999 by Professor Jordi Puig-Suari of California Polytechnic State University (Cal Poly), San Luis Obispo and Professor Bob Twiggs of Stanford University's Space Systems Development Laboratory (SSDL), was an initial attempt at standardizing design parameters for small satellites in order to reduce cost and development time. As a result, these standards have allowed for more frequent launches and therefore easier access to space due to the low-budget nature of CubeSats [1]. The CubeSat Project outlines the standards required for CubeSat development while describing specific parameters (i.e. dimensions, mass, deployment mechanisms, etc.) that must be met for the spacecraft to qualify as a CubeSat. More general information about CubeSats may be found at cubesat.org.

When considering dimensions, a 1U (1 unit) CubeSat must have the dimensions of 10cm x 10cm x 10cm. Alternate configurations exist and include 2U and 3U CubeSats with dimensions of 10cm x 10cm x 20cm and 10cm x 10cm x 30cm, respectively (see Figure 1). In addition to dimensions, mass limitations prohibit CubeSats from exceeding 1.3 kg per unit (U), meaning a 2U CubeSat must not exceed 2.6 kg while a 3U must not exceed 4.0 kg. These standards also limit the amount of power available for use on the spacecraft. The specified dimensions pose limitations regarding the surface area available for solar panels. Previous studies have shown that the average power of a CubeSat can vary from 1W (1U) and 5W (3U). However, assuming the spacecraft still meets the mass requirements, deployable solar panels can be used to significantly increase the amount of available power (i.e. a 3U CubeSat with deployable panels can have up to 20W of available power) [2].

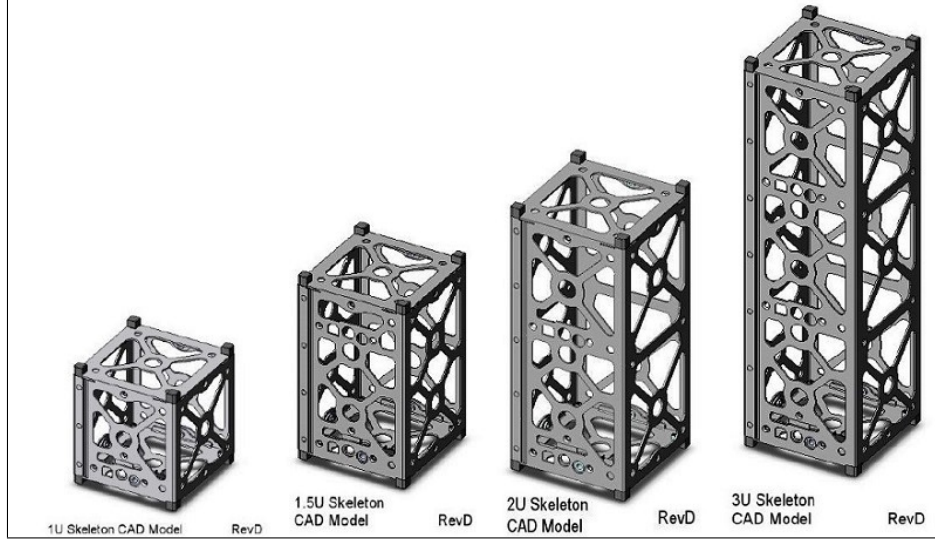


Figure 1: Example of CubeSat Configurations[3]

CubeSats that meet dimension and mass requirements can be launched from the Poly Picosatellite Orbital Deployer (P-POD) developed by Cal Poly. The P-POD serves as a standardized deployment system for up to three 1U CubeSats or any equivalent combination. Any CubeSat being deployed from a P-POD must adhere to additional specific guidelines in the CubeSat Design Specifications document in order to ensure compatibility for a successful deployment. Some recently proposed experiments, however, have been designed for 6U CubeSat structures, resulting in the need for an alternative deployer. Fortunately, NASA Wallops, NASA Ames, as well as other institutions have come up with designs for 6U deployers, all of which have been tested and have received a TRL of at least 6 [4].

