University-Class Spacecraft by the Numbers: Success, Failure, Debris. (But Mostly Success.)

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ABSTRACT

University-class satellites -- that is, spacecraft built by university students for the express purpose of student training -- have been flown since the early '70s. In the last 10 years, however, the trickle of university-class missions became a flood, enabled by (and enabling) the CubeSat class of secondary payloads. Whereas it took 40 years to launch the first 40 university-class spacecraft, now it is not unusual for 40 university-class missions to fly every year.

So what? Other than that clever bit of numerology, why does this matter? We believe that there are three important questions to address:

1) Do these missions matter? Given the 40% failure rate of university missions, do student-built spacecraft succeed often enough to warrant the launch slots they are given?

2) From a greater perspective, are university-class missions worth the investment? Are such programs more effective at meeting certain types of missions than their professional counterparts? Are their educational outcomes consistent with the investment?

3) What are the risks/costs of university-class missions? Specifically, are we accelerating an orbital-debris catastrophe by cluttering Earth orbit with student satellites?

The participants of this conference can provide essential insight to all of those questions. What we bring to the conversation is data: the number of missions, their classifications, rates of mission success and relative risk of fragmentation and collision. This data has been compiled over many years through a combination of launch logs, publications, presentations, press releases and personal communication.

In this paper, we will review the recent history of university-class missions, place them in the context of previous years, and address the questions raised above. In particular, we will show that the seemingly-high failure rate is consistent with the types of missions attempted and the experience of the participants. We will show that there are several types of missions that universities are best-suited to attempt, and that the orbital-debris risk posed by university-class missions (and CubeSats) is overblown.

INTRODUCTION

We have been documenting the history of university-class space missions for a dozen years.[1-11] The result of those studies can be broadly summarized as follows:

1) There sure are a lot of student-built satellites, and there will be even more next year.
2) University-class missions have had three watershed years:
   - **1981** The second university-class mission flew (UoSAT-1), starting a steady stream of university-class missions;
   - **2000** A string of on-orbit failures nearly ended student satellite missions in the United States (and directly led to the introduction of the CubeSat standard);
   - **2012** The CubeSat standard was fully embraced by industry professionals, greatly reducing barriers to entry for universities and broadening the numbers and types of participants.
3) While almost all modern university-class missions are CubeSats, not all CubeSats are university-class missions.
4) The student launchspace is dominated by three groups:
   a. ***Flagship universities***, whose satellites are the most reliable and have the most significant missions. These flagships fly a new spacecraft every few years;

b. ***Prolific independent universities***, who have developed their own string of successful missions, often using a sequence of missions to study specific science phenomena;

c. ***Hobbyists***, who are still learning how to build successful missions, and have low flight rates and high rates of on-orbit failure.

Why do we need another paper?

Well, beyond the obvious excuse to attend this conference, we have identified three frequently-asked questions. We believe that we have sufficient data to contribute to the conversation. These questions are:

1. <u>Do these missions matter</u>? Given the 40% failure rate of university missions, do student-built spacecraft succeed often enough to warrant the launch slots they are given?
2. <u>Are university-class missions worth the investment</u>? Are such programs more effective at meeting certain types of missions than their professional counterparts? Are their educational outcomes consistent with the investment?
3. <u>What are the risks/costs of university-class missions</u>? Specifically, are we accelerating an orbital-debris catastrophe by cluttering Earth orbit with student satellites?

In brief, the answers are ***Yes***, ***Yes*** and ***No***. In the rest of this paper, we will provide more complete, data-driven answers to these questions, using an extensive launch and orbit success database created and maintained by the authors.

Before we do all that, we must first define our terms. Following the definitions, we will issue our standard disclaimers about how this data was collected and how much it can be trusted.

Taxonomy

As discussed in previous papers, we narrowly define a ***university-class*** satellite as having three distinct features:

1. It is a functional spacecraft, rather than a payload instrument or component. To fit the definition, the device must operate in space with its own independent means of communications and command. However, self-contained objects that are attached to other vehicles are allowed under this definition (e.g. PCSat-2, Pehuensat-1).
2. Untrained personnel (i.e. students) performed a significant fraction of key design decisions, integration & testing, and flight operations.
3. The training of these people was as important as (if not more important) the nominal "mission" of the spacecraft itself.

Exclusion from the "university class" category does **not** imply a lack of educational value on a project's part; it simply indicates that other factors were more important than student education (e.g., schedule or on-orbit performance). Furthermore, several schools have "graduated" from university-class to professional programs – starting with the University of Surrey, who became SSTL, followed by schools such as the Technical University of Berlin, and the University of Toronto's Space Flight Laboratory (SFL).

Next, we define two broad categories of university-class programs: ***flagship*** and ***independent*** schools. A flagship university is designated by its government as a national center for spacecraft engineering research and development. Independent schools are not flagships. We further subdivide independent schools by identifying ***prolific*** independent schools; those that manifest four or more missions. Achieving this milestone is an indication of perseverance, internal capabilities and mission connections that result in very different outcomes. As of 2015, nine independent schools are considered to be prolific.

By definition, flagships enjoy financial sponsorship, access to facilities and launch opportunities that the independent schools do not have. Before 2010, these differences had a profound effect: generally speaking, flagship schools built bigger satellites with more "useful" payloads, and tended towards sustained programs with multiple launches over many years. By contrast, the satellites built by independent schools were three times more likely to fail, and for most of these programs, their first-ever spacecraft in orbit was also their last, i.e., the financial, administrative and student resources that were gathered together to built the first satellite are not available for the second. Much has changed in the last six years.

It is generally understood that a ***CubeSat-class*** spacecraft is one that adheres to the CubeSat/P-POD standard developed by Cal Poly and Stanford Universities (i.e., it fits inside the P-POD and follows the flight safety guidelines). However, for the purposes of this study, we also include all of the domestic and international analogs to the P-POD, a list that is too numerous to include here!

Disclaimers

This information was compiled from online sources, past conference proceedings and author interviews with students and faculty at many universities, as noted in the references. The opinions expressed in this paper are just that, opinions, reflecting the primary author's experience as both student project manager and faculty advisor to university-class projects. The authors accept sole responsibility for any factual (or interpretative) errors found in this paper and welcome any corrections. (The primary author has been cutting-and-pasting this disclaimer into every one of these papers for twelve years and has received only a handful of corrections, so he is left to conclude that either (a) he is the greatest fact-checker ever or (b) nobody reads these papers and/or cares enough to send him updates.)

UNIVERSITY-CLASS MANIFEST, UPDATED

A list of university-class spacecraft launched from 1970 until the end of 2015 is provided in the Appendix. Because the inclusion or omission of a spacecraft from this list may prove to be a contentious issue – not to mention the designation of whether a vehicle failed prematurely, it is worth repeating an explanation of the process for creating these tables.

First, using launch logs, the author's knowledge and several satellite databases, a list was created of all university-class small satellites that were placed on a rocket.[10-13] These remaining spacecraft were researched regarding mission duration, size, type and status, with information derived from published reports and project websites.

