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Reliving 24 Years in the Next 12 Minutes: A Statistical and Personal History of University-Class Satellites

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ABSTRACT

In 2018, university-class satellites -- spacecraft built by university students for the express purpose of student training -- are widely accepted as a means to recruit undergraduate students into the space workforce, train them effectively before graduation and retain them in the field after graduation. Hundreds of undergraduates at dozens of schools around the world have directly contributed to missions that operated on-orbit. The spacecraft themselves are capable of performance research-grade science or demonstrate new enabling technologies. This was not always the case. For the first forty years of spaceflight, there were exceedingly few university-class missions; those that flew were expensive, marginally-performing and had modest success rates. What changed? Why are university-class missions now commonplace? And, with respect to on-orbit success, are they as good (or as bad) as rumor and hearsay make them out to be?

In this paper and all-too-brief talk, the history of university-class spacecraft will be discussed, with an emphasis on the types of missions and their success rates. Beginning in 1994 (the author's first time attending this conference, as a wide-eyed student) and reaching through to 2018 (the author's 21st, now as a world-weary professor) a statistical and anecdotal review of university-class spacecraft will be presented. Particular attention will be paid to addressing these questions:

1) What kinds of missions have been flown, are being flown and should be flown?
2) What are historical and present-day mission success rates for university-class missions?
3) Why are the mission success rates so poor?

INTRODUCTION

This author has been documenting the history of university-class space missions nearly 15 years.[1-12] 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, the short answer is: new data and new questions. As many more missions fly, it is possible to collect statistically-relevant data sets regarding university-class missions.

For this year, three questions are being addressed.

1. What kinds of missions have been flown, are being flown and should be flown?
2. What are the historical and present-day mission success rates for university-class missions?
3. Why are the mission success rates so poor?

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 – 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 2017, twelve 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 eight 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 author's experience as both student project manager and faculty advisor to university-class projects. The author accepts sole responsibility for any factual (or interpretative) errors found in this paper and welcome any corrections. *[The author has been cutting-and-pasting this disclaimer into every one of these papers for fourteen 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 2017 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.[13-16] 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 author of reference 16 for his extensive archive describing satellite contacts.

CENSUS DATA AND OBSERVATIONS

2018 marks the author's 21st Smallsat conference since his first visit, as a wide-eyed graduate student in 1994. Much has changed, for both the author, the conference and university-class missions.

In keeping with the reflective theme of this paper, the census data will be studied in three sections:

- **1994-2001** This period cover's the author's graduate student years, and could be called "BC" (Before CubeSat). It also corresponds to the development lifecycle of the Sapphire mission, the author's first. As will be shown, these years are characterized by a few, large(r) missions coming out of a few schools. During this period, the flagships dominated the university-class category.
- **2002-2009** This middle period marked the start of the CubeSat expansion. Although in 2018, the rise of the CubeSats seems inevitable, it was by no means a sure thing. (Shameless plug: check the bibliography and read my papers from the time.) This period started the growth of the independent university spacecraft developers.
- **2010-2017** CubeSats are firmly entrenched in the smallsat world. This period is also marked by a significant shift from flagships to independents. A lot of independents.

But don't just take my word for it. As shown in Figure 2, there have been 353 university-class spacecraft launched since 1980, and 344 of them since 1994. And while it is not a perfect split to divide the last 24 years into 8-year eras, it is still instructive to show how many university-class missions have come along in the latter portion of this time period.

In terms of simple numbers: from 1 January 1994 until 31 December 2017, there have been 344 university-class spacecraft launched from 166 educational institutions in 47 countries worldwide. Two-thirds of those missions have come in the last 8 years.

While, as shown in Figure 1, a significant number of university missions are not CubeSats, CubeSats do comprise a sizeable majority of the missions.

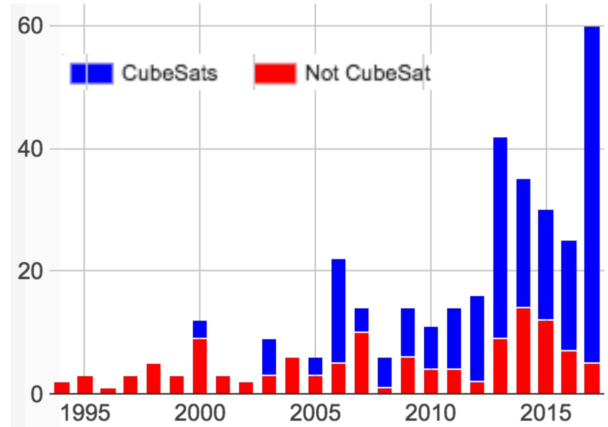

Figure 1: University-Class Missions by Form Factor

As we do in each paper, it is worth repeating how much has changed in the 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. This is worth noting and celebrating.

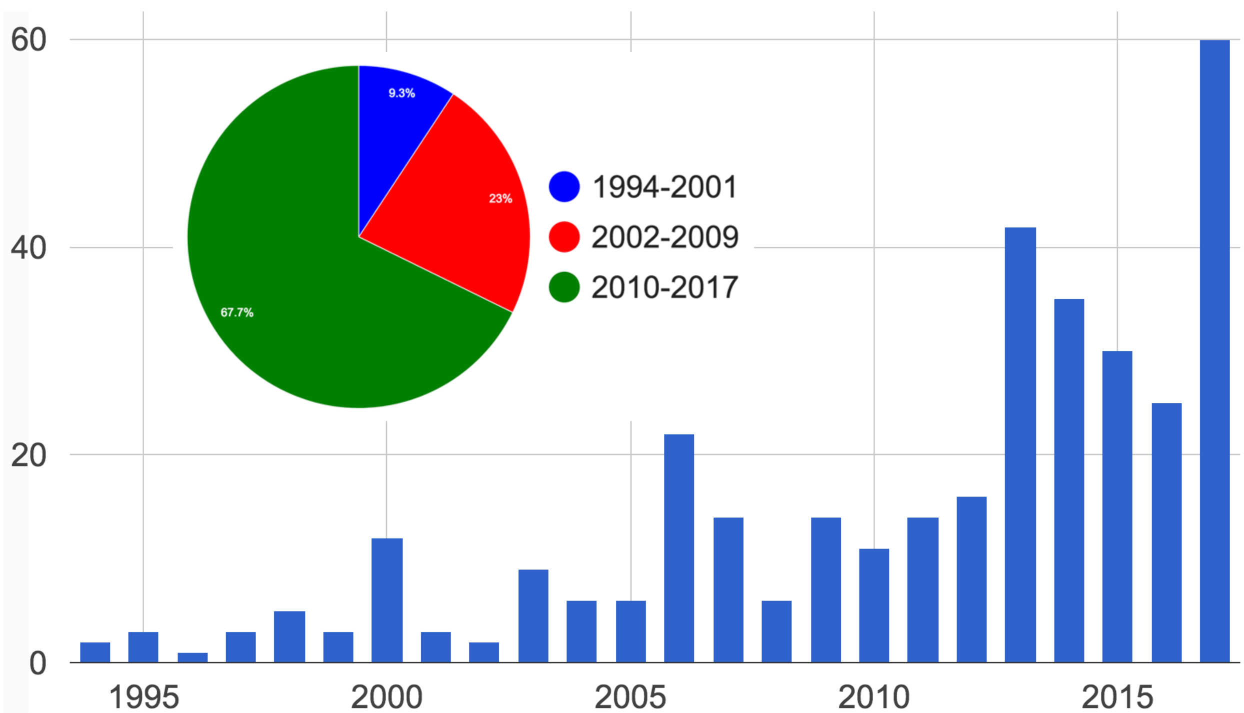

Figure 2: Number of University-Class Missions Launched Each Year, and Grouped by Era

Type of Builder

Three hundred fifty-three spacecraft is a large group to study, with a lot of variables within. Next, let us consider the flagship and independent categories of spacecraft builders. It is beneficial 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 3 and Figure 4; about a third of all independent missions have been produced by only 12 independent schools. Overall, independent schools produce nearly three-quarters of all university-class space missions and this share is climbing rapidly. As late as 2009, flagships still provided more than half; even two years ago, flagships were one third of the missions flown.

