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Beyond the Beep: Student-Built Satellites with Educational and 'Real' Missions

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ABSTRACT

Fifty student-built satellites have been launched in the past four years – as many as had been launched in the twenty years before. But this explosive growth has come at a cost: mission. About half of the satellites launched since 2003 carry no mission other than student education. But does that matter? For independent schools (those without long-term government sponsorship), the answer is a qualified yes. In this paper, we will analyze the launch history of student-built spacecraft to find recommendations for how independent schools can build sustained student-focused satellite projects.

INTRODUCTION

Assuming that the published launch schedule holds, the one-hundredth student-built satellite will be placed on a rocket in 2007. While that's an impressive total, it becomes more impressive when considering launch rates: we waited 13 years after the first student satellite (in 1981) to launch the 10th (in 1994), but only nine years elapsed between the 10th and 50th (in 2003). And then it took barely four years to launch the next 50! Therefore, it is fair to say that we have entered a golden age of student spacecraft, with many more on the way; informal estimates indicate that as many as 100 universities worldwide have pre-flight hardware.

While those numbers are good news, a deeper look at the numbers reveals two concerns: first, for most university programs, their first-every spacecraft in orbit is still 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. And, in a related issue, there is a growing disparity in launch rates and mission success between the "flagship" schools and the "independent" schools. (We define a flagship university as one designated by its government as a national center for spacecraft engineering research and development. Thus, by definition, flagships enjoy financial sponsorship, access to facilities and launch opportunities that the independent schools do not.) So, the question remains: how can independent schools build sustained university-class satellite programs?

This year, we will examine this question through the lens of the conference's theme, and ask, "Does the Mission Matter?" Do flagships and independents adopt different types of missions? (Short answer: yes.) Are independent schools choosing missions that make it more or less likely to get launches? (Short answer: maybe.) Are there types of missions that are going un-launched – and thus could indicate a hidden trove of opportunity for independent schools? (If you've read any of my previous papers on this topic,[1-3] you know the answer is a qualified yes.)

For this paper, we will begin by updating the tables and figures from previous papers, identifying any changes or emerging trends in terms of size, performance or the balance of flagship and independent schools. Next, we will analyze the launch manifest according to mission type in an attempt to draw general observations about the types of missions adopted by university-class projects. From there, we will focus our attention on five schools with sustained activity in space missions. We will conclude by offering advice on the types of missions that independent schools are not flying, but should. But first, we need to define our terms.

Definition: "University-Class"

As discussed in a previous paper,[3] we will restrict the discussion to ***university-class satellites***, which we narrowly define as has 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.

Again, 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).

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 welcomes any corrections.

UNIVERSITY-CLASS MANIFEST, UPDATED

A list of university-class spacecraft launched from 1981 until the submission of this paper (June 2007) are split between in Table 1 and Table 2, including the seven that are on the "official" manifests for the second half of 2007. 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 discussing the process for creating these tables.

Table 1. University-Class Spacecraft Launched From 1981 to 2003[4-7]