Regarding ***mission class***, we use the following definitions:

- ***C*** (Communications): The primary mission is to relay communications between two points. Amateur radio service and AIS tracking are common examples.
- ***E*** (Educational): The primary mission is the education/professional training of the participants in the spacecraft design lifecycle. To be and E-class mission any science returns or technology demonstrations must be of secondary value to the education. Typically, E-class missions have no science or technology value, except to the mission developers themselves. E-class missions are also called "Beepsats", as they don't do anything but "beep" health & status data back to the ground.
- ***I*** (Earth Imaging): The mission is to return images of the Earth for commercial and/or research purposes. Planet Labs' Dove constellation is the primary example.
- ***M*** (Military): The mission has military relevance that does not properly fit in the other categories. (For example, SIGINT missions.)
- ***S*** (Science): The mission collects data for scientific research, including Earth science, atmospheric science, space weather, etc. To be S-class, there must be a clear connection between the data collected and end-user researchers; a spacecraft that measures the Earth's magnetic field and publishes the data on the web, hoping that some scientist will find the data useful, is not an S-class mission. (It's probably an E-class mission.)
- ***T*** (Technology Demonstration): The mission involves the first flight of a new technology or capability, such that it is advanced one or more Technology Readiness Levels (or equivalent indicator). As with S-class missions, it is not enough to simply try out some new technology in space; there must be a clear, obvious process by which the behaviors of this new technology in orbit are validated.

We define levels of ***mission success*** based on what fraction (if any) of the mission objectives have been achieved. Mission status is distinct from spacecraft functional status; mission status is only concerned with how much of the primary mission has been achieved. An otherwise-functional spacecraft with a broken primary payload would be stuck at Level 3. A spacecraft that cannot downlink its mission data, for whatever reasons, would be stuck at whatever Level it achieved at the point of failure. A spacecraft that achieved its mission success and then died is still at Level 5.

0 ***Manifested***: A launch date has been published. We don't keep track of missions until a launch date has been published.
1 ***Launched***: The rocket began liftoff. (Launch failures usually stop at Mission Status 1.)
2 ***Deployed***: The spacecraft is confirmed to have released from the launch vehicle.
3 ***Commissioning***: The spacecraft has had at least one uplink and downlink.
4 ***Primary operations***: The spacecraft is taking actions that achieve primary mission success (i.e., receiving commands, downlinking mission data)
5 ***Mission success***: Primary mission objectives have been met. The spacecraft may continue to operate, run secondary missions, etc.

This list of spacecraft is complete to the best of the author's ability. The caveats from previous versions of this work still apply: launch masses should be considered approximate, as should mission durations. Special thanks are given to the authors of reference 17 for their extensive archive describing satellite contacts.

CENSUS DATA AND OBSERVATIONS

The entire manifest has been discussed in much detail in our work in previous conference;[1-3,4,6,8,10] for this paper, we will focus on the developments in the three years since the last publication.

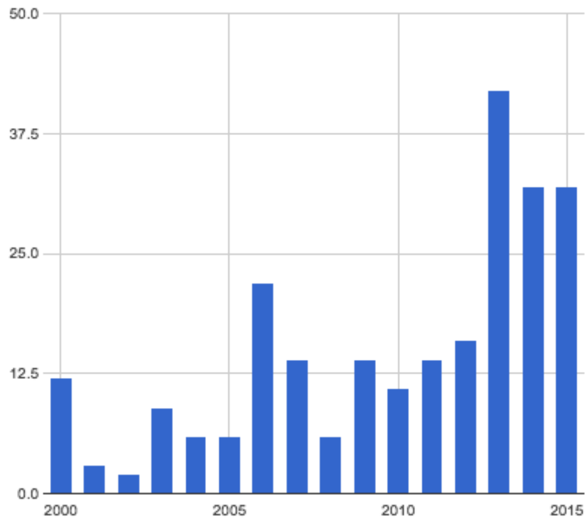

Figure 1: Number of University-Class Missions Launched Each Year

As shown in Figure 1, the last three years have shown a large increase in the number of university-class missions. A manifest of 30 missions per year is the norm. There have been 266 university-class missions launched through the end of 2015, with more than a third (106) coming in the last three years. While, as shown in Figure 2, a significant number of university missions are not CubeSats; CubeSats do comprise a sizeable majority of the missions.

It is worth noting how much has changed in the twelve short years since our first publication on this subject. In 2004, the idea of ten manifested missions a year would have been a delightful notion; today, that would be a significant step backward. CubeSats play an outsized role in the availability of spaceflight to universities.

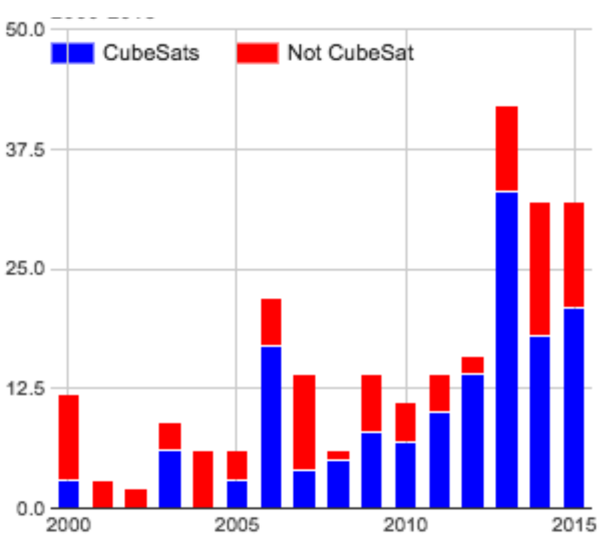

Figure 2: University-Class Missions by Form Factor

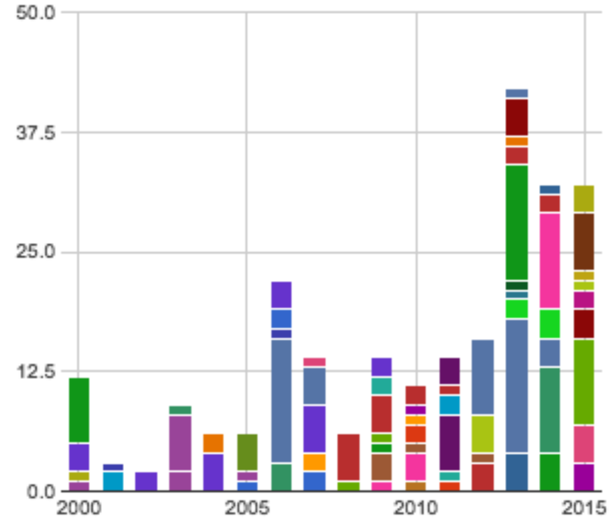

Figure 3: University-Class Missions Grouped by Launch

Another change in the way that universities reach orbit is shown in Figure 3; the plots are color-coded such that all the missions on the same launch in a given year are the same color. As noted in the Figure, most missions to fly in the last three years are part of large clusters released from a small number of launch vehicles.

International Participation

Who builds these spacecraft? As shown in Figure 4, university-class missions are truly international, with 40 nations from 6 continents providing spacecraft. The USA, Europe and Japan have built about 75% of all the university-class spacecraft.

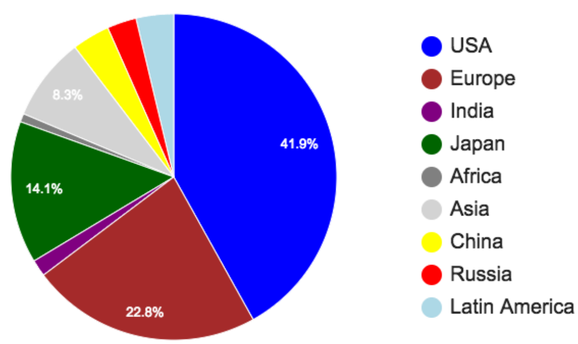

Figure 4: University-Class Missions by Nationality of Builder

Looking to Figure 5, we see that six nations/space agencies are responsible for launching these missions, with the USA and Russia each responsible for launching about a third of the spacecraft. We consider spacecraft ejected from the ISS to be a separate category, as there are several launch providers that feed the ISS ejectors. No matter how they got there, 20 university-class missions have been released from the ISS, and we expect that number to increase in the coming years.