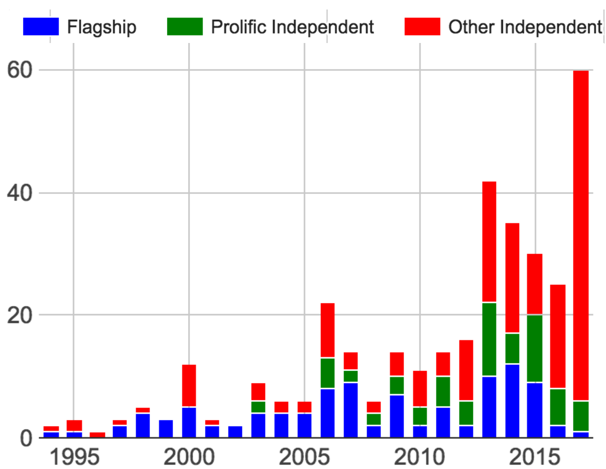

Figure 3: University-Class Missions Each Year by Type of Builder

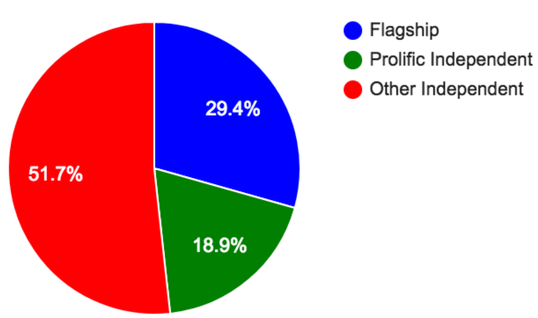

Figure 4: Allocation of University-Class Missions by Builder Type

As of December 2017, we have identified 128 schools that have built at least one university-class mission (Table 1). Flagships comprise 51 of those schools, and 12 of the 117 independent schools are prolific. It should be noted that 27 independent schools have flown their first mission since 2016, and 3 schools have become prolific in that time frame. Note that only 13 of the flagships schools fit the definition of prolific, and only 1 has joined the ranks since our last paper.

These 25 schools have produced 151 missions, an average of 6 per school and more than 40% of all missions; only 37 schools have flown 3 or more missions, and they are responsible for slightly more than half of the missions flown. By contrast, 95 of the 168 schools have produced only one mission. As was true in earlier reports, a subset 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, 47 independent schools have flown at least two missions, compared with only 26 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	1/23/70	1
2	University of Surrey	UK	10/6/81	4
3	Weber State	USA	4/29/85	3
4	Technical University of Berlin	Germany	7/17/91	11
5	KAIST	South Korea	8/10/92	4
6	CNES Amateurs (?)	France	5/12/93	1
7	University of Bremen	Germany	2/3/94	1
8	National University of Mexico	Mexico	3/28/95	2
9	Technion Institute of Technology	Israel	3/28/95	2
10	Universidad Politécnica de Madrid	Spain	7/7/95	2
11	Russian high school students	Russia	10/5/97	1
12	US Air Force Academy	USA	10/25/97	5
13	ESTEC	Europe	10/30/97	4

14	University of Colorado LASP	USA	2/26/98	2
15	University of Alabama-Huntsville	USA	10/24/98	2
16	Naval Postgraduate School	USA	10/29/98	2
17	University of Stellenbosch	South Africa	2/23/99	2
18	Arizona State University	USA	1/27/00	2
19	Stanford University	USA	1/27/00	3
20	Santa Clara University	USA	2/10/00	3
21	Tsinghua University	China	6/28/00	4
22	King Abdulaziz City for Science & Technology	Saudi Arabia	9/26/00	11
23	University of Rome "La Sapienza"	Italy	9/26/00	10
24	Umeå University / Luleå University of Technology	Sweden	11/21/00	1
25	US Naval Academy	USA	9/30/01	7
26	Aalborg University	Denmark	6/30/03	5
27	Technical University of Denmark	Denmark	6/30/03	2
28	Tokyo Institute of Technology	Japan	6/30/03	4
29	University of Tokyo	Japan	6/30/03	6
30	UTIAS (University of Toronto)	Canada	6/30/03	4
31	Universidade Norte do Paraná	Brazil	8/22/03	1
32	Mozhaiskiy Space Engineering Academy	Russia	9/27/03	2
33	New Mexico State University	USA	12/21/04	1
34	Norweigan Universities	Norway	10/27/05	2
35	University of Würzburg	Germany	10/27/05	3
36	Bauman Moscow State Technical University	Russia	7/26/06	2
37	Cal Poly	USA	7/26/06	11
38	Cornell University	USA	7/26/06	4
39	Hankuk Aviation University	South Korea	7/26/06	1
40	Montana State University	USA	7/26/06	8
41	Nihon University	Japan	7/26/06	3
42	Politecnico di Torino	Italy	7/26/06	3
43	University of Arizona	USA	7/26/06	2
44	University of Hawaii	USA	7/26/06	3

45	University of Illinois	USA	7/26/06	1
46	University of Kansas	USA	7/26/06	1
47	Hokkaido Institute of Technology	Japan	9/22/06	1
48	National University of Comahue	Argentina	1/10/07	1
49	University of Louisiana	USA	4/17/07	2
50	University of Sergio Arboleda	Colombia	4/17/07	1
51	Fachhochschule Aachen	Germany	4/28/08	2
52	Technical University of Delft	Netherlands	4/28/08	2
53	Kagawa University	Japan	1/23/09	3
54	Tohoku University	Japan	1/23/09	4
55	Tokyo Metropolitan College of Industrial Technology	Japan	1/23/09	1
56	Anna University	India	4/20/09	1
57	Texas A&M University	USA	7/15/09	2
58	University of Texas	USA	7/15/09	5
59	Ufa State Aviation Technical University	Russia	9/17/09	1
60	Ecole Polytechnique Fédérale de Lausanne	Switzerland	9/23/09	1
61	Istanbul Technical University	Turkey	9/23/09	4
62	Kagoshima University	Japan	5/20/10	2
63	Soka University	Japan	5/20/10	1
64	University Space Engineering Consortium	Japan	5/20/10	1
65	Waseda University	Japan	5/20/10	2
66	Indian university consortium	India	7/12/10	1
67	Scuola universitaria della Svizzera italiana	Switzerland	7/12/10	1
68	University of Michigan	USA	11/20/10	6
69	University of Southern California	USA	12/8/10	1
70	Colorado Space Grant Consortium	USA	3/4/11	3
71	Kentucky Space	USA	3/4/11	7
72	M.V. Lomonosov Moscow state university	Russia	4/20/11	1
73	Nanyang Technological University	Singapore	4/20/11	7