Launch	Launch ID	Launch Date	Mission	Primary School(s)	Nation	Mass (kg)	Mission Duration (months)	Status	Type
1981	1	10/6/1981	UoSAT-1 (UO-9)	University of Surrey	UK	52	96	N	S
1984	2	3/1/1984	UoSAT-2 (UO-11)	University of Surrey	UK	60	280	S	C
1985	3	4/29/1985	NUSAT	Weber State, Utah State University	USA	52	20	N	T
1990	4	1/22/1990	WeberSAT (WO-18)	Weber State	USA	16	96	N	C
1991	5	7/17/1991	TUBSAT-A	Technical University of Berlin	Germany	35	191	A	C
1992	6	8/10/1992	KITSAT-1 (KO-23)	Korean Advanced Institute of Science and Technology	Korea	49	77	N	T
1993	7	5/12/1993	ARSENE	CNES Amateurs (?)	France	154	4	F	C
	8	10/26/1993	KITSAT-2 (KO-25)	Korean Advanced Institute of Science and Technology	Korea	48	96	N	C
1994	9	1/25/1994	TUBSAT-B	Technical University of Berlin	Germany	45	1	F	T
	10	3/2/1994	BremSat	University of Bremen	Germany	63	11	N	S
1995	**11**	**8/28/1995**	Techsat 1-A	Technion Institute of Technology	Israel	50	-	LF	C
	11	8/28/1995	UNAMSAT-A	National University of Mexico	Mexico	10	-	LF	C
1996	12	5/9/1996	UNAMSAT-B (MO-30)	National University of Mexico	Mexico	10	0	F	C
1997	13	10/25/1997	Falcon Gold	US Air Force Academy	USA	18	0.5	N	T
	14	11/3/1997	RS-17	Russian high school students	Russia	3	2	N	E
1998	**15**	**7/7/1998**	TUBSAT-N	Technical University of Berlin	Germany	8	46	N	T
	15	7/7/1998	TUBSAT-N1	Technical University of Berlin	Germany	3	20	N	T
	16	7/10/1998	Techsat 1-B (GO-32)	Technion Institute of Technology	Israel	70	51	N	S
	17	**10/30/1998**	PANSAT (PO-34)	Naval Postgraduate School	USA	70	60	N	C
	17	10/30/1998	SEDSAT (SO-33)	University of Alabama, Huntsville	USA	41	33	F	T
1999	18	2/23/1999	Sunsat (SO-35)	University of Stellenbosch	South Africa	64	23	N	C
	19	**5/27/1999**	DLR-TUBSAT	Technical University of Berlin	Germany	45	97	A	S
	19	5/27/1999	KITSAT-3	Korean Advanced Institute of Science and Technology	Korea	110	55	N	T
2000	**20**	**1/27/2000**	JAWSAT (WO-39)	Weber State, USAFA	USA	191	1.0	F	T
	20	1/27/2000	Falconsat 1	US Air Force Academy	USA	52	1.0	F	E
	20	1/27/2000	ASUsat 1 (AO-37)	Arizona State University	USA	6	0.0	F	E
	20	1/27/2000	Opal (OO-38)	Stanford University	USA	23	29	N	T
	20	2/10/2000	JAK	Santa Clara University	USA	0.2	0	F	E
	20	**2/12/2000**	Louise	Santa Clara University	USA	0.5	0	F	S
	20	2/12/2000	Thelma	Santa Clara University	USA	0.5	0	F	S
	21	6/28/2000	Tsinghua-1	Tsinghua University	China	50	84	A	E
	22	**9/26/2000**	TiungSAT-1 (MO-46)	ATSB	Malaysia	50	39	N	S
	22	9/26/2000	Saudisat 1A (SO-41)	King Abdulaziz City for Science & Technology	Saudi Arabia	10	36	N	C
	22	9/26/2000	Saudisat 1B (SO-42)	King Abdulaziz City for Science & Technology	Saudi Arabia	10	27	N	C
	22	9/26/2000	UNISAT 1	University of Rome "La Sapienza"	Italy	12	24	N	E
	23	11/21/2000	Munin	Umeå University / Luleå University of Technology	Sweden	6	3	N	S
2001	**24**	**9/30/2001**	Sapphire (NO-45)	Stanford, USNA, Washington University	USA	20	36	N	E
	24	9/30/2001	PCSat 1 (NO-44)	US Naval Academy	USA	12	69	S	C
	25	10/12/2001	Maroc-TUBSAT	Technical University of Berlin	Germany	47	68	A	S
2002	**26**	**12/20/2002**	Saudisat 1C (SO-50)	King Abdulaziz City for Science & Technology	Saudi Arabia	10	54	A	C
	26	12/20/2002	UNISAT 2	University of Rome "La Sapienza"	Italy	17	24	N	E
2003	**27**	**6/30/2003**	QuakeSat	Stanford University	USA	3	48	S	S
	27	6/30/2003	CUTE-1 (CO-55)	Tokyo Institute of Technology	Japan	1	48	S	E
	27	6/30/2003	XI-IV (CO-57)	University of Tokyo	Japan	1	48	A	E
	27	6/30/2003	MOST	University of Toronto	Canada	60	48	A	S
	27	6/30/2003	CanX-1	University of Toronto	Canada	1	0	F	E
	27	6/30/2003	AAU Cubesat	University of Aalborg	Denmark	1	3	F	E
	27	6/30/2003	DTUsat	Technical University of Denmark	Denmark	1	0	F	E
	28	**9/27/2003**	STSAT-1	Korean Advanced Institute of Science and Technology	Korea	100	45	A	T
	28	9/27/2003	Mozhayets 4 (RS-22)	Mozhaisky military academy	Russia	64	45	A	C