The standards developed by Cal Poly have resulted in a significant increase in the number of small satellite missions launched over the past few years [5]. This is partially due to the development of commercial off-the-shelf (COTS) components specifically designed to meet all CubeSat requirements. Because of this, CubeSats have become relatively inexpensive, making them ideal educational tools in university and classroom settings. With the development of COTS components, there are a variety of options for various processors and operating systems; however, these options may not always meet the criteria required for various missions. It is for this reason that NASA IV&V has been asked to develop a portable, pure software build-and-test system that will provide the capability to develop, debug, and test software on a standard personal computer with no specialized hardware. Once this is developed, it is expected to be used in collaboration with NASA GSFC's SpaceCube development and testing.

2 Methodology

To determine possible options for a standardized NASA IV&V software, a comprehensive survey was conducted on past, present, and future CubeSat missions. This survey initially consisted of all CubeSat missions the research team could find - totalling slightly over 250 missions. For this particular report, it was decided that the focus would be on domestic missions which narrowed the search to approximately 150 missions, some of which had been launched while others were still only proposed concepts. This list was consolidated once more to focus on already launched missions as

well as missions with launch services confirmed in upcoming years. As a result, a comprehensive list of approximately 115 CubeSats has been developed.

To gather information, the first step involved creating a list of desired mission details. This information can be categorized as shown in Table 1. A first pass of obtaining data was accomplished by thoroughly searching the internet, although a significant amount of data was left incomplete. As a second pass, the project managers of each mission were emailed and asked specifically for information regarding data of potential interest to NASA IV&V as well as any other applicable information or further references. This helped fill in a significant amount of missing data which was used to create a spreadsheet that will be provided electronically upon delivery of this report and includes all data collected in the categories described in Table 1.

It should be noted that despite all efforts made in this project, the results of this survey only provide estimates used to identify trends in the presented data. For example, many of the surveyed missions were conducted by universities with limited budgets while others were sponsored by private companies or government agencies with higher budgets. This should be considered when analyzing numerical data obtained from this survey and will hopefully be made prominent through the discussion of results.

Table 1: Summary of Data Collected for CubeSat Survey

Mission Information	Launch Information	IV&V Information
Name of Satellite	Launch Date	Processor
Mission Objective	Launch Vehicle/Mission	Orbit
Sponsor	Mission Status	Uplink/Downlink
Manufacturer	Deployer	Attitude Determination
Domestic	Program	Attitude Control
Size	Orbit Parameters	Orbit Determination
Mass		Miscellaneous

3 Results of Survey & Discussion

3.1 Analysis of CubeSat Market and Survey Sample Set

A market assessment conducted by SpaceWorks Enterprises, Inc. in 2014 showed that of the nanosatellites launched between 2009 and 2013, 47% can be categorized as 1U CubeSats [5]. Although not enough information is given to determine how many 2U and 3U CubeSats have been launched, there seems to be a significant trend towards 3U CubeSat missions based on the information in Figure 2. These results show the increase in overall CubeSat missions and gives reason to believe this trend will continue in the near future.

Figure 3 shows the total number of U.S. CubeSats launched per year, divided by class (i.e. private, government, university, military, etc.). From this graph, it is evident that a majority of launches have been for university missions and educational purposes; however there has been a significant increase seen in government missions as well as privately funded missions.

Since the collected data providing processor information does not encapsulate the total CubeSat data set, it is important to point out that data may be skewed. It was believed that a majority of collected data came from university missions due to the missions being largely educational with project managers willing to provide information to other organizations. Military and government missions are more likely to be less available due to various restrictions which also would cause