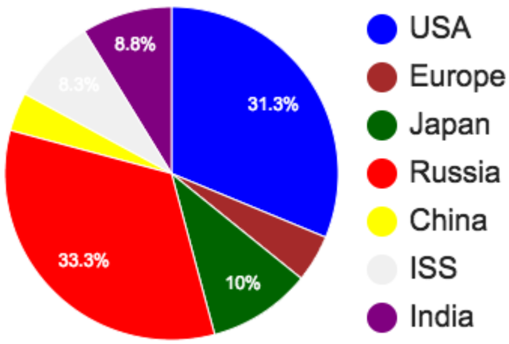

Figure 5: Launching Nation of University-Class Missions

Type of Builder

As noted above, we have decided to further subdivide the independent category of spacecraft builder into "prolific" and "regular" independent programs. A prolific program has launched four or more CubeSats on at least three separate occasions. We make this distinction because, as will be noted, prolific programs tend to have better overall mission success than the regular independents; these programs are comparable to the flagships in terms of their success.

The other reason for making the distinction is evident in Figure 6 and Figure 7; about a third of all independent missions have been produced by only 9 independent schools. Overall, independent schools produce about two-thirds of all university-class space missions. As late as 2009, flagships still provided more than half.

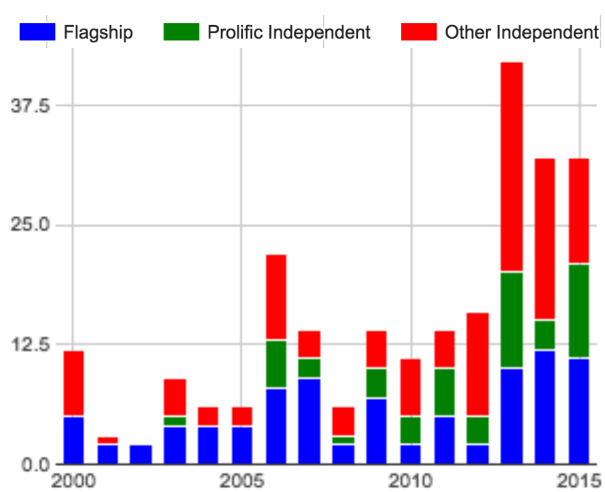

Figure 6: University-Class Missions Each Year by Type of Builder

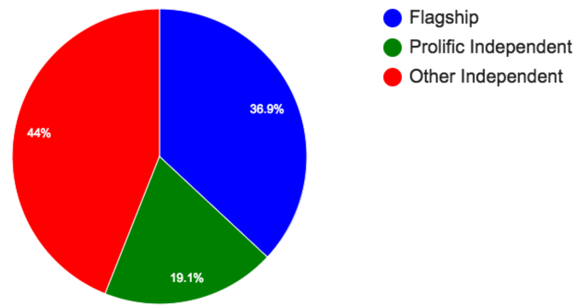

Figure 7: Allocation of University-Class Missions by Builder Type

As of the June 2016, we have identified 128 schools that have built at least one university-class mission (Table 1). Flagships comprise 38 of those schools, and 9 of the 90 independent schools are prolific. Note that only 12 of the flagships schools fit the definition of prolific. In fact, those 21 schools have produced 119 missions, an average of nearly 6 per school and more than 40% of all missions; only 35 schools have flown 3 or more missions, and they are responsible for 2/3rds of all missions. By contrast, 74 of the 128 schools have produced only one mission. As was true in earlier reports, a fraction of the schools are responsible for most of the missions, while the majority of schools only ever launch one.

What has changed are the magnitudes of our counts. In previous papers, we were excited that there were three independent schools with multiple missions. Today, 34 independent schools have flown at least two missions, compared with only 18 flagships. CubeSats have significantly upended the status quo for access to space.

Table 1: Spacefaring Universities. Flagships are highlighted in yellow, and prolific independents in green

	School	Nation	First Launch	Total
1	University of Melbourne	Australia	1/23/1970	1
2	University of Surrey	UK	10/6/1981	3
3	Weber State	USA	4/29/1985	3
4	Technical University of Berlin	Germany	7/17/1991	9
5	Korean Advanced Institute of Science and Technology	S. Korea	8/10/1992	4
6	CNES Amateurs (?)	France	5/12/1993	1
7	University of Bremen	Germany	2/3/1994	1
8	National University of Mexico	Mexico	3/28/1995	2
9	Technion Institute of Technology	Israel	3/28/1995	2

10	Russian high school students	Russia	10/5/1997	1
11	US Air Force Academy	USA	10/25/1997	5
12	ESTEC	Europe	10/30/1997	4
13	University of Colorado LASP	USA	2/26/1998	2
14	University of Alabama-Huntsville	USA	10/24/1998	2
15	Naval Postgraduate School	USA	10/29/1998	4
16	University of Stellenbosch	South Africa	2/23/1999	2
17	Arizona State University	USA	1/27/2000	2
18	Stanford University	USA	1/27/2000	3
19	Santa Clara University	USA	2/10/2000	3
20	Tsinghua University	China	6/28/2000	4
21	King Abdulaziz City for Science & Technology	Saudi Arabia	9/26/2000	11
22	University of Rome "La Sapienza"	Italy	9/26/2000	9
23	Umeå University / Luleå University of Technology	Sweden	11/21/2000	1
24	US Naval Academy	USA	9/30/2001	7
25	Aalborg University	Denmark	6/30/2003	5
26	Technical University of Denmark	Denmark	6/30/2003	2
27	Tokyo Institute of Technology	Japan	6/30/2003	4
28	University of Tokyo	Japan	6/30/2003	5
29	UTIAS (University of Toronto)	Canada	6/30/2003	3
30	Universidade Norte do Paraná	Brazil	8/22/2003	1
31	Mozhaiskiy Space Engineering Academy	Russia	9/27/2003	2
32	New Mexico State University	USA	12/21/2004	1
33	Norweigan Universities	Norway	10/27/2005	2
34	University of Würzburg	Germany	10/27/2005	3
35	Bauman Moscow State Technical University	Russia	7/26/2006	1
36	Cal Poly	USA	7/26/2006	10
37	Cornell University	USA	7/26/2006	4
38	Hankuk Aviation University	South Korea	7/26/2006	1
39	Montana State University	USA	7/26/2006	8
40	Nihon University	Japan	7/26/2006	3
41	Politecnico di Torino	Italy	7/26/2006	3
42	University of Arizona	USA	7/26/2006	2
43	University of Hawaii	USA	7/26/2006	3
44	University of Illinois	USA	7/26/2006	1
45	University of Kansas	USA	7/26/2006	1
46	Hokkaido Institute of Technology	Japan	9/22/2006	1
47	National University of Comahue	Argentina	1/10/2007	1
48	University of Louisiana	USA	4/17/2007	2
49	University of Sergio Arboleda	Colombia	4/17/2007	1
50	Fachhochschule Aachen	Germany	4/28/2008	1
51	Technical University of Delft	Netherlan ds	4/28/2008	2
52	Kagawa University	Japan	1/23/2009	2
53	Tohoku University	Japan	1/23/2009	4
54	Tokyo Metropolitan College of Industrial Technology	Japan	1/23/2009	1
55	Anna University	India	4/20/2009	1
56	Texas A&M University	USA	7/15/2009	3
57	University of Texas	USA	7/15/2009	4
58	Ufa State Aviation Technical University	Russia	9/17/2009	1
59	Ecole Polytechnique Fédérale de Lausanne	Switzerla nd	9/23/2009	1
60	Istanbul Technical University	Turkey	9/23/2009	2
61	Kagoshima University	Japan	5/20/2010	2
62	Soka University	Japan	5/20/2010	1
63	University Space Engineering Consortium	Japan	5/20/2010	1
64	Waseda University	Japan	5/20/2010	1
65	Indian university consortium	India	7/12/2010	1
66	Scuola universitaria della Svizzera italiana	Switzer-land	7/12/2010	1
67	University of Michigan	USA	11/20/2010	5
68	University of Southern California	USA	12/8/2010	1
69	Colorado Space Grant Consortium	USA	3/4/2011	3
70	Kentucky Space	USA	3/4/2011	5
71	M.V. Lomonosov Moscow state university	Russia	4/20/2011	1
72	Nanyang Technological University	Singapore	4/20/2011	4
73	Indian Institute of Technology Kanpur	India	10/12/2011	1
74	Auburn University	USA	10/28/2011	1
75	Utah State University	USA	10/28/2011	2