Table 2. University-Class Spacecraft Launched (or Manifested) From 2004 to 2007

Launch	Launch ID	Launch Date	Mission	Primary School(s)	Nation	Mass (kg)	Mission Duration (months)	Status	Type
2004	29	4/18/2004	Naxing-1 (NS-1)	Tsinghua University	China	25	38	A	T
	30	6/29/2004	SaudiSat 2	King Abdulaziz City for Science & Technology	Saudi Arabia	15	36	A	S
	30	6/29/2004	SaudiComsat-1	King Abdulaziz City for Science & Technology	Saudi Arabia	12	36	A	C
	30	6/29/2004	SaudiComsat-2	King Abdulaziz City for Science & Technology	Saudi Arabia	12	36	A	C
	30	6/29/2004	UNISAT 3	University of Rome "La Sapienza"	Italy	12	36	A	T
	31	12/21/2004	3CS: Sparky	ASU/NMSU/CU Boulder	USA	16	-	LF	E
	31	12/21/2004	3CS: Ralphie	ASU/NMSU/CU Boulder	USA	16	-	LF	E
2005	32	8/3/2005	PCSat 2	US Naval Academy	USA	12	13	N	C
	33	10/27/2005	XI-V (CO-58)	University of Tokyo	Japan	1	20	A	E
	33	10/27/2005	Mozhayets 5	Mozhaisky military academy	Russia	64	0	F	E
	33	10/27/2005	UWE-1	University of Würzburg	Germany	1	1	F	E
	33	10/27/2005	Ncube II	Norwegian Universities	Norway	1	0	F	E
	33	10/27/2005	SSETI Express (XO-53)	European Universities	Europe	62	0	F	C
2006	34	2/21/2006	CUTE-1.7 (CO-56)	Tokyo Institute of Technology	Japan	10	16	F	C
	35	3/24/2006	Falconsat 2	US Air Force Academy	USA	20	-	LF	S
	36	7/26/2006	UNISAT 4	University of Rome "La Sapienza"	Italy	12	-	LF	E
	36	7/26/2006	Ncube	Norwegian Universites	Norway	1	-	LF	E
	36	7/26/2006	KUTESat	University of Kansas	USA	1	-	LF	E
	36	7/26/2006	CP2	Cal Poly San Luis Obispo	USA	1	-	LF	E
	36	7/26/2006	CP1	Cal Poly San Luis Obispo	USA	1	-	LF	E
	36	7/26/2006	ION	University of Illinois	USA	2	-	LF	T
	36	7/26/2006	ICE CUBE1	Cornell University	USA	1	-	LF	T
	36	7/26/2006	ICE CUBE2	Cornell University	USA	1	-	LF	T
	36	7/26/2006	PiCPoT	Politecnico di Torino, Italy	Italy	2.5	-	LF	E
	36	7/26/2006	SEEDS	Nihon University	Japan	1	-	LF	E
	36	7/26/2006	SACRED	University of Arizona	USA	1	-	LF	E
	36	7/26/2006	Rincon	University of Arizona	USA	1	-	LF	E
	36	7/26/2006	MEROPE	Montana State University	USA	1	-	LF	S
	36	7/26/2006	HAUSAT-1	Hankuk Aviation University	S. Korea	1	-	LF	E
	36	7/26/2006	Baumanets 1	Bauman Moscow State Technical University	Russia	92	-	LF	E
	37	9/22/2006	HITSat (HO-59)	Hokkaido Institute of Technology	Japan	2.7	9	S	C
	38	12/21/2006	RAFT-1	US Naval Academy	USA	1	5	N	C
	38	12/21/2006	MARScom	US Naval Academy	USA	1	6	A	C
	38	12/21/2006	ANDE	US Naval Academy	USA	75	6	A	C
2007	39	1/10/2007	LAPAN-Tubsat	Technical University of Berlin	Germany	56	5	A	C
	39	1/10/2007	PEHUENSAT-1	UNIVERSIDAD NACIONAL DEL COMAHUE	Argentina	6	3	N	C
	40	3/9/2007	Falconsat 3	US Air Force Academy	USA	54	3	A	S
	40	3/9/2007	MidSTAR-1	US Naval Academy	USA	120	3	A	T
	41	4/17/2007	Saudi ComSat-3	King Abdulaziz City for Science & Technology	Saudi Arabia	12	2	A	C
	41	4/17/2007	Saudi ComSat-4	King Abdulaziz City for Science & Technology	Saudi Arabia	12	2	A	C
	41	4/17/2007	Saudi ComSat-5	King Abdulaziz City for Science & Technology	Saudi Arabia	12	2	A	C
	41	4/17/2007	Saudi ComSat-6	King Abdulaziz City for Science & Technology	Saudi Arabia	12	2	A	C
	41	4/17/2007	Saudi ComSat-7	King Abdulaziz City for Science & Technology	Saudi Arabia	12	2	A	C
	41	4/17/2007	SaudiSat-3	King Abdulaziz City for Science & Technology	Saudi Arabia	200	2	A	S
	41	4/17/2007	CP4	Cal Poly San Luis Obispo	USA	1	2	A	E
	41	4/17/2007	CP3	Cal Poly San Luis Obispo	USA	1	2	A	E
	41	4/17/2007	Libertad-1	University of Sergio Arboleda	Columbia	1	2	A	E
	41	4/17/2007	CAPE-1	University of Louisiana	USA	1	2	A	E
	42	8/31/2007	Cute 1.7 + APD II	Tokyo Institute of Technology	Japan	2	n/a	-	E
	42	8/31/2007	CanX 2	University of Toronto	Canada	2	n/a	-	T
	42	8/31/2007	AAUsat II	University of Aalborg	Denmark	1	n/a	-	T
	42	8/31/2007	SEEDS 2	Nihon University	Japan	1	n/a	-	E
	42	8/31/2007	COMPASS 1	Fachhochschule Aachen	Germany	1	n/a	-	E
	42	8/31/2007	Delfi-C3	Technical University of Delft	Netherlands	3	n/a	-	T
	43	12/31/2007	SumbandilaSat	University of Stellenbosch	South Africa	80	n/a	-	T

First, a list of all university-related small satellites that reached orbit (however low) was assembled from launch logs, the author's knowledge and several satellite databases.[4-7] Because of the difficulty in compiling and verifying information about student missions that were started but not completed, we have only included projects with a verifiable launch date. Furthermore, missions that did not meet the definition of "university-class" as defined above were removed from this list.