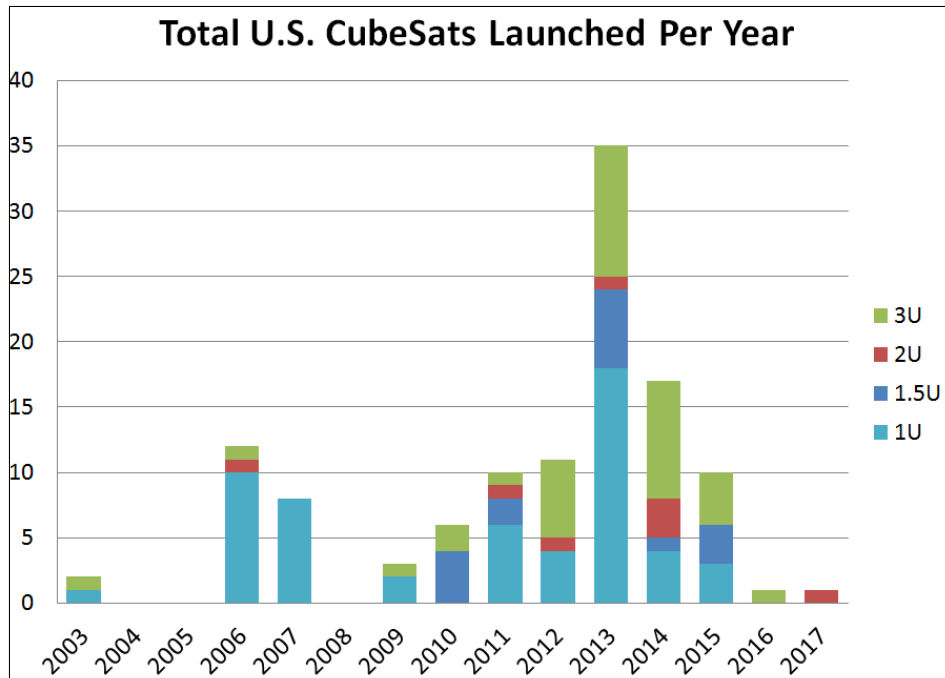


Figure 2: Results of survey showing the size and number of CubeSats launched per year as of August 2014 (based on 116 CubeSats with applicable data)

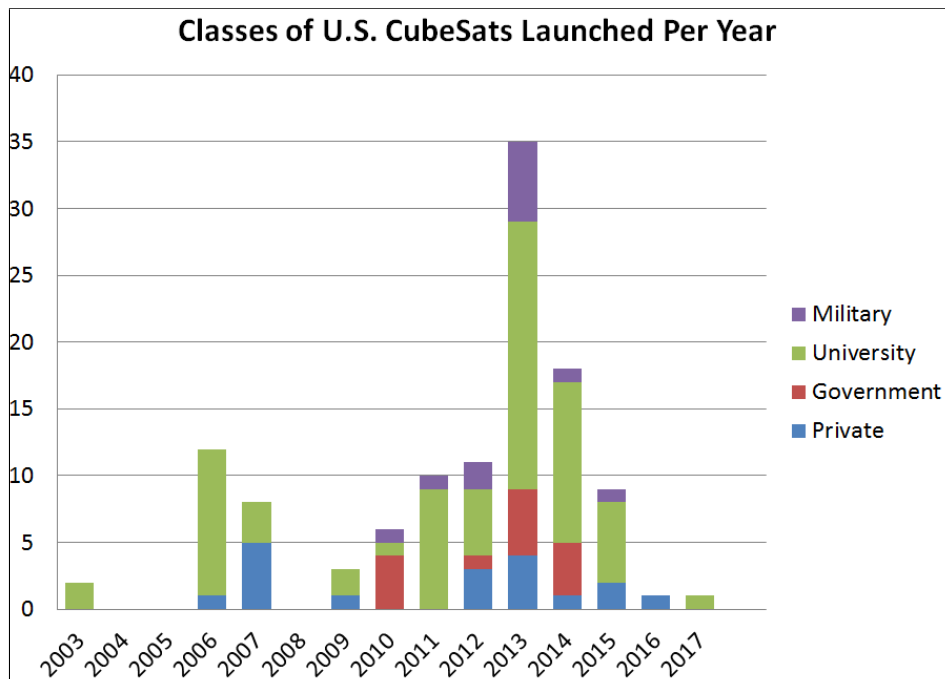


Figure 3: Results of survey showing the number of U.S. CubeSats launched per year, divided by class, as of August 2014 (based on 116 CubeSats with applicable data)

results to encompass mostly university missions. However, upon further investigation, it was found that the sampled data set was similar to that total data set as seen in Figures 4 and 5.