74	Indian Institute of Technology Kanpur	India	10/12/11	1
75	Auburn University	USA	10/28/11	1
76	Utah State University	USA	10/28/11	2
77	Nanjing University	China	11/9/11	2
78	Budapest University of Technology and Economics	Hungary	2/13/12	1
79	University of Bologna	Italy	2/13/12	1
80	University of Bucharest	Romania	2/13/12	1
81	University of Montpellier II	France	2/13/12	2
82	University of Vigo	Spain	2/13/12	2
83	Warsaw University of Technology	Poland	2/13/12	1
84	Kyushu Institute of Technology	Japan	5/17/12	7
85	FPT Technology Research Institute	Vietnam	10/4/12	1
86	Fukuoka Institute of Technology	Japan	10/4/12	1
87	San Jose State University	USA	10/4/12	5
88	Samara Aerospace University	Russia	4/19/13	4
89	Technical University of Dresden	Germany	4/19/13	2
90	University of Tartu	Estonia	5/7/13	1
91	COSMIAC	USA	11/20/13	1
92	Drexel University	USA	11/20/13	1
93	Saint Louis University	USA	11/20/13	2
94	Thomas Jefferson High School	USA	11/20/13	1
95	University of Florida	USA	11/20/13	1
96	US Military Academy	USA	11/20/13	1
97	Vermont Technical College	USA	11/20/13	1
98	Cape Peninsula University of Technology	South Africa	11/21/13	1
99	Institute of Space Technology Islamabad	Turkey	11/21/13	1
100	Narvik University College	Norway	11/21/13	1
101	Pontifical Catholic University of Peru	Peru	11/21/13	3
102	Technical University of Munich	Germany	11/21/13	1
103	University of Maryland Baltimore County	USA	11/21/13	1
104	City University of New York	USA	12/6/13	1
105	Kaunas University of Technology	Lithuania	1/9/14	2
106	Osaka Prefecture University	Japan	2/27/14	1
107	Shinsu University	Japan	2/27/14	1
108	Tama Art University	Japan	2/27/14	1
109	Teikyou University	Japan	2/27/14	1
110	University of Tsukuba	Japan	2/27/14	2
111	Taylor University	USA	4/18/14	1
112	Wakayama University	Japan	5/24/14	1
113	National Cheng Kung University	Taiwan	6/19/14	2
114	National Technical University of Ukraine	Ukraine	6/19/14	2
115	Space Lab Herzliya Science Center	Israel	6/19/14	1
116	University of the Republic (Uruguay)	Uruguay	6/19/14	1
117	Greek Silicon Valley Folks	USA	7/13/14	1
118	MIT/SSL	USA	7/13/14	2
119	National University of Engineering	Peru	8/19/14	1
120	Kyushu University	Japan	11/6/14	1
121	Nagoya University, Daido University	Japan	11/6/14	3
122	SERPENS	Brazil	8/19/15	1
123	Harbin Institute of Technology	China	9/19/15	2
124	Zhejiang University	China	9/19/15	2
125	Salish Kootenai College	USA	10/8/15	1
126	University of Alaska Fairbanks	USA	10/8/15	1
127	St. Thomas More Cathedral School	USA	12/6/15	1
128	National University of Singapore	Singapore	12/16/15	1
129	Tomsk Polytechnic University	Russia	3/31/16	1
130	Université de Liège	Belgium	4/25/16	1
131	College of Engineering, Pune	India	6/22/16	1

132	Sathyabama University	India	6/22/16	1
133	Shaanxi Engineering Laboratory	China	6/25/16	1
134	Universidad Politécnica de Cataluña	Spain	8/15/16	1
135	IIT Bombay	India	9/26/16	1
136	Escola Municipal Presidente Tancredo de Almeida Neves	Brazil	12/9/16	1
137	Nakashimada Engineering Works, Tohoku University	Japan	12/9/16	1
138	CAST	China	12/28/16	1
139	Nanjing University of Technology	China	1/9/17	1
140	Northwestern Polytechnical University	China	1/9/17	2
141	Al-Farabi Kazakh National University	Kazakhstan	2/15/17	1
142	Aalto University	Finland	4/18/17	2
143	Cal State Northridge	USA	4/18/17	1
144	Democritus University of Thrace	Greece	4/18/17	1
145	École de Mines	France	4/18/17	1
146	École Polytechnique	France	4/18/17	1
147	Nanjin University of Science and Technology	China	4/18/17	1
148	Seoul National University	South Korea	4/18/17	2
149	Universidad del Turabo	USA	4/18/17	1
150	University of Adelaide	Australia	4/18/17	1
151	University of Alberta	Canada	4/18/17	1
152	University of Colorado	USA	4/18/17	1
153	University of New South Wales	Australia	4/18/17	2
154	University of Patras	Greece	4/18/17	1
155	University of Sydney	Australia	4/18/17	1
156	Southwestern State University	Russia	6/14/17	3
157	Fachhochschule Wiener Neustadt	Austria	6/23/17	1
158	Noorul Islam University	India	6/23/17	1
159	Slovak Organization for Space Activities	Slovakia	6/23/17	1
160	Universidad de Chile	Chile	6/23/17	1
161	University College London	UK	6/23/17	1
162	Ventspils University	Latvia	6/23/17	1
163	CosmoMayak	Russia	7/14/17	1
164	Moscow Aviation Institute	Russia	7/14/17	1
165	University of Stuttgart	Germany	7/14/17	1
166	Penn State University	USA	8/14/17	1
167	Embry-Riddle	USA	11/18/17	1
168	Northwest Nazarene University	USA	11/18/17	1

MISSIONS AND SUCCESS RATES

And that brings us back to the original question.

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 5 and Figure 6, university-class missions have pursued a wide assortment of industry-relevant activities. If we split by our three eras (Figure 7, Figure 8, Figure 9), interesting trends emerge. The number of communications missions has remained relatively constant even as the total number of missions has increased; this indicates a trend away from the radio Amateur payloads from which the university-class programs emerged. For a time in the start of this century, most university-class missions were E-class (Beepsats), though the percentage has dropped off in the most recent era, replaced by science and technology demonstrations. This shift is indicative of two trends: the increased capability of small spacecraft, and the higher standards placed by NASA, NSF, JAXA, etc when sponsoring launches. 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 advanced missions.[10]