The remaining spacecraft were researched regarding mission duration, mass and mission categories, with information derived from published reports and project websites as indicated. A **T-class** (technology) mission flight-tests a component or subsystem that is new to the satellite industry (not just new to the university). An **S –class** (science) mission creates science data relevant to that particular field of study (including remote sensing). A **C-class** (communications) mission provides communications services to some part of the world (often in the Amateur radio service). While every university-class mission is by definition educational, those spacecraft listed as **E-class** (education) missions lack any of the other payloads and serve mainly to train students and improve the satellite-building capabilities of that particular school; typical E-class payloads are COTS imagers (low-resolution Earth imagery), on-board telemetry, and beacon communications. Finally, a spacecraft is indicated to have failed prematurely when its operational lifetime was significantly less than published reports predicted and/or if the university who created the spacecraft indicates that it failed.

In this paper, we will spend considerable time examining the success rate for "first-time" and "sustained" programs (that is to say, universities which have only launched one spacecraft, and those who appear to have a steady program of building and flying space hardware. To fit the definition of a "repeat" school, a university must place spacecraft on more than one launch (i.e., two CubeSats on the same flight count as one mission for this evaluation), and the second spacecraft must be different than the first (i.e., not simply a reflight of a failed first attempt). The reason for this nit-picking gets to the heart of the issue: a sustained satellite-building program brings multiple generations of students through the design/build/fly process; two launches of distinct spacecraft, separated in time, indicates that the program is more than the product of a few highly-motivated students.*

This list of spacecraft is complete to the best of the author's ability. For example, the listed launch masses should be considered approximate, as the variance in mass among different published records can reach as high as 50%. Similarly, values in the Mission Duration column are approximate; in the course of our research, we found some spacecraft that were known to have lost most or all of the primary payloads and communications equipment and yet were still listed as "operational"! In other cases, spacecraft that have greatly exceeded their planned mission lifetime may be left idle or even abandoned by their primary operators, and thus the failure date of the vehicle is unknown.

OBSERVATIONS

We gave extensive discussion of the launch manifest in previous papers, so we will only comment on emerging trends or follow up on previous questions. Following that review, we will examine the question of mission.

Updated: Number crunching

First of all, as shown in Figure 1, the large number of student launches in 2006 has carried over to 2007. This is largely driven by the CubeSat/Dnepr multi-satellite launch opportunities. Given the success of those activities (even after the 2006 Dnepr failure), one should expect to see a dozen or more student satellites launched per year into the indefinite future.

A second continuing trend is the dominance of "flagship" schools in the manifest (Figure 2). In fact, new flagship schools are emerging, including Hankuk Aviation University (S. Korea), Bauman Moscow State Technical University (Russia) and the Technical University of Delft (Netherlands).

Somewhat surprisingly, the CubeSat-class spacecraft only account for half of the launch manifest for 2007 (Figure 3). Now that the backlog of first-generation CubeSats has cleared, it will be interesting to track whether the launch opportunities outstrip the supply of available CubeSats.

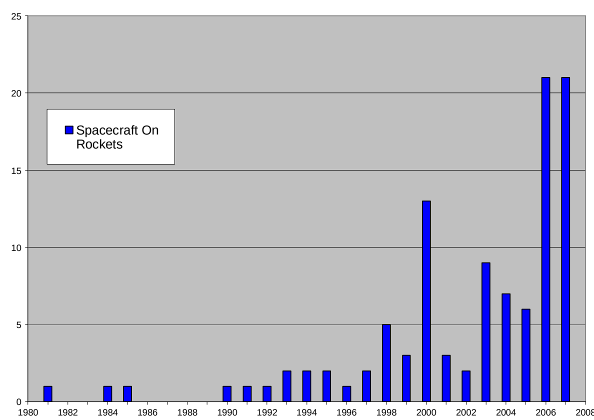

Figure 1. Total number of manifested university-class spacecraft per year

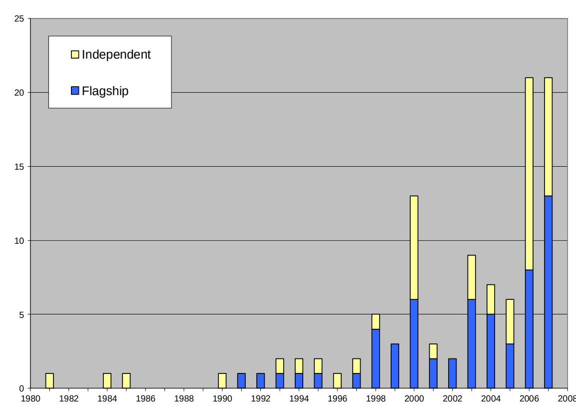

Figure 2. Flagship vs. independent missions.