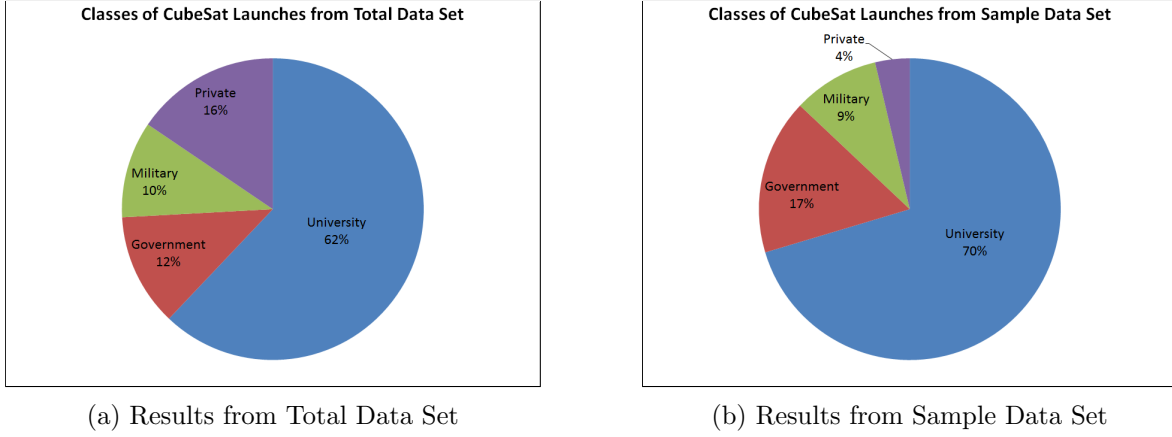


Figure 4: Comparison of CubeSat class percentages based on data from all information collected and the sample set in which processor information was known.

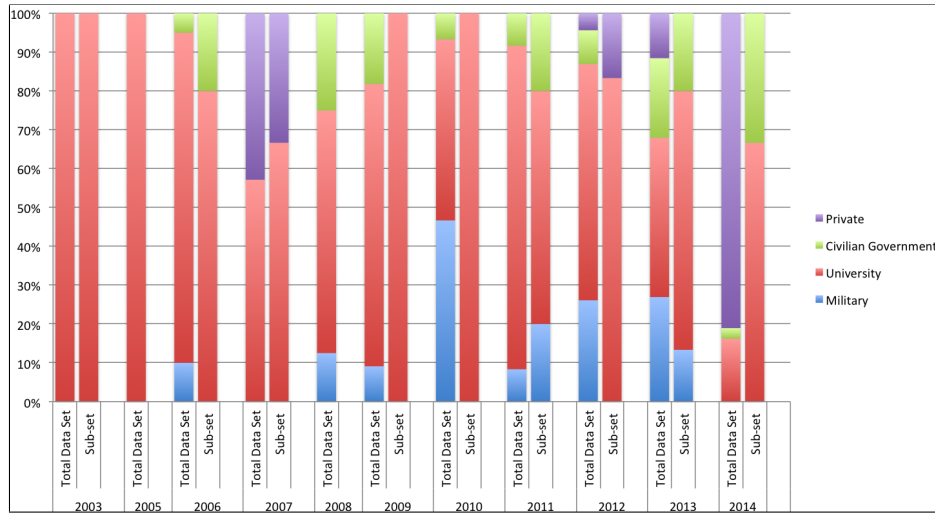


Figure 5: Bar graph visualization comparing classes from total data set and sampled data set

3.2 Flight Processors

For this report, it is assumed that processors and operating systems are of most importance to NASA IV&V. This will provide insight into which processors are most popular within the CubeSat community and will allow IV&V to develop approaches with the widest possible impact. Based on the 55 missions where processor data was attainable, almost 40% of these missions utilized PIC processors. Of these processors, 52% used the PIC18. These results are summarized in Figure 6. Upon further investigation, it was concluded that 90% of the PIC18 processors were used in 1U missions. Table 4 in the Appendix shows an abbreviated list of CubeSat missions sorted by size to show the trend of processors used. It is also important to note that Pumpkin currently provides Pluggable Processor Modules (PPM) available with their CubeSat Kit and is capable of incorporating the following processors into the flight module: SiLabs C805, PIC24, PIC33, and TI MSP430. The convenience of purchasing processors with a Pumpkin CubeSat Kit may play a key role in processor trends, especially for 1U CubeSats, although many factors were not accounted for in this analysis (i.e. budget, development time, cost of materials, etc.) and could have played a

key role in determining the processors as well.