76	Nanjing University	China	11/9/2011	2
77	Budapest University of Technology and Economics	Hungary	2/13/2012	1
78	University of Bologna	Italy	2/13/2012	1
79	University of Bucharest	Romania	2/13/2012	1
80	University of Montpellier II	France	2/13/2012	1
81	University of Vigo	Spain	2/13/2012	2
82	Warsaw University of Technology	Poland	2/13/2012	1
83	Kyushu Institute of Technology (KIT)	Japan	5/17/2012	1
84	FPT Technology Research Institute	Vietnam	10/4/2012	1
85	Fukuoka Institute of Technology	Japan	10/4/2012	1
86	San Jose State University	USA	10/4/2012	3
87	Samara Aerospace University	Russia	4/19/2013	4
88	Technical University of Dresden	Germany	4/19/2013	1
89	University of Tartu	Estonia	5/7/2013	1
90	COSMIAC	USA	11/20/2013	1
91	Drexel University	USA	11/20/2013	1
92	Saint Louis University	USA	11/20/2013	2
93	Thomas Jefferson High School	USA	11/20/2013	1
94	University of Florida	USA	11/20/2013	1
95	US Military Academy	USA	11/20/2013	1
96	Vermont Technical College	USA	11/20/2013	1
97	Cape Peninsula University of Technology	South Africa	11/21/2013	1
98	Institute of Space Technology Islamabad	Turkey	11/21/2013	1
99	Narvik University College	Norway	11/21/2013	1
100	Pontifical Catholic University of Peru	Peru	11/21/2013	3
101	Technical University of Munich	Germany	11/21/2013	1
102	University of Maryland Baltimore County	USA	11/21/2013	1
103	City University of New York	USA	12/6/2013	1
104	Osaka Prefecture University	Japan	2/27/2014	1
105	Shinsu University	Japan	2/27/2014	1
106	Tama Art University	Japan	2/27/2014	1
107	Teikyou University	Japan	2/27/2014	1
108	University of Tsukuba	Japan	2/27/2014	1
109	Kaunas University of Technology	Lithuania	2/28/2014	2
110	Taylor University	USA	4/18/2014	1
111	Wakayama University	Japan	5/24/2014	1
112	University of the Republic (Uruguay)	Uruguay	6/19/2014	1
113	National Cheng Kung University	Taiwan	6/19/2014	1
114	National Technical University of Ukraine	Ukraine	6/19/2014	1
115	National University of Engineering	Peru	8/19/2014	1
116	Kyushu University	Japan	11/6/2014	1
117	Nagoya University, Daido University	Japan	11/6/2014	3
118	Greek Silicon Valley Folks	USA	3/4/2015	1
119	MIT	USA	3/4/2015	1
120	SERPENS	Brazil	9/17/2015	1
121	Harbin Institute of Technology	China	9/19/2015	1
122	Zhejiang University	China	9/19/2015	2
123	Salish Kootenai College	USA	10/8/2015	1
124	University of Alaska Fairbanks	USA	10/8/2015	1
125	St. Thomas More Cathedral School	USA	12/6/2015	1
126	Kyusyu Institute of Technology (KIT)	Japan	2/17/2016	1
127	Tomsk Polytechnic University	Russia	3/31/2016	1
128	Université de Liège	Belgium	4/25/2016	1

MISSIONS AND SUCCESS RATES

Having reviewed the launch manifest and the changes since 2012, we can address the questions posed in the introduction.

Do these missions matter?

Do university-class missions have useful outcomes? Do these spacecraft produce science, engineering and/or educational results that justify their launch slots, or are they expensive educational vanity projects?

As shown in Figure 8, university-class missions have pursued a wide assortment of industry-relevant activities. While it is true that in the first part of this century the university-class missions were E-class (i.e., lacking in real relevance), the fraction of E-class missions has dropped significantly in the last five years. Moreover, among the flagships and prolific independents, E-class missions have been seen as a "starter mission", a way to quickly gain flight experience before taking on more advance missions.[10]

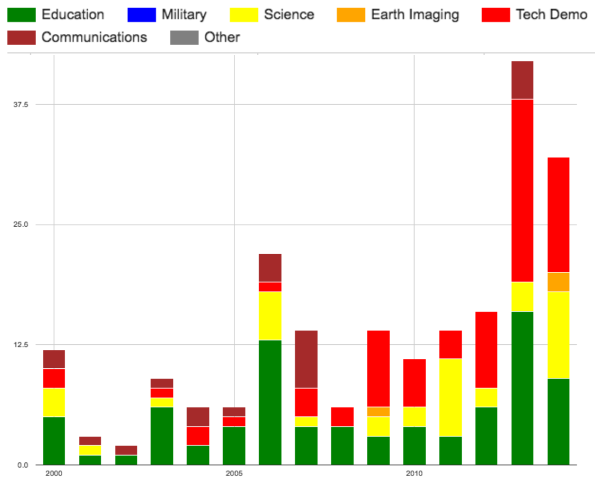

Figure 8: Mission Type by Launch Year

As seen in Figures 9-11, the regular independent schools pursue a different mission profile than the flagships and prolific independents. However, even the regular independents have relevant missions more than half the time. As noted in previous papers, credit must be given to NSF and the NASA ELaNa program, who made mission relevance a necessary criteria for securing launch sponsorship.

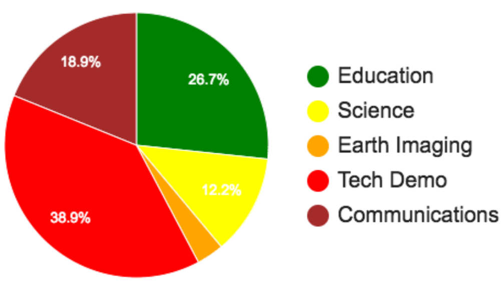

Figure 9: Mission Types for Flagship Schools

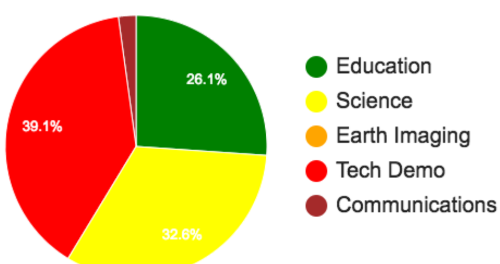

Figure 10: Mission Types for Prolific Independent Schools

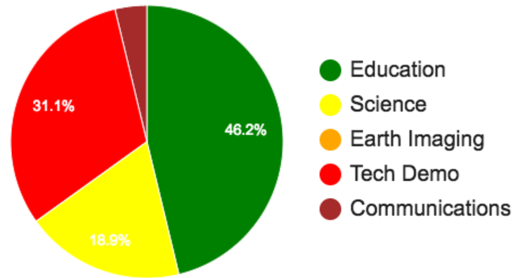

Figure 11: Mission Types for Regular Independent Schools

Still, having a mission is "relevant" to industry is not the same as a mission that actually contributes. It is beyond the scope of this paper to discuss and verify the science or technology relevance of individual missions – although we would very much like to see such a paper! Instead, we will point out that we only assign S-class status to missions with a publishing science PI with an instrument on the spacecraft and/or an external peer-reviewed science sponsor (e.g. NSF or NASA EPSCOR). Similarly, the C-class missions carry capable Amateur radio transponders or participate in Automatic Identification System (AIS) tracking and communications. And the T-class missions must be operating and collecting data on a device or subsystem that advances the state of the art for small satellites. It is not enough to fly a camera that no one has flown before; that camera must have capabilities that have not flown before.