* Which is **not** a slight to highly-motivated students or to the enormous contributions they make to sustain student satellite projects. In fact, I'd be more than happy for all highly-motivated students to contact me for information about graduate studies at Washington University…

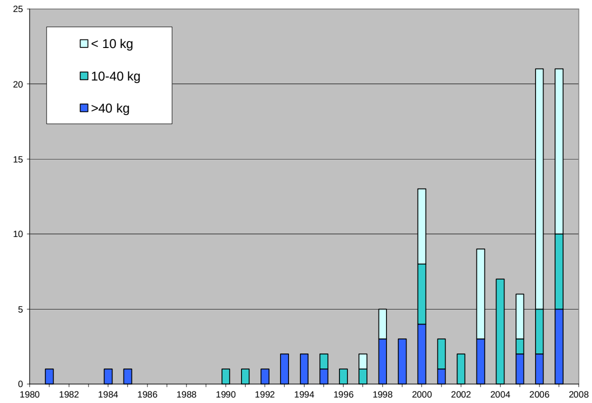

Figure 3. Spacecraft mass by year.

Another continuing trend is the dominance of the launch manifest by the same set of schools (Figure 4 and Figure 5): 11 of 21 satellites on the manifest for 2007 represent the third (or later) satellite by flagship schools, a twelfth is a second-time flagship, and another is the second flight by an independent. Three of the remaining eight are reflights of previous CubeSats, and thus only five satellites represent the first-time launch by a school. (And yet, perhaps this is a matter of perspective: before 2003, launching five student-satellites in one year would be a noteworthy event, first-timers or no! It's only in comparison to the number of repeat flagship launches this decade that the first-time tally seems small.) And it should be noted that the "repeat independent" club added its 5th member (Cal Poly), and the 6th is waiting for launch (Aalborg).

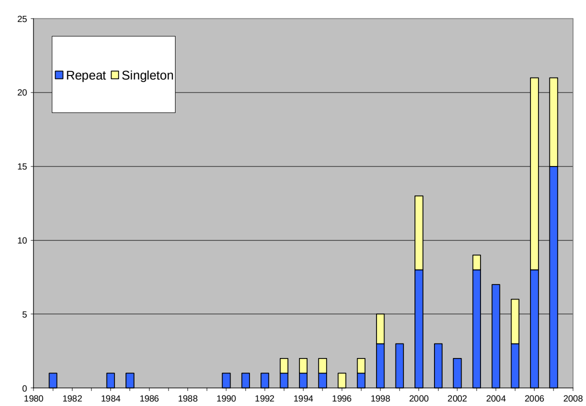

Figure 4. Repeat missions vs. single-launch programs.

Still, as noted in 2006, eleven schools lost their first-ever satellites in that Dnepr failure; given the history of student-built satellites, the odds are against most of those schools mustering the resources for a second launch. Only three of those schools are on the manifest for 2007, and we will continue to track the "Class of 2006" in future papers.

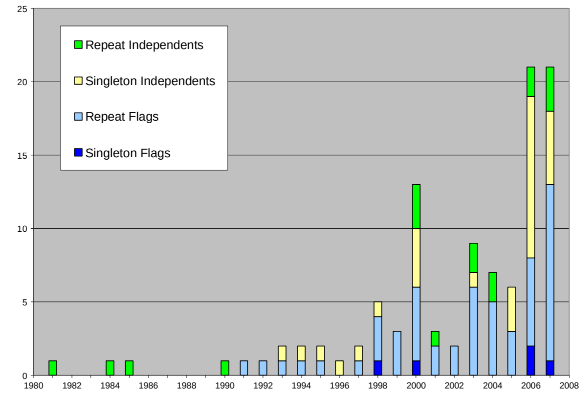

Figure 5. Comparison of repeat launches by flagship status.

Updated: What Breaks First?

Whether out of embarrassment, proprietary concerns, or simply a lack of interest, university-class missions are notoriously bad about publishing (or perhaps even writing?) failure reports. The following information is the author's best guess based on news articles and the few published failure reports and has been revised since the last paper. Of the 18 spacecraft we have identified as failing prematurely (Figure 6), the failures can be attributed to (or guessed to be) the following:

- **Radiation:** 1 (TUBSAT-B[8]). Killed by the Van Allen Belts due to its orbit altitude of 1250 km.
- **Launch interface:** 1 (Mozhayets 5). Failed to separate from the launch vehicle; it appears to have been a signals problem in the launch interface.
- **Thermal:** 1 (UNAMSAT-B); UNAMSAT's uplink oscillator was too cold before launch and the spacecraft could not be contacted in time to change the battery charging parameters for the cold conditions, and the system failed.
- **Communications:** 4½ (Arsene, SEDsat [partial], JAWSAT, Cute-1.7, UWE-1). These four spacecraft were operational for at least a little bit of time, but lost either their transmitters or receivers (or both) unexpectedly. Bad wiring is suspected in some cases.
- **Power:** 4½ (SEDSat [partial], ASUSat-1, FalconSAT-1, AAU CubeSat-I, SSETI-Express). The reasons vary, but all of these vehicles had problems, typically with the connection between batteries and solar arrays.
- **Unknown:** 6 (JAK, Louise, Thelma, CanX-1, DTUsat, NCube II). These six spacecraft were confirmed to have released, but contact was never made. Bad communications or bad power is suspected.