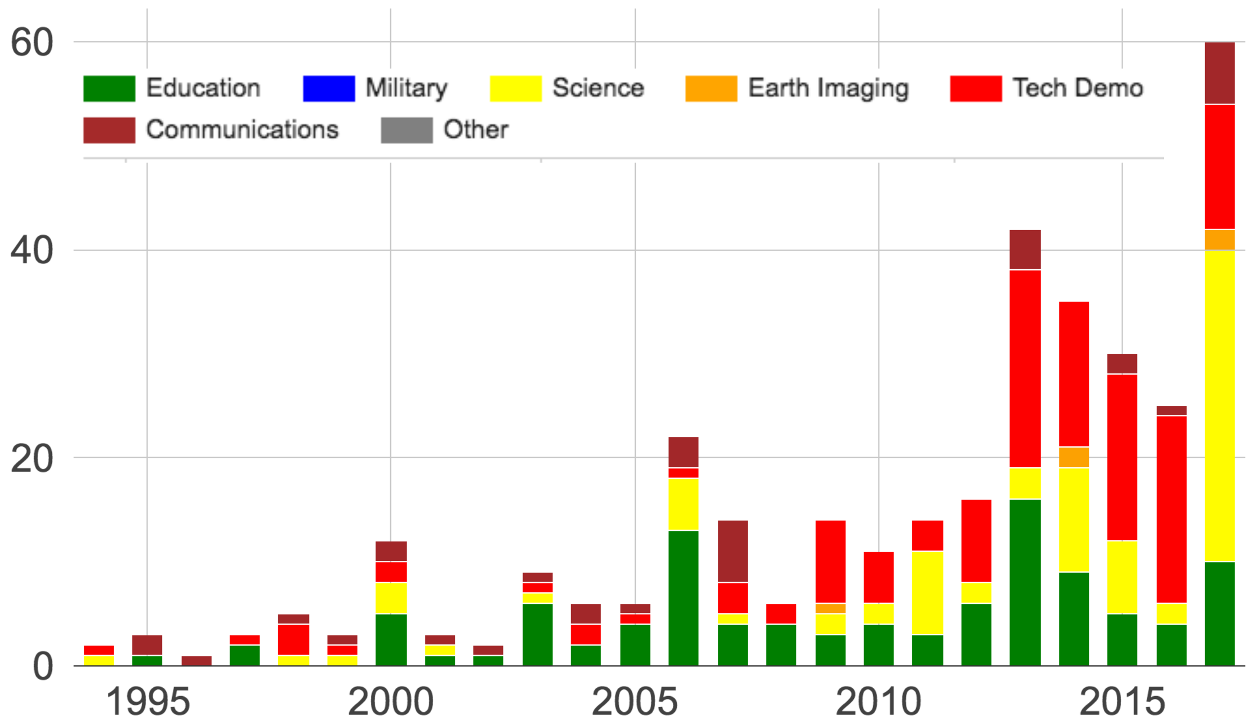

Figure 5: Mission Type by Launch Year

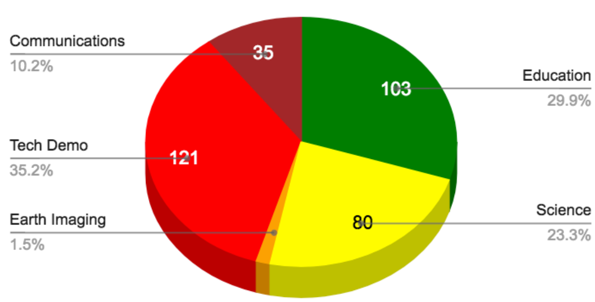

Figure 6. University-Class Missions by Mission Type, 1994-2017

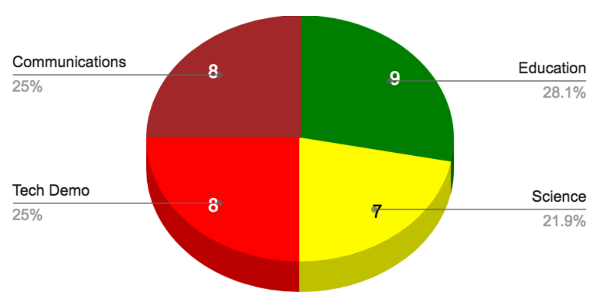

Figure 7. University-Class Missions by Mission Type, 1994-2001

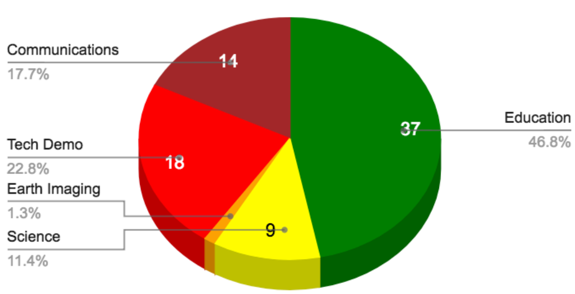

Figure 8. University-Class Missions by Mission Type, 2002-2009

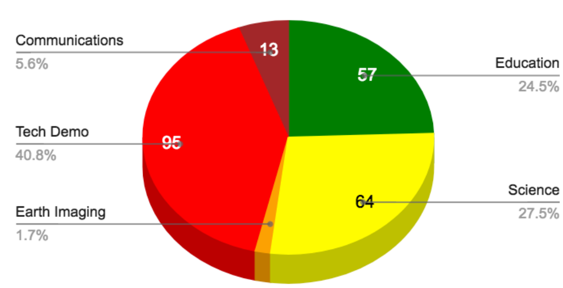

Figure 9. University-Class Missions by Mission Type, 2010-2017

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.

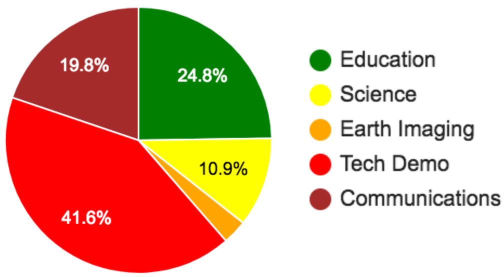

Figure 10: Mission Types for Flagship Schools

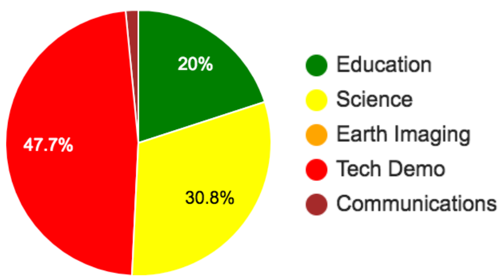

Figure 11: Mission Types for Prolific Independent Schools

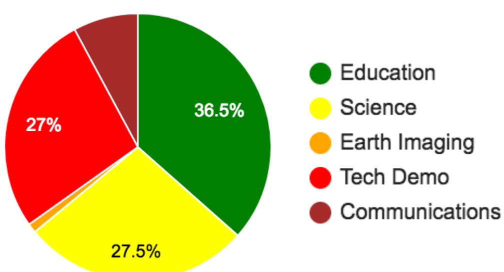

Figure 12: Mission Types for Regular Independent Schools

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.[1]

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 13). What is striking about this plot is first that about one-tenth 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 i, university-class missions tend to be launched in groups of 6 to 20. When a rocket fails, a lot of university missions are lost.

When we take a closer look at each of the eras (Figure 14, Figure 15, Figure 16), it looks as though university-class missions went through a string of bad luck in the middle era (2002-2009)

[1] 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.

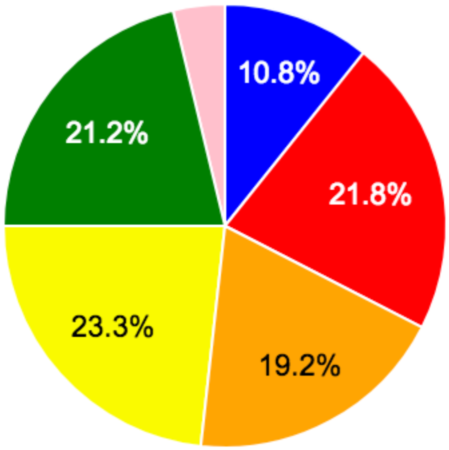

Figure 13. Mission Status for All University-Class Missions (1994-2017)

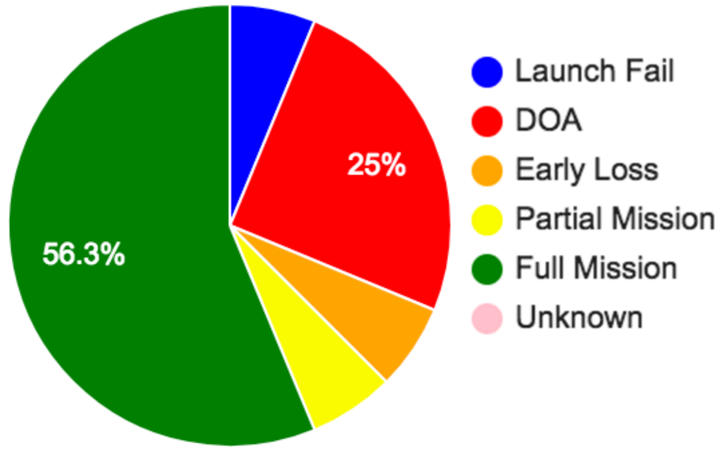

Figure 14. Mission Status for University-Class Missions (1994-2001)

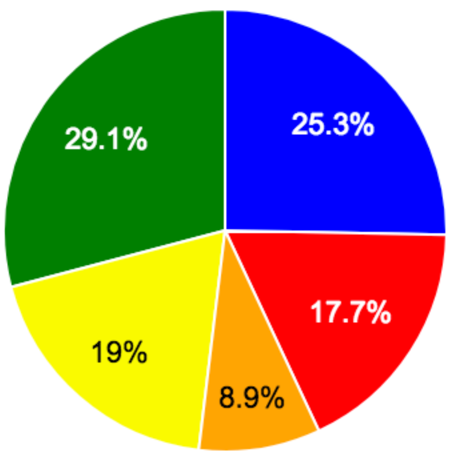

Figure 15. Mission Status for University-Class Missions (2002-2009)

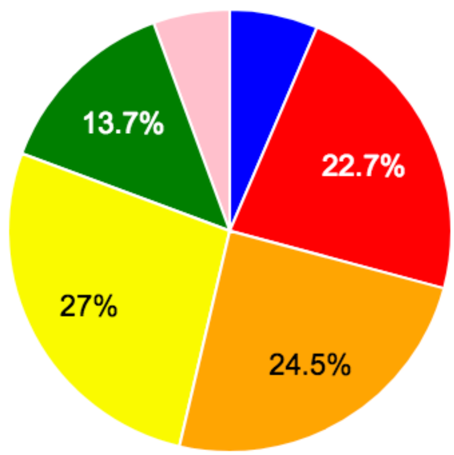

Figure 16. Mission Status for University-Class Missions (2010-2017)

The second observation from Figure 13 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%. Furthermore, mission success rates appear to be decreasing over time, from roughly two-thirds in the first era to on the order of 40% in over the last eight years.