The last, admittedly anecdotal, evidence for the relevance of university-class missions has two parts: first, the ubiquitous acceptance of the CubeSat standard and the ubiquitous presence of university-class mission alumni in every part of the space industry. The latter claim is easy to justify to the target audience for this paper, as the Smallsat conference is overrun with alumni of student-built spacecraft missions. As for the former, References 4, 6 and 8 detail the fact that the overwhelming fraction of the first hundred CubeSats were university-class missions, and now the overwhelming fraction of CubeSat launches in 2015 were not. As early adopters, the universities retired risk associated with CubeSat component development and served as the launch customers for qualifying dispensers and multi-mission opportunities.*

* In addition to universities, credit must be given to the Aerospace Corporation's sequence of Picosat/MEPSI missions, launched from 2000-2006. Without those missions, there may not have been a CubeSat program for universities to adopt and bolster.

Whose Risk Is It, Anyway?

Next, let us consider the issue of mission success and failure. Using the mission status scale discussed, above, we first examine the results for all university-class missions (Figure 12). What is striking about this plot is first that about one-eighth of all university missions are lost to launch failure. This is a number out of proportion with the number of launch failures each year. The reason for this high rate is twofold: university missions are often placed on rocket platforms making their first-ever launch attempt (e.g, ORS-4). First-flights have a significantly higher failure rate than later flights. Secondly, as noted in Figure 3, university-class missions tend to be launched in groups of 6 to 20. When a rocket fails, a lot of university missions are lost.

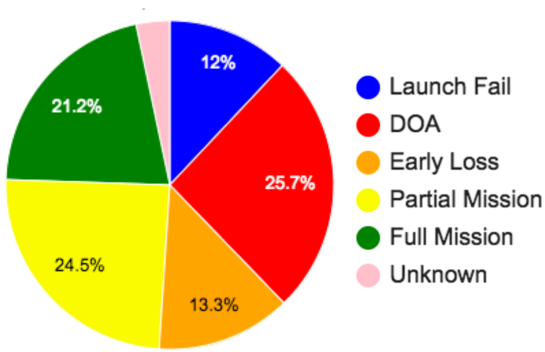

Figure 12: Mission Status for all University-Class Missions

The second observation from Figure 12 is that about 40% of all manifested university-class missions fail to achieve any of their primary mission objectives (i.e. the DOA and Early Loss categories on the chart). When the launch failures are factored out, the failure rate approaches 50%.

What is happening? First, let us factor out the launch failures and subdivide missions into our three builder categories: flagships (Figure 13), prolific independents (Figure 14) and regular independents (Figure 15). Doing so confirms observations from previous papers: flagships have a relatively low failure rate (25%) compared to regular independents (65%). Prolific programs split the difference.

Why is there such a difference? As outline in previous papers, we believe that flagship programs, by nature of their national government sponsorship, have access to resources, facilities and mentoring that lead to greater mission success. By their very nature, independent schools do not have such access. And, since prolific schools manage to produce multiple missions, they have an opportunity to implement lessons learned and best practices into their development process. We find it very encouraging to note that the prolific schools still have a failure rate near 40%, if only to point out that mission failure does not need to spell the end of a university spacecraft program. The prolific schools managed to persist through failure. Regardless of whether their persistence is due to visionary leadership, persuasive project managers or just sheer stubbornness, it would be worthwhile to study those nine prolific schools to identify common characteristics.

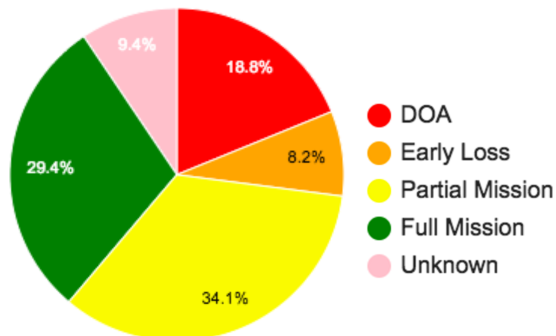

Figure 13: Mission Status for Flagship Schools that Reach Orbit

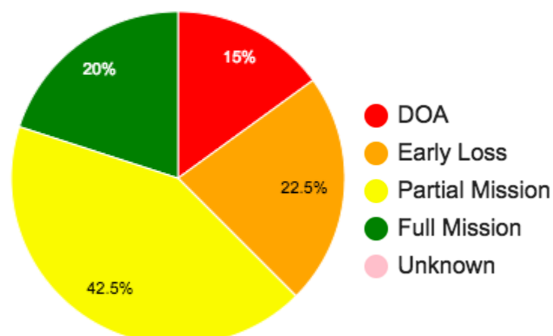

Figure 14: Mission Status for Prolific Independent Schools that Reach Orbit

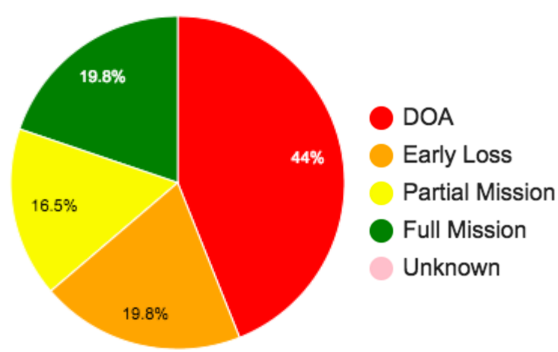

Figure 15: Mission Status for Regular Independent Schools that Reach Orbit

But we are sidestepping the question. Is a 65% failure rate among regular independent schools too high? Yes! Why do we continue to sponsor regular independent schools in the face of those dismal numbers? We don't know. But we think it is a combination of (a) the lack of knowledge of the actual failure rates and (b) the high turnover among regular independent schools. In the past seven years, between 5 and 11 regular independent schools produce their first spacecraft each year, and then never produce a second. In that way the loss of each mission is viewed in isolation, and not as a trend.

What can be done? In the lead author's twenty years of experience with university-class missions, he has noted that student-led projects often fail because of a lack of time/resources given to systems-level testing. This lack of testing is driven by a lack of time; university missions fly as secondaries, and they cannot force a slip in the launch schedule when typical integration problems arise. The only available option to these programs is to reduce or eliminate system-level testing.

Since it is unlikely that launch vehicles will slip their schedules to accommodate secondary payloads (and we are not recommending that they do!), the only option is to better prepare independent programs for the likelihood of schedule constraints, and help them prepare their design/complexity accordingly

At the other end, is a 25% failure rate among flagships too high? Maybe! We strongly assert that a failure rate in the 10-20% is an acceptable figure for university-class missions; these programs have cost and schedule constraints that will force an elevated risk profile. Universities should also accept an elevated risk profile as a matter of course; universities should be pushing the envelope of mission performance to develop new missions and new capabilities.

Therefore, to finally address the original question: the fact that university missions fail at a greater rate than professional missions is not a reason to dismiss university missions. The failure rate is too high for certain groups, and more could be done to introduce and enforce best practices for those groups.

CUBESATS AND DEBRIS

The (limited) risk of CubeSats compared to other sources of orbit debris is covered in great detail by the lead author in Reference 19. In this review, the collision risk posed by all CubeSats is used as a proxy for the collision risk of all university-class missions. Given that about a third of all CubeSats are university-class missions, and that the number of non-university CubeSats outnumbers the non-CubeSat university missions, this substitution is appropriate for the scope of this argument.