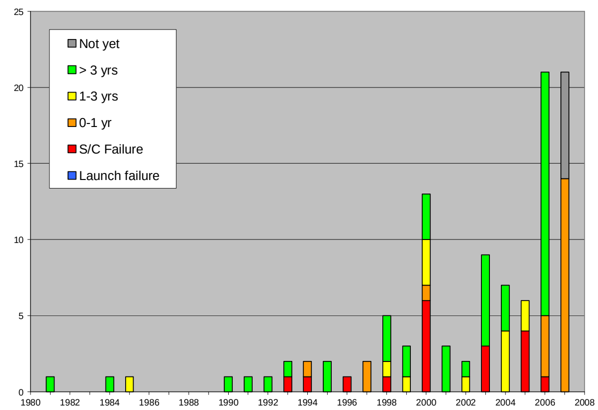

Figure 6. Spacecraft lifetime by year

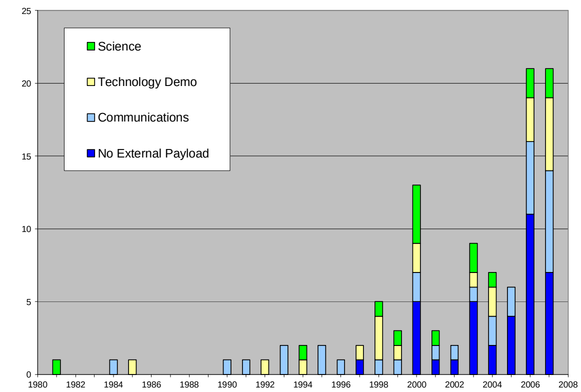

Figure 7. Mission type by year.

Arguably, all of the known failures save TUBSAT-B (and potentially many of the unknown failures) can be attributed to incomplete system-level testing or system-level design. In all those cases, either the spacecraft was in an unexpected operational environment, or a component failure led to an operational mode from which ground operators could not recover (e.g. loss of uplink or a disconnect between batteries and solar arrays). While we cannot presume to know what was and was not tested, it would appear that rigorous, extensive fully-integrated functional testing might have caught these problems before launch.

It is worth updating a statement from last year's paper: not one of the 78 student-built spacecraft that made it to orbit is known to have had structural problems – and, in fact, one of the student-built satellites that did not reach orbit (FalconSat 2) survived its return to Earth! And only one of 78 student-built spacecraft is known to have had on-orbit thermal problems.[†] Again, while no one should discount the importance of sound structural & thermal analysis/testing, nor should students ignore the risks of COTS electronics, the flight history suggests that more time needs to be devoted to system-level functional testing rather than these three issues.

New Analysis: Mission Type

As a final bit of data analysis, let us examine the launch manifest by mission type (Figure 7) and then further subdivided by flagship and independent (Figure 8). As shown in Figure 7, there has been a significant increase in the E-class (or "Beepsat") spacecraft in the past six years. This trend matches – but does not exactly correspond to – the growth of CubeSat-class missions (Figure 3, again); about two-thirds of CubeSat-class spacecraft (27 of 44) were Beepsats, compared with one-sixth of larger spacecraft (10 of 61).

Beepsats are also concentrated in – but not exclusive to – the independent schools (Figure 8). While about a quarter of flagship spacecraft (13 of 58) have been Beepsats, more than half the independent spacecraft are (24 of 47). More importantly, of the 13 flagship Beepsats, 9 were built by schools that later flew a "real" payload (and two others were first-flight Beepsats where the flagship has not yet built a second). Thus, the trend seems to indicate that flagship schools use Beepsats as an "entry-level" mission before adding more complex payloads.

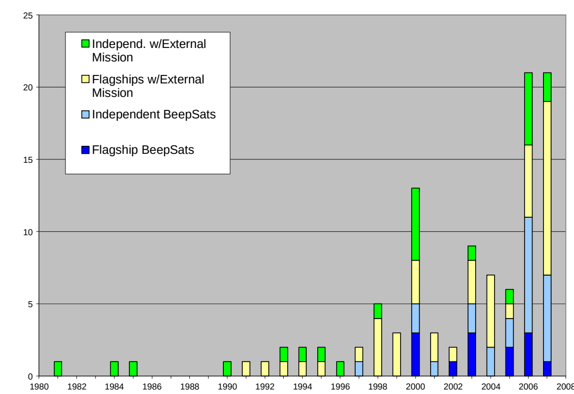

Figure 8. Mission type by year and university category.