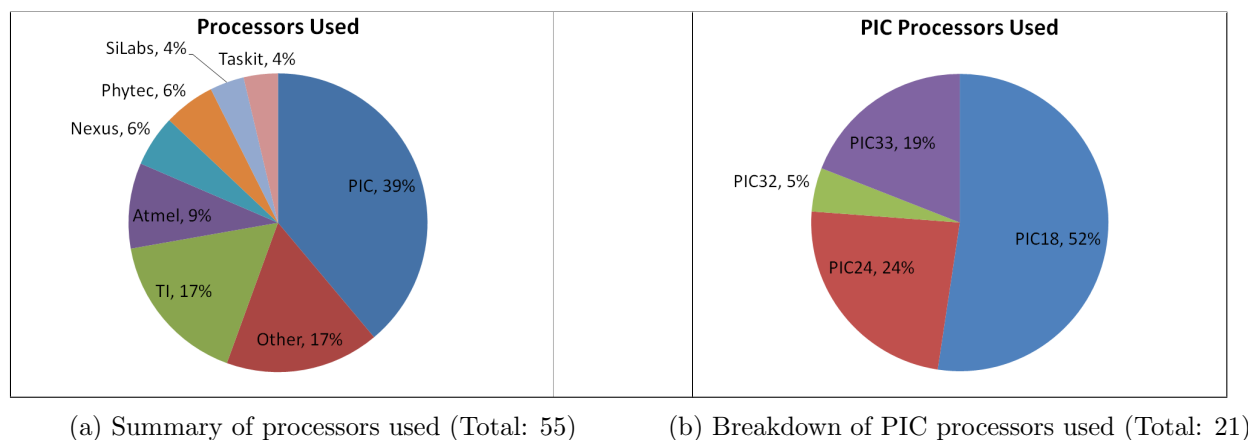


Figure 6: Summary of processors used in CubeSats

To counter the potential skewness presented by the large percentage of university missions when considering processors, Figure 7 shows the percentage of processors used on all non-university missions. However, the results were once again consistent such that PIC processors totaled over 50% of all processor data recorded.

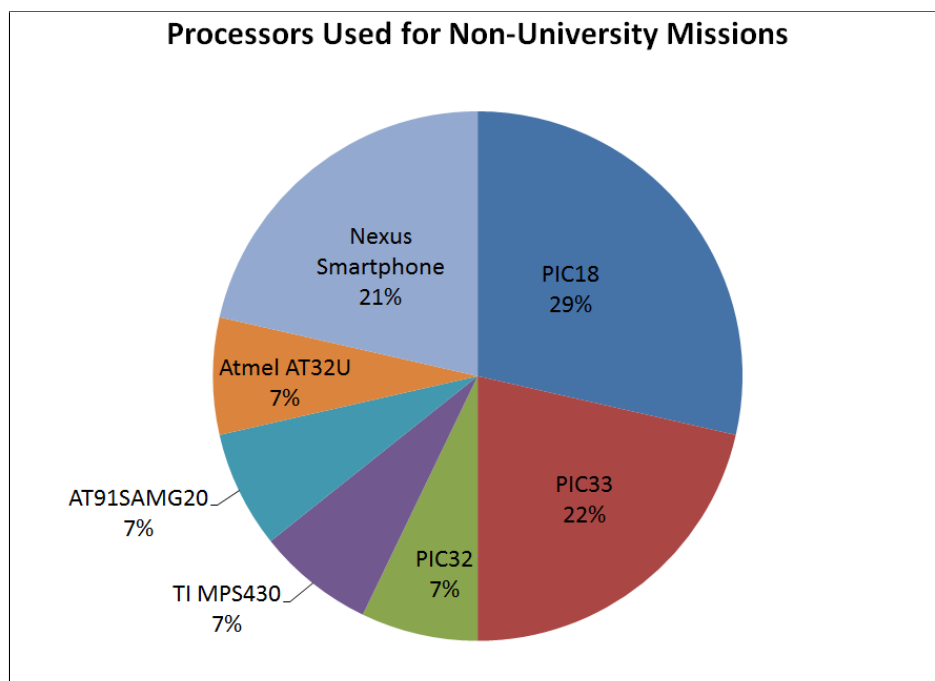


Figure 7: Results of survey showing the processors used for non-university missions (Total: 14)

3.3 Operating Systems

Salvo and Linux were the two most commonly used operating systems in the CubeSat missions surveyed. Salvo is available with the purchase of any Pumpkin PPM and is included with the purchase of a Pumpkin CubeSat Kit. Most processors provide various options for programming

and therefore no concrete conclusion can be made as to which operating system should be used by IV&V.