Argument Using Orders of Magnitude

Our first argument is simply to count the number of objects in orbit.

- 461 CubeSat-class spacecraft have been launched since 2000. 233 are currently in orbit (which means that half of the CubeSats launched have already deorbited). Similarly, only 244 university-class missions have reached orbit; 137 are CubeSats and already included in the CubeSat counts, and the other 107 are other form factors.
- By contrast, there have been more than 40,000 manmade objects placed into Earth orbit, of which about 17,000 remain. That number includes functional spacecraft, non-functional spacecraft, rocket bodies and (especially) fragments from collision and breakup of larger objects. About 13,000 of the objects remaining in orbit are classified as debris, leaving 4,000 'payloads' ('useful' spacecraft).[20]
- NASA's Office of Space Debris estimates there are 500,000 objects in Earth orbit between 1 cm and 10 cm in size (i.e., slightly smaller than a CubeSat).[20] This includes natural objects and manmade debris, although it should be noted that no more than 13,000 of those objects are manmade. In addition, the 500,000 number is an estimate; natural objects are much more difficult to detect using radar, as they lack the metals contained spacecraft.

In summary, out of 4,000 active spacecraft in Earth orbit, only 233 are CubeSats, and less than 100 are other university-class missions. Meanwhile, there are some 13,000 debris objects, and on the order of 500,000 natural objects. University-class spacecraft are a tiny fraction of the objects on-orbit, and will continue to be.

Second Argument: Fragmentation is More Dangerous

In fact, a few documented collisions have created more debris fragments than there are CubeSats on orbit.

- When Iridium-33 and Kosmos-2251 slammed into each other, 2 objects became 2,200 CubeSat-sized fragments.
- When China performed an antisatellite demonstration on its own Fengyun-1C spacecraft, at least 3,400 CubeSat-sized fragments were created. Evidence indicates that one of those fragments collided with the Russian BLITS spacecraft, creating at least two more debris fragments.[20]
- The lead article in Reference 20 discusses the need for the International Space Station (ISS) to take evasive maneuvers because of debris fragments. In

one case, the threatening fragment had been broken off from the 1500 kg METEOR 2-5, which has been in orbit, inactive, for about 35 years.

To first order, then, the number of CubeSats and university-class spacecraft on-orbit are dwarfed by the existence of fragmentation debris and natural objects. And collisions between existing, larger spacecraft have created many more debris fragments than the number of CubeSats on-orbit.

CONCLUSIONS

University-class missions are a relatively small element of the overall secondary launch market, but their significance is outsized. University-led spacecraft programs are an important source of recruitment and training for engineers and scientists entering the workforce. Such programs can flight-test novel or risky concepts – with no example more obvious, or more significant than the very CubeSat itself.

While the failure rate of university missions is too high, the high rates are concentrated with "one-and-done" independent schools; schools that produce multiple spacecraft see significant improvements in success. The failure rates of university programs should not approach zero, as universities are uniquely situated in the space industry to approach higher-risk, novel missions and technologies.

And, although dozens of university-class missions are launched each year, they pose a comparatively low risk for debris and collisions. If launch providers can maintain their best practices (i.e., placing university missions in naturally-decaying orbits with lifetimes of a few years), then university-class missions will continue to be low risk.

Finally, it was extremely rewarding to review the earlier papers we have published on this topic, and compare the concerns of five and ten years ago to the situation today. We can happily report that we were wrong about all of most dire predictions, and even our optimistic predictions were not optimistic enough. Ten years ago, a launch rate of 8-10 university-class missions per year was thought to be too good to be sustainable, whereas now 8 missions is the average quarterly output.

Such an observation causes us to be thankful for all of the industry professionals who went far out of their way to support university projects – too many to name in this paper, but AFRL, NSF and NASA ELaNa deserve special recognition, as do the organizers and sponsors of this conference. We hope that they are able to see and enjoy the fruits of their efforts. We look forward to revisiting this topic in another 2-3 years to see how much everything has changed, again. We hope that it is as pleasant a paper to write as this one has been.

ACKNOWLEDGMENTS

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APPENDIX

All University-Class Missions, 1971-2015

Launch Date	Mission	School	Mission Status
1/23/70	Australis OSCAR 5	University of Melbourne	5
10/6/81	OSCAR 9 (UoSAT 1)	University of Surrey	5
3/1/84	OSCAR 11 (UoSAT 2)	University of Surrey	5
4/29/85	NUSAT 1	Weber State	5
1/22/90	OSCAR 18 (WEBERSAT)	Weber State	5
7/17/91	TUBSAT A	Technical University of Berlin	5
8/10/92	OSCAR 23 (KITSAT 1)	Korean Advanced Institute of Science and Technology	5
5/12/93	ARASENE	CNES Amateurs (?)	5
9/26/93	KITSAT B	Korean Advanced Institute of Science and Technology	5
1/25/94	TUBSAT B	Technical University of Berlin	2
2/3/94	BREMSAT	University of Bremen	5
3/28/95	UNAMSAT A	National University of Mexico	1
3/28/95	Techsat 1 (Gurwin 1 Oscar (29))	Technion Institute of Technology	1
9/5/96	UNAMSAT B	National University of Mexico	2
10/5/97	SPUTNIK JR	Russian high school students	5
10/25/97	Falcon Gold	US Air Force Academy	5
10/30/97	TEAMSAT	ESTEC	4
7/7/98	TUBSAT N	Technical University of Berlin	4
7/7/98	TUBSAT N1	Technical University of Berlin	5
7/10/98	TECHSAT 1B	Technion Institute of Technology	5
10/24/98	SEDSAT 1	University of Alabama-Huntsville	2
10/29/98	PAN SAT	Naval Postgraduate School	5
2/23/99	SUNSAT	University of Stellenbosch	5
5/26/99	KITSAT 3	Korean Advanced Institute of Science and Technology	5
5/26/99	TUBSAT-A	Technical University of Berlin	5
1/27/00	JAWSAT	Weber State	2
1/27/00	OPAL	Stanford University	5
1/27/00	FALCONSAT	US Air Force Academy	3
1/27/00	ASUSAT	Arizona State University	3
2/10/00	PICOSAT 3 (JAK)	Santa Clara University	2
2/12/00	PICOSAT 4 (Thelma)	Santa Clara University	2
2/12/00	PICOSAT 5 (Louise)	Santa Clara University	2
6/28/00	TZINGHUA 1	Tsinghua University	5
9/26/00	SAUDISAT 1A	King Abdulaziz City for Science & Technology	5
9/26/00	UNISAT	University of Rome "La Sapienza"	5
9/26/00	SAUDISAT 1B	King Abdulaziz City for Science & Technology	2
11/21/00	MUNIN	Umea University / Lulea University of Technology	5
9/30/01	PCSAT	US Naval Academy	5
9/30/01	SAPPHIRE	Stanford University	5
12/10/01	MAROC TUBSAT	Technical University of Berlin	5
12/20/02	SAUDISAT 1C	King Abdulaziz City for Science & Technology	5