By contrast, those 24 independently-built Beepsats came from 18 schools, of which only 3 have also flown "real" missions. Of course, these numbers are skewed by the fact that only five of those 18 schools have put any type of satellite on more than one rocket. Still, it is fair to say that Beepsats (and typically, CubeSats) have become the "entry-level" spacecraft for all schools. And while the flagship schools tend to graduate from Beepsats to more complex missions, we have yet to see many independent schools launch a second satellite, whether it be Beepsat or not.

[†] It also must be noted that 6 spacecraft have unknown root causes of failure, and structural and/or thermal problems cannot be ruled out.

Lost in this crunching of numbers is another simple fact: from 1981-2000, the "entry-level" satellite of choice was a Amateur radio repeater. As payloads go, repeaters are straightforward to implement on a student-built satellite. And while a first look at Figure 7 indicates that the number of student-built communications satellites are on the rise, 15 of the 21 C-class satellites launched since 2000 have come from only two schools: the King Abdulaziz City for Science & Technology (KACST) in Saudi Arabia (SaudiSat 1A, 1B, 1C and SaudiComSat 1-7) and the U.S. Naval Academy (PCSat 1-2, ANDE, RAFT, and MARScom). We will consider KACST and USNA in the next section, and discuss the relative absence of C-class missions in the conclusion.

EXAMPLES OF SUSTAINED PROGRAMS

We will briefly examine five schools with sustained space programs. Not surprisingly, three of these schools are flagships, who are following three different representative paths. The other two are independent schools and, perhaps equally unsurprisingly, their sustained activities are not in building university-class spacecraft per se, but in services necessary for university-class spacecraft.

Technical University of Berlin[8-13]

The Institute for Air and Space Travel at the Technical University of Berlin was the fourth school to launch university-class missions and has had seven spacecraft launched in the past 16 years: TUBSAT-A, TUBSAT-B, TUBSAT-N, TUBSAT-N1, DLR-TUBSAT, MAROC-TUBSAT and LAPAN-TUBSAT. Two have had their orbits decay, and the third was high in the Van Allen belts. The other four are still operational.

The TUBSAT program appears to be following the "Surrey Model" of building increasingly-sophisticated remote sensing platforms and then using their standard spacecraft bus to training engineers from national space agencies to develop their own space programs (e.g, Morocco and Indonesia). The TUBSATs have focused on high-end Earth imaging, including the precise pointing control and high-data-rate communications necessary to conduct such missions. In fact, like Surrey, the capability of these spacecraft and their significant external funding may have reached the point that TUBSATs have "graduated" from university-class to a professional activity.

King Abdulaziz City for Science & Technology

The Saudi Institute for Space Research of KACST has put more university-class spacecraft in orbit than any other: twelve launched since 2000. Five of those have been in the SaudiSat communications/technology demonstration series (SaudiSat 1A, 1B, 1C, 2, 3) and the other seven have been part of a communications constellation (SaudiComSat 1-7). With the SaudiSat series, KACST appears to be following the typical path of increasingly-capable systems to demonstrate more advanced technologies; at 200 kg, SaudiSat 3 is 20 times heavier than the SaudiSat-1 series, and is intended for high-resolution remote imagery.

We must confess ignorance about much of the KACST activity; they have published little (at least in the Western press) and place very little information on their website – and especially no status information about the spacecraft in orbit. Similarly, while SaudiSats 1A-1C were advertised as general-use Amateur radio payloads, they were only available to the public for a short time (if at all).

Still, it is apparent that they are following a TUBSAT-like path of developing high-performance remote sensing spacecraft to support national interests. The SaudiComSat constellation is supposed to contain 24 spacecraft for a commercial store-and-forward application. Thus, like TUBSAT and Surrey before them, KACST appears to be headed for "graduation" from university-class program to a professional activity.

U.S. Naval Academy[14]

As mentioned above, KACST and USNA are the two schools responsible for most of the communication satellites in this decade. In addition to the very small PCSat-1/2 amateur repeaters, USNA recently launched three CubeSat-class missions: ANDE, RAFT and MARScom. However, those missions have led to a much larger spacecraft: the 120-kg MidSTAR-1. MidSTAR-1 is the first of a series of student-built platforms carrying external payloads; for MidSTAR-1, this included a range of NASA and Naval science and technology experiments. Similarly, MidSTAR-2 will carry NASA Goddard science instruments.

Thus, in the same vein of the previous programs, the USNA approach appears to be settling on a "standard" bus to be used by a range of external customers. Unlike the previous programs, it appears that the USNA activity will remain within the bounds of university-class missions, given the stated objective of training USNA midshipmen in spacecraft design and operations.