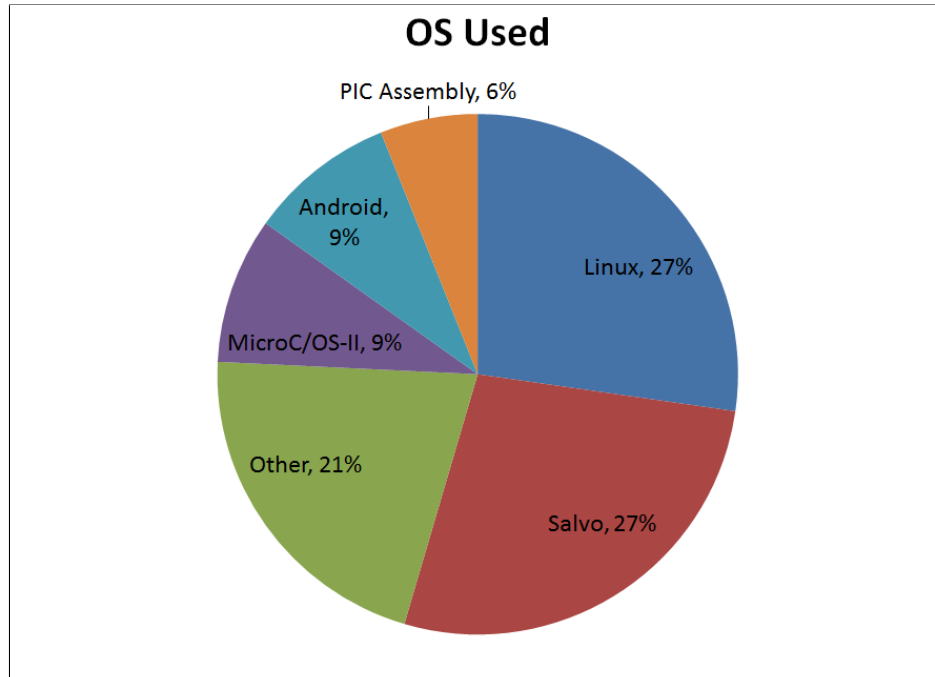


Figure 8: Results of survey showing the percentage of OS used in CubeSat missions (Total: 33)

3.4 Discussion

Based on the information collected from this survey, a majority of CubeSat missions have used PIC processors (specifically PIC18) with either Linux or Salvo operating systems. The availability of Pumpkin CubeSat kits is likely a major contributor to these results, although this was not confirmed in this survey. As mentioned before, the results of this survey do not take into consideration factors such as budget, time constraints, component availability, etc. so it is our recommendation that NASA IV&V use their previous knowledge and experience with processors and operating systems to create their own verification and validation software. Some crucial aspects to consider when choosing a processor are cost, user interface, and power requirements, each of which will be determined by the nature of the mission. In addition, it is worth noting that the results of this survey lead us to believe that successful missions can be achieved through the use of PIC processors and Linux or Salvo operating systems. Electronically attached to this report are data sheets for the processors used in this survey.

4 Future Work

Evident in the NASA's FY 2015 budget request is the agency's near-term interest in CubeSats. The requested 2015 NASA budget indicates a \$25M allocation to CubeSat projects over the next five years [6]. In light of this, there are currently multiple open or future planned solicitations accepting CubeSat based mission proposals. In particular, a review of the NSPIRES website (nspires.nasaprs.com), shows at least three specific solicitations that request CubeSat proposals, listed in Table 3.