12/20/02	UNISAT 2	University of Rome "La Sapienza"	5
6/30/03	DTUSAT 1	Technical University of Denmark	2
6/30/03	CUTE-1 (CO-55)	Tokyo Institute of Technology	3
6/30/03	QUAKESAT 1	Stanford University	5
6/30/03	AAU CUBESAT 1	Aalborg University	2
6/30/03	CANX-1	UTIAS (University of Toronto)	2
6/30/03	CUBESAT XI-IV (CO-57)	University of Tokyo	4
8/22/03	UNOSAT 1	Universidade Norte do Parana	1
9/27/03	MOZHAYETS 4	Mozhaiskiy Space Engineering Academy	5
9/27/03	KAISTSAT 4 / STSAT-1	Korean Advanced Institute of Science and Technology	5
6/29/04	SAUDICOMSAT 1	King Abdulaziz City for Science & Technology	4
6/29/04	SAUDICOMSAT 2	King Abdulaziz City for Science & Technology	4
6/29/04	SAUDISAT 2	King Abdulaziz City for Science & Technology	4
6/29/04	UNISAT 3	University of Rome "La Sapienza"	5
12/21/04	3CS: Ralphie	New Mexico State University	1
12/21/04	3CS: Sparkie	Arizona State University	1
8/3/05	PCSat 2	US Naval Academy	5
10/27/05	Mozhayets 5	Mozhaiskiy Space Engineering Academy	2
10/27/05	UWE-1	University of Wurzburg	3
10/27/05	SSETI-EXPRESS	ESTEC	2
10/27/05	CUBESAT XI-V (CO-58)	University of Tokyo	5
10/27/05	Ncube 2	Norweigan Universities	2
2/21/06	CUTE 1.7	Tokyo Institute of Technology	2
3/24/06	FalconSat 2	US Air Force Academy	1
7/26/06	SEEDS	Nihon University	1
7/26/06	SACRED	University of Arizona	1
7/26/06	Rincon 1	University of Arizona	1
7/26/06	Ncube 1	Norweigan Universities	1
7/26/06	MEROPE	Montana State University	1
7/26/06	Mea Huaka'I (Voyager)	University of Hawaii	1
7/26/06	KUTESat Pathfinder	University of Kansas	1
7/26/06	ION	University of Illinois	1
7/26/06	ICECube 2	Cornell University	1
7/26/06	ICECube 1	Cornell University	1
7/26/06	HAUSAT 1	Hankuk Aviation University	1
7/26/06	CP 2	Cal Poly	1
7/26/06	CP 1 (K7RR-Sat)	Cal Poly	1
7/26/06	PicPot	Politecnico di Torino	1
7/26/06	Unisat 4	University of Rome "La Sapienza"	1
7/26/06	Baumanets 1	Bauman Moscow State Technical University	1
9/22/06	HITSAT (HO-59)	Hokkaido Institute of Technology	4
12/10/06	ANDE FCAL SPHERE 2	US Naval Academy	5
12/20/06	RAFT (NO 60)	US Naval Academy	5
12/20/06	MARSCOM	US Naval Academy	5
1/10/07	PEHUENSAT 1	National University of Comahue	5
3/9/07	MIDSTAR 1	US Naval Academy	4
3/9/07	FALCONSAT 3	US Air Force Academy	4

4/17/07	SAUDICOMSAT 7	King Abdulaziz City for Science & Technology	4
4/17/07	SAUDICOMSAT 6	King Abdulaziz City for Science & Technology	4
4/17/07	SAUDICOMSAT 5	King Abdulaziz City for Science & Technology	4
4/17/07	SAUDICOMSAT 3	King Abdulaziz City for Science & Technology	4
4/17/07	SAUDICOMSAT 4	King Abdulaziz City for Science & Technology	4
4/17/07	LIBERTAD 1	University of Sergio Arboleda	2
4/17/07	CP3	Cal Poly	2
4/17/07	CAPE 1	University of Louisiana	3
4/17/07	CP4	Cal Poly	3
9/25/07	YES2/FOTINO	ESTEC	2
9/25/07	YES2/FLOYD	ESTEC	5
4/28/08	CUTE-1.7+APD II	Tokyo Institute of Technology	5
4/28/08	COMPASS 1	Fachhochschule Aachen	5
4/28/08	AAUSAT 2	Aalborg University	5
4/28/08	DELFI C3 (DO-64)	Technical University of Delft	5
4/28/08	CANX 2	UTIAS (University of Toronto)	5
4/28/08	SEEDS 2 (CO-66)	Nihon University	5
1/23/09	PRISM (HITOMI)	University of Tokyo	5
1/23/09	SPRITE-SAT (RISING)	Tohoku University	3
1/23/09	STARS (KUKAI)	Kagawa University	3
1/23/09	KKS-1 (KISEKI)	Tokyo Metropolitan College of Industrial Technology	3
4/20/09	ANUSAT	Anna University	5
5/19/09	CP 6	Cal Poly	4
7/15/09	BEVO 1	University of Texas	2
7/15/09	DRAGONSAT 2 (AggieSat 2)	Texas A&M University	4
9/17/09	UGATUSAT	Ufa State Aviation Technical University	2
9/17/09	SUMBANDILA	University of Stellenbosch	5
9/23/09	SWISSCUBE (SwissCube 1)	Ecole Polytechnique Federale de Lausanne	4
9/23/09	BEESAT	Technical University of Berlin	5
9/23/09	UWE-2	University of Wurzburg	2
9/23/09	ITu-pSAT 1	Istanbul Technical University	2
5/20/10	HAYATO (K-SAT)	Kagoshima University	2
5/20/10	WASEDA-SAT2	Waseda University	2
5/20/10	NEGAI-STAR (Negai-Boshi)	Soka University	5
5/20/10	UNITEC-1	University Space Engineering Consortium	2
7/12/10	STUDSAT	Indian university consortium	2
7/12/10	TISAT 1	Scuola universitaria della Svizzera italiana	5
11/20/10	RAX 1 (USA 218)	University of Michigan	4
11/20/10	FALCONSAT 5 (USA 221)	US Air Force Academy	4
11/20/10	FAST 1 (USA 222)	University of Texas	4
11/20/10	FAST 2 (USA 228)	University of Texas	4
12/8/10	Mayflower-Caerus	University of Southern California	2
3/4/11	Hermes	Colorado Space Grant Consortium	1
3/4/11	KySat 1	Kentucky Space	1
3/4/11	E1P (Explorer 1 Prime)	Montana State University	1
4/20/11	YOUTHSAT	M.V. Lomonosov Moscow state university	4
4/20/11	XSAT	Nanyang Technological University	5

8/17/11	EDUSAT	University of Rome "La Sapienza"	4
10/12/11	JUGNU	Indian Institute of Technology Kanpur	4
10/28/11	DICE 1 (DICE X)	Utah State University	5
10/28/11	DICE 2 (DICE Y)	Utah State University	5
10/28/11	RAX 2	University of Michigan	5
10/28/11	AubieSat1 (AO-71)	Auburn University	3
10/28/11	M-Cubed (w/HRBE)	Montana State University	2
10/28/11	HRBE (Explorer-1 PRIME)	University of Michigan	4
11/9/11	TX 1	Nanjing University	4
2/13/12	ALMASAT-1	University of Bologna	2
2/13/12	e-st@r	Politecnico di Torino	2
2/13/12	Goliat	University of Bucharest	2
2/13/12	MaSat 1 (MO-72)	Budapest University of Technology and Economics	5
2/13/12	XaTcobeo	University of Vigo	5
2/13/12	PW-Sat 1	Warsaw University of Technology	2
2/13/12	ROBUSTA	University of Montpellier II	2
2/13/12	UniCubeSat-GGs	University of Rome "La Sapienza"	2
5/17/12	HORYU 2	Kyushu Institute of Technology (KIT)	4
9/13/12	CSSWE	University of Colorado LASP	5
9/13/12	CXBN	Kentucky Space	3
9/13/12	CP5	Cal Poly	3
10/4/12	Raiko	Tohoku University	5
10/4/12	FITSAT-1 (NIWAKA)	Fukuoka Institute of Technology	5
10/4/12	TechEdSat	San Jose State University	4
10/4/12	F1	FPT Technology Research Institute	2
2/25/13	AAUSAT 3	Aalborg University	5
2/25/13	STRAND-1	University of Surrey	4
4/19/13	AIST 2	Samara Aerospace University	4
4/19/13	BeeSat 3	Technical University of Berlin	2
4/19/13	SOMP	Technical University of Dresden	3
4/19/13	BeeSat 2	Technical University of Berlin	4
4/26/13	TURKSAT 3USAT	Istanbul Technical University	3
5/7/13	ESTCube-1	University of Tartu	4
9/29/13	CUSat	Cornell University	3
9/29/13	Dande	Colorado Space Grant Consortium	3
11/20/13	CAPE 2	University of Louisiana	4
11/20/13	DragonSat	Drexel University	2
11/20/13	KYSat II	Kentucky Space	4
11/20/13	TJSat	Thomas Jefferson High School	2
11/20/13	NPS-SCAT	Naval Postgraduate School	3
11/20/13	COPPER	Saint Louis University	2
11/20/13	Black Knight	US Military Academy	2
11/20/13	SPA-1 Trailblazer	COSMIAC	2
11/20/13	SwampSat	University of Florida	2
11/20/13	Ho'oponopono-2	University of Hawaii	2
11/20/13	ChargerSat	University of Alabama-Huntsville	2
11/20/13	Vermont Lunar	Vermont Technical College	5