What is happening? First, let us factor out the launch failures and subdivide missions into our three builder categories: flagships, prolific independents, and regular independents. Let us look at the performance of each of those categories during our three eras of study. This results in eight plots (there were no prolific independents flying in the 1994-2001 era), displayed in Figures 17-24.

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. However, as noted in Figures 20 and 21, the success rate for prolific missions has increased notably in the last eight years. Given that these schools are by definition flying multiple missions over multiple years, there is evidence that they are learning from past mistakes.

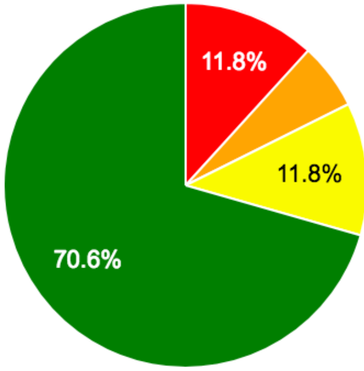

Figure 17. Mission Status (1994-2001) for Flagship Schools

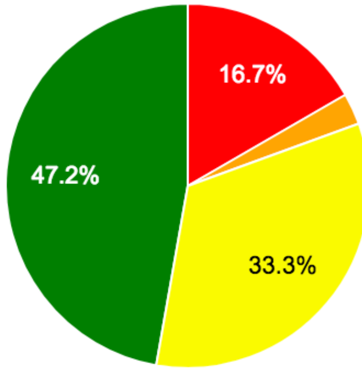

Figure 18. Mission Status (2002-2009) for Flagship Schools

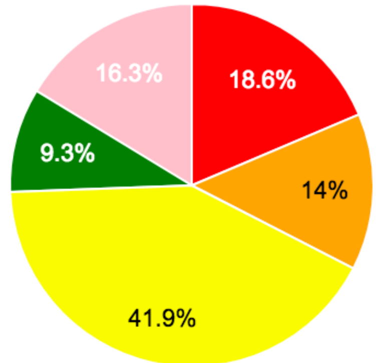

Figure 19. Mission Status (2010-2017) for Flagship Schools

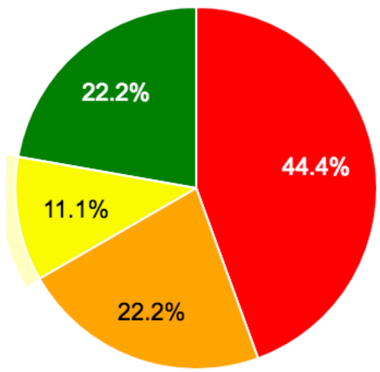

Figure 20. Mission Status (2002-2009) for Prolific Independent Schools

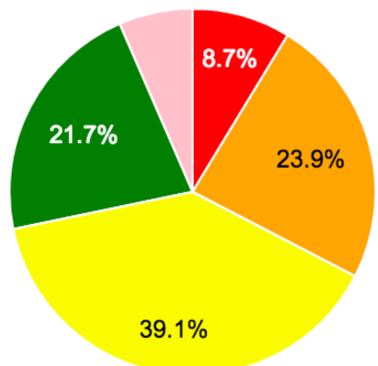

Figure 21. Mission Status (2010-2017) for Prolific Independent Schools

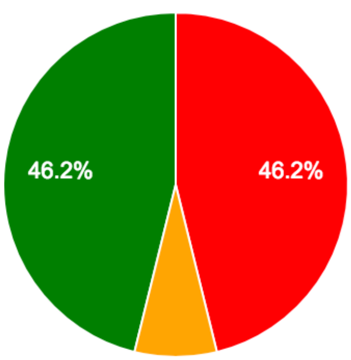

Figure 22. Mission Status (1994-2001) for Regular Independent Schools

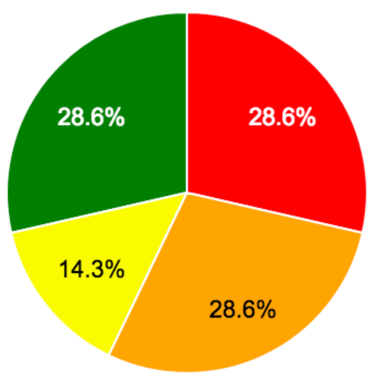

Figure 23. Mission Status (2002-2009) for Regular Independent Schools

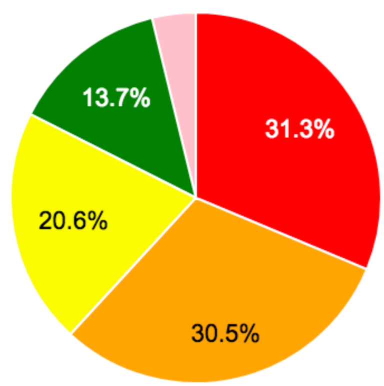

Figure 24. Mission Status (2010-2017) for Regular Independent Schools

The news is not so good for the regular independents however. As shown in Figures 22-24, the success rate for regular independents has stalled at around 33%, a slight drop from earlier eras. Contrasted with the prolific independents, this group as whole does not seem to be learning from mistakes.

Why is there such a difference? As outlined 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. 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 twelve prolific schools to identify common characteristics. In fact, the twelve prolific programs appear to be overtaking the flagship schools in terms of mission performance. Again, this is likely evidence that the prolific programs have developed good mission assurance practices; it also indicates that our "flagship" definition may not be as useful as it was 10 years ago.

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-five 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.

[Full, sad disclosure: the previous two paragraphs are direct cut-and-pastes from the author's 2016 Smallsat conference paper. Nothing has changed.]

At the other end, is a 25% failure rate among flagships and the prolific independents 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.

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.