Table 2: Processor Specifications

Processor	Max. Operating Frequency (MHz)	Max. Program Memory (KB)	Clock Speed
PIC18	40	32	32 kHz
PIC24	32	256	32 kHz
PIC32	50	256	32 kHz
PIC33	16	536	32 kHz
TI MPS430	24	512	32 kHz
SiLabs 8051	50	32	16 MHz
Freescale HC12	50	512	32 kHz
Atmel AtxMega	32	128	32 kHz
Atmel AT91SAM9	210	8	32 kHz
Phytec phyCORE-LPC3250	208	32	13 MHz
Taskit Stamp9G20	396	32	32 kHz

In addition to the \$25M line-item, NASA Earth Science Technology Office (ESTO) funds missions to validate technology through its In-Space Validation of Earth Science Technologies (InVEST) program. Currently InVEST is planning to spend \$13M over four years on four 3U CubeSat missions [7]. One mission currently in development is ICECUBE or Earth-1, which is being built at Goddard Space Flight Center.

Table 3: CubeSat Proposal Opportunities

CubeSat Proposal Opportunities		
Name	Solicitation Number	Description
Remote Sensing Theory for Earth Science	NNH14ZDA001N-RST	Remote sensing science to establish a theoretical basis for measuring Earth surface properties using reflected, emitted, and scattered electromagnetic radiation and to develop the methodologies and technical approaches to analyze and interpret such measurements lies at the heart of NASAs mission.
Heliophysics Technology and Instrument Development for Science	NNH13ZDA001N-HTIDS	The H-TIDeS program solicits proposals for investigations that are relevant to NASA's programs in Heliophysics.
Astrophysics Research and Analysis Program	NNH13ZDA001N-APRA	The Astrophysics Research and Analysis Program (APRA) program solicits basic research proposals for investigations that are relevant to NASA's programs in astronomy and astrophysics and includes research over the entire range of photons, gravitational waves, and particle astrophysics.
Smallsat Technology Partnership	NNA13ZUA001C	NASA has selected 13 university teams for collaborative projects to develop and demonstrate new technologies and capabilities and spur innovation in communication, navigation, propulsion, science instruments, and advanced manufacturing for small spacecraft.
Human Exploration and Operations Mission Directorate	NNH14HEOMD001L	Proposed CubeSat investigations must address an aspect of science, technology development, education, or operations encompassed by NASAs strategic goals and outcomes as identified in the NASA Strategic Plan.
Spacecraft Operating Software System in Support of CubeSat Vault Electronics	NNL14518620Q	NASA/LARC has a requirement for Spacecraft Operating Software System in support of CubeSat Vault Electronics.
Opportunity Notice to Participate in ITS Centennial Challenges Program as an Allied Organization for Small Spacecraft Challenges	NNH14STMD005L	Organizations may submit proposals for consideration as either Lead Allied Organization or Supporting Allied Organization for CubeSat based Centennial Challenge.

Further, NASAs interest in the future of CubeSats is evidenced in its plans to host a CubeSat based Centennial Challenge competition in order to spur the advancement of propulsion and communication technologies for deep space applications. Primarily, the challenge is designed to develop innovative ways to return error free data from deep space without government assistance, and to demonstrate lunar orbital plane change from equatorial to polar [8]. This Centennial challenge will inevitably lead to technology and knowledge that will advance the field beyond its current state. NASAs investment in this event demonstrates the agencys commitment to the field.

NASA is showing a great commitment to the use of CubeSats for rigorous scientific endeavors as demonstrated by the availability of funding opportunities and the development of a CubeSat Centennial Challenge.

5 Appendix

Table 4: Abbreviated summary of CubeSat missions grouped by size, displaying launch date, processor used, and operating system used