11/20/13	TechEdSat-3	San Jose State University	4
11/21/13	ZACUBE 1	Cape Peninsula University of Technology	4
11/21/13	UniSat 5	University of Rome "La Sapienza"	5
11/21/13	Delfi-n3Xt	Technical University of Delft	4
11/21/13	ICube 1	Institute of Space Technology Islamabad	2
11/21/13	HumSat-D	University of Vigo	4
11/21/13	$50SAT / BeakerSat 2 / Eagle 2	Kentucky Space	4
11/21/13	BeakerSat 1 / Eagle 1	Kentucky Space	4
11/21/13	VELOX-P 2	Nanyang Technological University	4
11/21/13	First-MOVE	Technical University of Munich	3
11/21/13	PUCP-SAT 1	Pontifical Catholic University of Peru	3
11/21/13	QubeScout	University of Maryland Baltimore County	2
11/21/13	HiNCube	Narvik University College	2
11/21/13	UWE 3	University of Wurzburg	4
12/6/13	Pocket-PUCP	Pontifical Catholic University of Peru	2
12/6/13	FIREBIRD 1	Montana State University	4
12/6/13	FIREBIRD 2	Montana State University	4
12/6/13	M-Cubed-2	University of Michigan	4
12/6/13	CUNYSat-1	City University of New York	2
12/28/13	AIST 1 (RS-41)	Samara Aerospace University	4
2/27/14	ShindaiSat	Shinsu University	3
2/27/14	IFT 1 (Yui)	University of Tsukuba	2
2/27/14	OPUSAT (CosMoz)	Osaka Prefecture University	3
2/27/14	TeikyoSat 3	Teikyou University	2
2/27/14	INVADER (CO-77)	Tama Art University	5
2/27/14	KSAT 2 (Hayato 2)	Kagoshima University	3
2/27/14	STARS 2 (Gennai)	Kagawa University	3
2/28/14	UAPSat	Pontifical Catholic University of Peru	2
2/28/14	LitSat 1	Kaunas University of Technology	5
2/28/14	LituanicaSAT 1	Kaunas University of Technology	4
4/18/14	TSAT (TestSat-Lite)	Taylor University	4
4/18/14	ALL-STAR/THEIA	Colorado Space Grant Consortium	2
4/18/14	KickSat 1	Cornell University	3
5/24/14	UNIFORM 1	Wakayama University	4
5/24/14	Rising 2	Tohoku University	5
5/24/14	SPROUT	Nihon University	4
6/19/14	Hodoyoshi 4	University of Tokyo	4
6/19/14	UniSat 6	University of Rome "La Sapienza"	4
6/19/14	Hodoyoshi 3	University of Tokyo	4
6/19/14	PACE	National Cheng Kung University	2
6/19/14	DTUSat 2	Technical University of Denmark	2
6/19/14	ANTELSAT	University of the Republic (Uruguay)	4
6/19/14	PolyITAN 1	National Technical University of Ukraine	4
6/19/14	Tigrisat	University of Rome "La Sapienza"	4
6/19/14	BRITE-CA 2 (BRITE-Montreal CanX 3F)	UTIAS (University of Toronto)	1
6/30/14	VELOX PIII	Nanyang Technological University	1
6/30/14	VELOX I-NSAT	Nanyang Technological University	3

8/19/14	Chasqui 1	National University of Engineering	2
10/28/14	RACE	University of Texas	1
11/6/14	ChubuSat 1	Nagoya University Daido University	3
11/6/14	QSAT-EOS	Kyushu University	4
11/6/14	Tsubame	Tokyo Institute of Technology	3
1/31/15	FIREBIRD-IIA	Montana State University	4
1/31/15	FIREBIRD-IIB	Montana State University	4
1/31/15	EXOCUBE (CP10)	Cal Poly	3
3/4/15	TechEdSat 4 (TES 4)	San Jose State University	2
3/4/15	MicroMAS	MIT	2
3/4/15	Lambdasat	Greek Silicon Valley folks	3
5/20/15	USS Langley	US Naval Academy	2
5/20/15	OptiCube 1	Cal Poly	5
5/20/15	OptiCube 2	Cal Poly	5
5/20/15	OptiCube 3	Cal Poly	5
9/17/15	SERPENS	SERPENS	2
9/17/15	S-CUBE	Tohoku University	2
9/19/15	Zheda Pixing 2A	Zhejiang University	?
9/19/15	Zheda Pixing 2B	Zhejiang University	?
9/19/15	ZJ 2 (Kongjian Shiyan 1) NORAD UNCERTAIN	Tsinghua University	?
9/19/15	Naxing 2	Tsinghua University	?
9/19/15	LilacSat 2 (CAS 3H)	Harbin Institute of Technology	4
9/19/15	Zijing 1 (NORAD UNCERTAIN)	Tsinghua University	?
9/25/15	NJUST 2 (TW 1B)	Nanjing University	?
10/5/15	AAUSAT-5	Aalborg University	3
10/8/15	BisonSat	Salish Kootenai College	3
10/8/15	ARC-1	University of Alaska Fairbanks	2
10/8/15	PropCube Merryweather	Naval Postgraduate School	?
10/8/15	PropCube Flora	Naval Postgraduate School	?
11/3/15	PrintSat	Montana State University	1
11/3/15	Argus	Saint Louis University	1
11/3/15	HiakaSat	University of Hawaii	1
12/6/15	AggieSat 4	Texas A&M University	2
12/6/15	Bevo 2	University of Texas	3
12/6/15	MinXSS	University of Colorado LASP	4
12/6/15	CADRE	University of Michigan	2
12/6/15	STMSat 1	St. Thomas More Cathedral School	2
2/17/16	ChubuSat 2 (Kinshachi 2)	Nagoya University Daido University	1
2/17/16	ChubuSat 3 (Kinshachi 3)	Nagoya University Daido University	1
2/17/16	Horyu 4 (AEGIS)	Kyusyu Institute of Technology (KIT)	1
3/31/16	Tomsk-TPU 120	Tomsk Polytechnic University	1
4/25/16	OUFTI 1	University de Liege	3
4/25/16	e-st@r 2	Politecnico di Torino	1
4/25/16	AAUSAT-4	Aalborg University	4
4/28/16	Aist 2D	Samara Aerospace University	4
4/28/16	SamSat-218/D (Kontakt-Nanosputnik)	Samara Aerospace University	3