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, 1971-2017

Launch Date	Contractor	Name	Mission Status
1/23/70	University of Melbourne	Australis OSCAR 5	5
10/6/81	University of Surrey	OSCAR 9 (UoSAT 1)	5
3/1/84	University of Surrey	OSCAR 11 (UoSAT 2)	5
4/29/85	Weber State	NUSAT 1	5
1/22/90	Weber State	OSCAR 18 (WEBERSAT)	5
7/17/91	Technical University of Berlin	TUBSAT A	5
8/10/92	Korean Advanced Institute of Science and Technology	OSCAR 23 (KITSAT 1)	5
5/12/93	CNES Amateurs (?)	ARASENE	5
9/26/93	Korean Advanced Institute of Science and Technology	KITSAT B	5
1/25/94	Technical University of Berlin	TUBSAT B	2
2/3/94	University of Bremen	BREMSAT	5
3/28/95	National University of Mexico	UNAMSAT A	1
3/28/95	Technion Institute of Technology	Techsat 1 (Gurwin 1 Oscar (29))	1
7/7/95	Universidad Polit√©cnica de Madrid	UPMSat-1	5
9/5/96	National University of Mexico	UNAMSAT B	2
10/5/97	Russian high school students	SPUTNIK JR	5
10/25/97	US Air Force Academy	Falcon Gold	5
10/30/97	ESTEC	TEAMSAT	4
7/7/98	Technical University of Berlin	TUBSAT N	4
7/7/98	Technical University of Berlin	TUBSAT N1	5
7/10/98	Technion Institute of Technology	TECHSAT 1B	5
10/24/98	University of Alabama-Huntsville	SEDSAT 1	2
10/29/98	Naval Postgraduate School	PAN SAT	5
2/23/99	University of Stellenbosch	SUNSAT	5
5/26/99	Korean Advanced Institute of Science and Technology	KITSAT 3	5
5/26/99	Technical University of Berlin	TUBSAT-A	5
1/27/00	Weber State	JAWSAT	2
1/27/00	Stanford University	OPAL	5
1/27/00	US Air Force Academy	FALCONSAT	3
1/27/00	Arizona State University	ASUSAT	3
2/10/00	Santa Clara University	PICOSAT 3 (JAK)	2
2/12/00	Santa Clara University	PICOSAT 4 (Thelma)	2
2/12/00	Santa Clara University	PICOSAT 5 (Louise)	2
6/28/00	Tsinghua University	TZINGHUA 1	5
9/26/00	King Abdulaziz City for Science & Technology	SAUDISAT 1A	5
9/26/00	University of Rome "La Sapienza"	UNISAT	5
9/26/00	King Abdulaziz City for Science & Technology	SAUDISAT 1B	2
11/21/00	Ume√• University / Lule√• University of Technology	MUNIN	5
9/30/01	US Naval Academy	PCSAT	5
9/30/01	Stanford University	SAPPHIRE	5
12/10/01	Technical University of Berlin	MAROC TUBSAT	5
12/20/02	King Abdulaziz City for Science & Technology	SAUDISAT 1C	5
12/20/02	University of Rome "La Sapienza"	UNISAT 2	5
6/30/03	Technical University of Denmark	DTUSAT 1	2
6/30/03	Tokyo Institute of Technology	CUTE-1 (CO-55)	3
6/30/03	Stanford University	QUAKESAT 1	5
6/30/03	Aalborg University	AAU CUBESAT 1	2
6/30/03	UTIAS (University of Toronto)	CANX-1	2
6/30/03	University of Tokyo	CUBESAT XI-IV (CO-57)	4
8/22/03	Universidade Norte do Paran√°	UNOSAT 1	1
9/27/03	Mozhaiskiy Space Engineering Academy	MOZHAYETS 4	5
9/27/03	Korean Advanced Institute of Science and Technology	KAISTSAT 4 / STSAT-1	5
6/29/04	King Abdulaziz City for Science & Technology	SAUDICOMSAT 1	4
6/29/04	King Abdulaziz City for Science & Technology	SAUDICOMSAT 2	4
6/29/04	King Abdulaziz City for Science & Technology	SAUDISAT 2	4
6/29/04	University of Rome "La Sapienza"	UNISAT 3	5
12/21/04	New Mexico State University	3CS: Ralphie	1
12/21/04	Arizona State University	3CS: Sparkie	1
8/3/05	US Naval Academy	PCSat 2	5

10/27/05	Mozhaiskiy Space Engineering Academy	Mozhayets 5	2
10/27/05	University of W√ºrzburg	UWE-1	3
10/27/05	ESTEC	SSETI-EXPRESS	2
10/27/05	University of Tokyo	CUBESAT XI-V (CO-58)	5
10/27/05	Norweigan Universities	Ncube 2	2
2/21/06	Tokyo Institute of Technology	CUTE 1.7	2
3/24/06	US Air Force Academy	FalconSat 2	1
7/26/06	Nihon University	SEEDS	1
7/26/06	University of Arizona	SACRED	1
7/26/06	University of Arizona	Rincon 1	1
7/26/06	Norweigan Universities	Ncube 1	1
7/26/06	Montana State University	MEROPE	1
7/26/06	University of Hawaii	Mea Huaka'I (Voyager)	1
7/26/06	University of Kansas	KUTESat Pathfinder	1
7/26/06	University of Illinois	ION	1
7/26/06	Cornell University	ICECube 2	1
7/26/06	Cornell University	ICECube 1	1
7/26/06	Hankuk Aviation University	HAUSAT 1	1
7/26/06	Cal Poly	CP 2	1
7/26/06	Cal Poly	CP 1 (K7RR-Sat)	1
7/26/06	Politecnico di Torino	PicPot	1
7/26/06	University of Rome "La Sapienza"	Unisat 4	1
7/26/06	Bauman Moscow State Technical University	Baumanets 1	1
9/22/06	Hokkaido Institute of Technology	HITSAT (HO-59)	4
12/10/06	US Naval Academy	ANDE FCAL SPHERE 2	5
12/20/06	US Naval Academy	RAFT (NO 60)	5
12/20/06	US Naval Academy	MARSCOM	5
1/10/07	National University of Comahue	PEHUENSAT 1	5
3/9/07	US Naval Academy	MIDSTAR 1	4
3/9/07	US Air Force Academy	FALCONSAT 3	4
4/17/07	King Abdulaziz City for Science & Technology	SAUDICOMSAT 7	4
4/17/07	King Abdulaziz City for Science & Technology	SAUDICOMSAT 6	4
4/17/07	King Abdulaziz City for Science & Technology	SAUDICOMSAT 5	4
4/17/07	King Abdulaziz City for Science & Technology	SAUDICOMSAT 3	4
4/17/07	King Abdulaziz City for Science & Technology	SAUDICOMSAT 4	4
4/17/07	University of Sergio Arboleda	LIBERTAD 1	2
4/17/07	Cal Poly	CP3	2
4/17/07	University of Louisiana	CAPE 1	3
4/17/07	Cal Poly	CP4	3
9/25/07	ESTEC	YES2/FOTINO	2
9/25/07	ESTEC	YES2/FLOYD	5
4/28/08	Tokyo Institute of Technology	CUTE-1.7+APD II	5
4/28/08	Fachhochschule Aachen	COMPASS 1	5
4/28/08	Aalborg University	AAUSAT 2	5
4/28/08	Technical University of Delft	DELFI C3 (DO-64)	5
4/28/08	UTIAS (University of Toronto)	CANX 2	5
4/28/08	Nihon University	SEEDS 2 (CO-66)	5
1/23/09	University of Tokyo	PRISM (HITOMI)	5
1/23/09	Tohoku University	SPRITE-SAT (RISING)	3
1/23/09	Kagawa University	STARS (KUKAI)	3
1/23/09	Tokyo Metropolitan College of Industrial Technology	KKS-1 (KISEKI)	3
4/20/09	Anna University	ANUSAT	5
5/19/09	Cal Poly	CP 6	4
7/15/09	University of Texas	BEVO 1	2
7/15/09	Texas A&M University	DRAGONSAT 2 (AggieSat 2)	4
9/17/09	Ufa State Aviation Technical University	UGATUSAT	2
9/17/09	University of Stellenbosch	SUMBANDILA	5
9/23/09	Ecole Polytechnique F√©d√©rale de Lausanne	SWISSCUBE (SwissCube 1)	4
9/23/09	Technical University of Berlin	BEESAT	5
9/23/09	University of W√ºrzburg	UWE-2	2
9/23/09	Istanbul Technical University	ITu-pSAT 1	2
5/20/10	Kagoshima University	HAYATO (K-SAT)	2
5/20/10	Waseda University	WASEDA-SAT2	2
5/20/10	Soka University	NEGAI-STAR (Negai-Boshi)	5
5/20/10	University Space Engineering Consortium	UNITEC-1	2
7/12/10	Indian university consortium	STUDSAT	2