Name of Satellite	Size	Launch Date	Processor	OS
TUSat1	1U	2003	i80386	DOS 3.0
CP-1	1U	7/26/2006	PIC18	Not Supplied
CP-2	1U	7/26/2006	PIC18	Not Supplied
MEROPE	1U	7/26/2006	HCS12	C
CP-3	1U	4/17/2007	PIC18	Not Supplied
CP-4	1U	4/17/2007	PIC18	Not Supplied
MAST	3x1U	4/17/2007	PIC18	Not Supplied
CP-6	1U	5/19/2009	PIC18	Not Supplied
Explorer-1 Prime 2 (HRBE)	1U	10/28/2011	HCS12	Not Supplied
MCubed/COVE	1U	10/28/2011	Stamp9G20	Linux
CP-5	1U	9/13/2012	PIC18	Not Supplied
PhoneSat v1a (Graham)	1U	4/21/2013	HTC	Android 2.3.3
PhoneSat v1b (Bell)	1U	4/21/2013	HTC	Android 2.3.3
PhoneSat v2.0 (Alexander)	1U	4/21/2013	Samsung	Android 2.3.3
COPPER	1U	11/19/2013	PIC24	Not Supplied
UAH/ChargerSat-1	1U	11/19/2013	ATxmega128A1U	Atmel Studio
SwampSat	1U	11/19/2013	TI MSP430	Not Supplied
KySat-2	1U	11/19/2013	SiLabs 8051	Not Supplied
Trailblazer	1U	11/19/2013	Pumpkin	Salvo
DragonSat-1	1U	11/19/2013	PIC33	Salvo
Lunar Orbiter/Lander CubeSat	1U	11/19/2013	TI MSP430	SPARK
NPS-SCAT	1U	11/19/2013	TI MSP430	Salvo
CP-8/IPEX	1U	12/6/2013	AT91SAM9	Linux
MCubed/COVE 2	1U	12/6/2013	Stamp9G20	Linux
DICE	2x1.5U	10/28/2011	TI MSP430	Salvo
FIREBIRD 1A	2x1.5U	12/6/2013	PIC24	Salvo
FIREBIRD 1B	2x1.5U	12/6/2013	PIC24	Salvo
PSAT	2x1.5U	2015	basicStamp	basic
BRICSat-P	1.5U	2015	PIC33	Salvo
ION	2U	7/26/2006	SH2	SID
PSSC-2	2U	7/8/2011	PIC18	PIC Assembly
CXBN	2U	9/13/2012	TI MPS430	Not Supplied
LMRSat	2U	2014	TI MPS430	Salvo
CP-9	2U	TBA	AT91SAM9	Linux
QuakeSat	3U	6/30/2003	i80486	Linux
GeneSat-1	3U	12/16/2006	PIC	C++
RAX-1	3U	11/19/2010	TI MPS430	Not Supplied
RAX-2	3U	10/28/2011	TI MPS430	Not Supplied
CINEMA 1	3U	9/13/2012	PIC33	Not Supplied

Continued on next page

Table 4 – continued from previous page

Name of Satellite	Size	Launch Date	Processor	OS
CSSWE	3U	9/13/2012	TI MPS430	Salvo
Aeneas	3U	9/13/2012	PIC24	Not Supplied
ALL-STAR/THEIA	3U	4/18/2014	AT32UC3A3256S	Not Supplied
KickSat	3U	4/18/2014	TI CC430	Not Supplied
SporeSat	3U	4/18/2014	PIC32	uC/OS-II
INSPIRE	3U	2014	AT91SAM9	Not Supplied
RACE	3U	2014	LPC3250	Linux
RAVAN	3U	2015	SiLabs 8051	Not Supplied
ARMADILLO	3U	2015	LPC3250	Linux
USS Langley	3U	2015	PIC33	Salvo
CP-10/EXOCUBE	3U	2015	AT91SAM9	Linux
Bevo-2	3U	TBA	LPC3250	Linux

References

- [1] California Polytechnic State University, San Luis Obispo, “CubeSat Design Specifications Rev. 13,” February 2014.
- [2] Clark, C. and Logan, R., “Power Budgets for Mission Success,” ClydeSpace, April 2011.
- [3] Naik, S. R., “CubeSat Constellation around Mars,” 2011.
- [4] Mission Design Division Staff, “Small Spacecraft Technology State of the Art,” Tech. rep., NASA Ames Research Center, July 2014.
- [5] Buchen, E. and DePasquale, D., “2014 Nano/Microsatellite Market Assessment,” SpaceWorks Enterprises, Inc., 2011.
- [6] “FY 2015 President’s Budget Request Summary,” 2014.
- [7] Klumpar, D. M., “An Enhanced Role for Scientific CubeSats at NASA,” *Cal-Poly Annual Meeting for CubeSat Developers*, April 2014.
- [8] “NASA Centennial Challenges Program - Small Spacecraft Challenges,” February 2014.