7/12/10	Scuola universitaria della Svizzera italiana	TISAT 1	5
11/20/10	University of Michigan	RAX 1 (USA 218)	4
11/20/10	US Air Force Academy	FALCONSAT 5 (USA 221)	4
11/20/10	University of Texas	FAST 1 (USA 222)	4
11/20/10	University of Texas	FAST 2 (USA 228)	4
12/8/10	University of Southern California	Mayflower-Caerus	2
3/4/11	Colorado Space Grant Consortium	Hermes	1
3/4/11	Kentucky Space	KySat 1	1
3/4/11	Montana State University	E1P (Explorer 1 Prime)	1
4/20/11	M.V. Lomonosov Moscow state university	YOUTHSAT	4
4/20/11	Nanyang Technological University	XSAT	5
8/17/11	University of Rome "La Sapienza"	EDUSAT	4
10/12/11	Indian Institute of Technology Kanpur	JUGNU	4
10/28/11	Utah State University	DICE 1 (DICE X)	5
10/28/11	Utah State University	DICE 2 (DICE Y)	5
10/28/11	University of Michigan	RAX 2	5
10/28/11	Auburn University	AubieSat1 (AO-71)	3
10/28/11	Montana State University	HRBE (Explorer-1 PRIME)	4
10/28/11	University of Michigan	M-Cubed (w/HRBE)	2
11/9/11	Nanjing University	TX 1	4
2/13/12	University of Bologna	ALMASAT-1	2
2/13/12	Politecnico di Torino	e-st@r	2
2/13/12	University of Bucharest	Goliat	2
2/13/12	Budapest University of Technology and Economics	MaSat 1 (MO-72)	5
2/13/12	University of Vigo	XaTcobeo	5
2/13/12	Warsaw University of Technology	PW-Sat 1	2
2/13/12	University of Montpellier II	ROBUSTA	2
2/13/12	University of Rome "La Sapienza"	UniCubeSat-GGs	2
5/17/12	Kyushu Institute of Technology	HORYU 2	4
9/13/12	University of Colorado LASP	CSSWE	5
9/13/12	Kentucky Space	CXBN	3
9/13/12	Cal Poly	CP5	3
10/4/12	Tohoku University	Raiko	5
10/4/12	Fukuoka Institute of Technology	FITSAT-1 (NIWAKA)	5
10/4/12	San Jose State University	TechEdSat	4
10/4/12	FPT Technology Research Institute	F1	2
2/25/13	Aalborg University	AAUSAT 3	5
2/25/13	University of Surrey	STRAND-1	4
4/19/13	Samara Aerospace University	AIST 2	4
4/19/13	Technical University of Berlin	BeeSat 3	2
4/19/13	Technical University of Dresden	SOMP	3
4/19/13	Technical University of Berlin	BeeSat 2	4
4/26/13	Istanbul Technical University	TURKSAT 3USAT	3
5/7/13	University of Tartu	ESTCube-1	4
9/29/13	Cornell University	CUSat	3
9/29/13	Colorado Space Grant Consortium	Dande	3
11/20/13	University of Louisiana	CAPE 2	4
11/20/13	Drexel University	DragonSat	2
11/20/13	Kentucky Space	KYSat II	4
11/20/13	Thomas Jefferson High School	TJSat	2
11/20/13	Naval Postgraduate School	NPS-SCAT	3
11/20/13	Saint Louis University	COPPER	2
11/20/13	US Military Academy	Black Knight	2
11/20/13	COSMIAC	SPA-1 Trailblazer	2
11/20/13	University of Florida	SwampSat	2
11/20/13	University of Hawaii	Ho'oponopono-2	2
11/20/13	University of Alabama-Huntsville	ChargerSat	2
11/20/13	Vermont Technical College	Vermont Lunar	5
11/20/13	San Jose State University	TechEdSat-3	4
11/21/13	Cape Peninsula University of Technology	ZACUBE 1	4
11/21/13	University of Rome "La Sapienza"	UniSat 5	5
11/21/13	Technical University of Delft	Delfi-n3Xt	4
11/21/13	Institute of Space Technology Islamabad	ICube 1	2
11/21/13	University of Vigo	HumSat-D	5
11/21/13	Kentucky Space	$50SAT / BeakerSat 2 / Eagle 2	4
11/21/13	Kentucky Space	BeakerSat 1 / Eagle 1	4

11/21/13	Nanyang Technological University	VELOX-P 2	4
11/21/13	Technical University of Munich	First-MOVE	3
11/21/13	Pontifical Catholic University of Peru	PUCP-SAT 1	3
11/21/13	University of Maryland Baltimore County	QubeScout	2
11/21/13	Narvik University College	HiNCube	2
11/21/13	University of W√°rzburg	UWE 3	4
12/6/13	Pontifical Catholic University of Peru	Pocket-PUCP	2
12/6/13	Montana State University	FIREBIRD 1	4
12/6/13	Montana State University	FIREBIRD 2	4
12/6/13	University of Michigan	M-Cubed-2	4
12/6/13	City University of New York	CUNYSat-1	2
12/28/13	Samara Aerospace University	AIST 1 (RS-41)	4
2/27/14	Shinsu University	ShindaiSat	3
2/27/14	University of Tsukuba	IFT 1 (Yui)	2
2/27/14	Osaka Prefecture University	OPUSAT (CosMoz)	3
2/27/14	Teikyou University	TeikyoSat 3	2
2/27/14	Tama Art University	INVADER (CO-77)	5
2/27/14	Kagoshima University	KSAT 2 (Hayato 2)	3
2/27/14	Kagawa University	STARS 2 (Gennai)	3
1/9/14	Pontifical Catholic University of Peru	UAPSat	2
1/9/14	Kaunas University of Technology	LitSat 1	5
1/9/14	Kaunas University of Technology	LituanicaSAT 1	4
4/18/14	Taylor University	TSAT (TestSat-Lite)	4
4/18/14	Colorado Space Grant Consortium	ALL-STAR/THEIA	2
4/18/14	Cornell University	KickSat 1	3
5/24/14	Wakayama University	UNIFORM 1	4
5/24/14	Tohoku University	Rising 2	5
5/24/14	Nihon University	SPROUT	4
6/19/14	University of Tokyo	Hodoyoshi 4	4
6/19/14	University of Rome "La Sapienza"	UniSat 6	4
6/19/14	University of Tokyo	Hodoyoshi 3	4
6/19/14	National Cheng Kung University	PACE	2
6/19/14	Technical University of Denmark	DTUSat 2	2
6/19/14	University of the Republic (Uruguay)	ANTELSAT	4
6/19/14	National Technical University of Ukraine	PolyITAN 1	4
6/19/14	University of Rome "La Sapienza"	Tigrisat	4
6/19/14	UTIAS (University of Toronto)	BRITE-CA 2 (BRITE-Montreal CanX 3F)	1
6/30/14	Nanyang Technological University	VELOX PIII	1
6/30/14	Nanyang Technological University	VELOX I-NSAT	3
8/19/14	National University of Engineering	Chasqui 1	2
10/28/14	University of Texas	RACE	1
11/6/14	Nagoya University Daido University	ChubuSat 1	3
11/6/14	Kyushu University	QSAT-EOS	4
11/6/14	Tokyo Institute of Technology	Tsubame	3
1/31/15	Montana State University	FIREBIRD-IIA	5
1/31/15	Montana State University	FIREBIRD-IIB	5
1/31/15	Cal Poly	EXOCUBE (CP10)	3
7/13/14	San Jose State University	TechEdSat 4 (TES 4)	2
7/13/14	MIT/SSL	MicroMAS	3
7/13/14	Greek Silicon Valley folks	Lambdasat	3
5/20/15	US Naval Academy	USS Langley	2
5/20/15	Cal Poly	OptiCube 1	5
5/20/15	Cal Poly	OptiCube 2	5
5/20/15	Cal Poly	OptiCube 3	5
8/19/15	SERPENS	SERPENS	5
8/19/15	Tohoku University	S-CUBE	2
9/19/15	Zhejiang University	Zheda Pixing 2A	?
9/19/15	Zhejiang University	Zheda Pixing 2B	?
9/19/15	Tsinghua University	ZJ 2 (Kongjian Shiyan 1)	?
9/19/15	Tsinghua University	Naxing 2	?
9/19/15	Harbin Institute of Technology	LilacSat 2 (CAS 3H)	4
9/19/15	Tsinghua University	Zijing 1	?
9/25/15	Nanjing University	STU-2B (TW 1B)	4
10/5/15	Aalborg University	AAUSAT-5	3
10/8/15	Salish Kootenai College	BisonSat	3
10/8/15	University of Alaska Fairbanks	ARC-1	2

11/3/15	University of Hawaii	HiakaSat	1
11/3/15	Saint Louis University	Argus	1
11/3/15	Montana State University	PrintSat	1
12/6/15	Texas A&M University	AggieSat 4	2
12/6/15	University of Texas	Bevo 2	3
12/6/15	University of Michigan	CADRE	2
12/6/15	University of Colorado LASP	MinXSS	5
12/6/15	St. Thomas More Cathedral School	STMSat 1	2
12/16/15	Nanyang Technological University	VELOX C1	5
12/16/15	National University of Singapore	Galassia	4
12/16/15	Nanyang Technological University	VELOX II	5
2/17/16	Nagoya University Daido University	ChubuSat 2 (Kinshachi 2)	1
2/17/16	Nagoya University Daido University	ChubuSat 3 (Kinshachi 3)	1
2/17/16	Kyushu Institute of Technology	Horyu 4 (AEGIS)	1
3/31/16	Tomsk Polytechnic University	Tomsk-TPU 120	1
4/25/16	Universit√© de Li√®ge	OUFTI 1	3
4/25/16	Politecnico di Torino	e-st@r 2	1
4/25/16	Aalborg University	AAUSAT-4	4
4/28/16	Samara Aerospace University	Aist 2D	4
4/28/16	Samara Aerospace University	SamSat-218/D (Kontakt-Nanosputnik)	3
6/22/16	Sathyabama University	SathyabamaSat	3
6/22/16	College of Engineering Pune	Swayam	3
6/22/16	Technical University of Berlin	BeeSat-4	3
6/25/16	Shaanxi Engineering Laboratory	Aoxiang zhixing	4
8/15/16	Universidad Polit√©cnica de Catalu√±a	3CAT-2	5
9/26/16	IIT Bombay	Pratham	3
9/26/16	UTIAS (University of Toronto)	CanX-7	4
11/11/16	Cal Poly	Opticube 4	?
12/9/16	San Jose State University	TechEdSat 5	?
12/9/16	University of Tokyo	EGG	?
12/9/16	Nanyang Technological University	AOBA-VELOX 3	4
12/9/16	Kagawa University	STARS C	3
12/9/16	University of Tsukuba	Yui-2 (ITF-2)	5
12/9/16	Waseda University	Waseda-SAT 3	?
12/9/16	Escola Municipal Presidente Tancredo de Almeida Neves	Tancredo 1	4
12/28/16	CAST	BY70-1	5
1/9/17	Northwestern Polytechnical University	Xingyun Shiyan 1	?
1/9/17	Nanjing University of Technology	Kaidun 1	?
2/15/17	Al-Farabi Kazakh National University	Al-Farabi	?
4/18/17	Technical University of Dresden	SOMP-2 (QB50 DE02)	2
4/18/17	Istanbul Technical University	HAVELSAT (QB50 TR02)	2
4/18/17	Universidad del Turabo	QBUS 4 (QB50 US04 Columbia)	3
4/18/17	Kentucky Space	KySat 3 (SGSat)	3
4/18/17	Kentucky Space	CXBN 2	3
4/18/17	National Cheng Kung University	Phoenix (QB50 TW01)	3
4/18/17	√âcole Polytechnique	X-CubeSat (QB50 FR01)	3
4/18/17	Cal State Northridge	CSUNSat 1	4
4/18/17	University of Patras	UPSat (QB50 GR02)	2
4/18/17	√âcole de Mines	SpaceCube (QB50 FR05)	3
4/18/17	Space Lab Herzliya Science Center	Hoopoe (QB50 IL01)	3
4/18/17	University of New South Wales	UNSW-ECO (QB50 AU02)	4
4/18/17	Nanjin University of Science and Technology	NJUST 1 (QB50 CN03)	3
4/18/17	University of Colorado	QBUS 1 (QB50 US01 Challenger)	3
4/18/17	Democritus University of Thrace	DUTHSat (QB50 GR01)	2
4/18/17	Harbin Institute of Technology	LilacSat 1 (QB50 CN02)	3
4/18/17	Seoul National University	SNUSAT 1b (QB50 KR03)	3
4/18/17	Universidad Polit√©cnica de Madrid	QBITO (QB50 ES01)	2
4/18/17	Aalto University	Aalto 2 (QB50 FI01)	3
4/18/17	University of Adelaide	SUSat (QB50 AU01)	2
4/18/17	University of Sydney	i-INSPIRE 2 (QB50 AU03)	4
4/18/17	Seoul National University	SNUSAT 1 (QB50 KR02)	3
4/18/17	National Technical University of Ukraine	PolyITAN-2-SAU (QB50 UA01)	3
4/18/17	University of Alberta	Ex-Alta 1 (QB50 CA03)	4
4/18/17	Northwestern Polytechnical University	Aoxiang 1 (QB50 CN04)	2
4/18/17	Istanbul Technical University	BeEagleSat (QB50 TR01)	3
4/18/17	University of Michigan	QBUS 2 (QB50 U202 Atlantis)	3

6/23/17	University College London	UCLSat (QB50 GB03)	3
6/23/17	Noorul Islam University	NIUSAT (Keralshree)	3
6/23/17	University of Surrey	InflateSail (QB50 GB06)	5
6/23/17	Aalto University	Aalto 1	3
6/23/17	Fachhochschule Aachen	COMPASS 2	2
6/23/17	Fachhochschule Wiener Neustadt	Pegasus (QB50 AT03)	3
6/23/17	Universidad de Chile	SUCHAI	3
6/23/17	Slovak Organization for Space Activities	skCUBE	3
6/23/17	Ventspils University	Venta 1	3
6/23/17	University of Montpellier II	ROBUSTA 1B	3
6/23/17	University of Rome "La Sapienza"	URSA MAIOR (QB50 IT02)	3
7/14/17	University of Stuttgart	Flying Laptop	4
7/14/17	Technical University of Berlin	TechnoSat	4
7/14/17	CosmoMayak	Mayak	2
7/14/17	Moscow Aviation Institute	Iskra-MAI-85	2
7/14/17	Southwestern State University	Ecuador-UTE-YuZGU	3
6/3/17	Kyushu Institute of Technology	Bird B (BRAC Onnesha)	4
6/3/17	Kyushu Institute of Technology	Bird G (GhanaSat 1)	4
6/3/17	Kyushu Institute of Technology	Bird J (Toki)	4
6/3/17	Kyushu Institute of Technology	Bird M (Mazaalai NUMSAT 1)	4
6/3/17	Kyushu Institute of Technology	Bird N (EduSat 1)	4
6/14/17	Southwestern State University	Tanyusha-YuZGU 1	4
6/14/17	Southwestern State University	Tanyusha-YuZGU 2	4
8/14/17	MIT/SSL	ASTERIA	5
8/14/17	Penn State University	OSIRIS-3U	2
11/12/17	San Jose State University	TechEdSat-6	?
11/18/17	University of New South Wales	Buccaneer-RRM	4
11/18/17	Embry-Riddle	EagleSat	2
11/18/17	Northwest Nazarene University	MakerSat 0	4
11/28/17	Bauman Moscow State Technical University	Baumanets 2	1