Cal Poly (San Luis Obispo)[15-17]

Cal Poly is one of only three active independent schools to have put spacecraft on more than one rocket (the others being Stanford and Nihon University). At the moment, the Polysat series appear to be increasingly capable CubeSats lacking external payloads. Where Cal Poly distinguishes itself from the other schools is in the spacecraft services: with Stanford's help, they developed the P-POD launch interface for CubeSats, and they continue to provide launch brokerage and integration services for other schools (and professional projects). The P-POD carries as many as three CubeSat-class spacecraft in a strap-on launch container which provides a spring-launched ejection after reaching orbit.

To date, there have been 12 P-PODs on 4 launches, carrying 23 student-built satellites and 6 professional CubeSats (including Boeing's CSTB-1, the Aerospace Corporation's AeroCube 1-2, Tethers Unlimited's MAST, and NASA's GeneSat-1). Two more P-PODs are in the manifest for 2007.

Clearly, while the P-POD doesn't fit the definition of a university-class satellite, Cal Poly's work is definitely a valid, sustained university space engineering activity. The activity has spawned activities in Japan and Canada to provide P-POD analogs for other launches.

Santa Clara University[18-20]

Like Cal Poly, Santa Clara has an active satellite-building program, but is carving out a service niche. In their case, Santa Clara provides mission operations. Spacecraft operated by SCU include Sapphire, GeneBox, GeneSat-1 and MAST. They are also involved with the upcoming NASA missions GeneSat-2 and PharmaSat.

Assessment

Though it should come as a shock to no one, it is clear that sustained programs at flagship universities focus on developing a "standard" bus platform that can be used for a variety of external payloads. By definition, a flagship program exists to improve the nation's overall space program – and flying the nation's space experiments is certainly one way to do that. Neither is it surprising that, as the universities move up the "value chain" to more and more capable systems, that they exit the "university-class" category (as Surrey did 20 years ago, and as TUB and KACST appear poised to do).

However, it <u>is</u> surprising that only five schools – KACST, USNA, the U.S. Air Force Academy, the Technical University of Berlin, and the Korean Advanced Institute of Science and Technology – are responsible for one-third of all student-built satellites ever launched. (Add 6 more flagships – Israel's Technion, the University of Rome, the University of Tokyo and Tokyo Tech, China's Tsinghua University, and the University of Toronto – and eleven schools provided half of all student-built satellites ever launched.)

And, as we have been writing for several years, the launch history indicates that it is extremely hard for independent schools to build sustained spacecraft projects; there have only been six such schools to date (and only three are still active). The CubeSat class of spacecraft was designed in part to overcome this challenge by creating constraints that would lead to short-development time, low-cost systems that could be launched on a range of launch vehicles. The next three years should test the validity of that aim; the first generation of CubeSats have cleared the launch queue, and it remains to be seen which schools (if any) will continue to build spacecraft. It is instructive to note that four of the five schools to fly two CubeSats (not counting reflights) are flagships.

Simply looking at the numbers, one is tempted to conclude that independent schools cannot sustain spacecraft programs. The extremely rare exceptions to the rule tend to find niche "support services" that allow them to participate in many space projects without having to build and fly all their own space hardware.

<u>DOES</u> THE MISSION MATTER?

This year's conference theme is, "It's the Mission that Matters". But does the mission truly matter for university-class spacecraft? The answer depends on our goals.

If our goal is to see large number of universities launch spacecraft, then the answer is **no**; the 38 E-class spacecraft prove that universities can launch spacecraft without a compelling on-board payload. Or, perhaps more optimistically: the education and training of student engineers was a sufficiently-valid mission to justify the development and launch costs for 38 spacecraft.

But, if our goal is to see large numbers of <u>sustainable</u> university programs, then perhaps the mission does matter. For flagship universities, certainly, developing the capability to fly "real" payloads is fundamental to their charters. For independent schools, the set of active, sustained programs is so small that we cannot draw strong conclusions from the data. Is the relative absence of "real" missions on independent satellites in this decade a cause or an effect of the "one-and-done" university projects? Do independent schools lack the means of securing real payloads, or do they choose not to fly them out of ignorance or a misguided attempt to streamline the development cycle?

Anecdotally, we can say that the development cycle for E-class CubeSats is much shorter than for "real" payloads on spacecraft of any size. But it appears to be more difficult for E-class spacecraft of any side to find launch sponsorship (especially for the second and subsequent launches.) Thus, it is with great anticipation that we await the launch manifests of 2008-2010, which should indicate whether independent schools can sustain activity with E-class CubeSats, or if they need to build up to more substantial missions.

The Large, Dark Cloud: Access to Space

As with professional spacecraft, the cost and scarcity of launches is a real impediment to university-class missions. There are perhaps a hundred active student spacecraft projects worldwide today (most of them CubeSats), and an admittedly much-smaller subset of that group with hardware that could be launched in the next two years. But smaller still is the number of university-class spacecraft that will, in fact, fly.

In the U.S., university-class spacecraft that lack the means to pay for launch depend on the Department of Defense's Space Test Program (STP); except in extremely unique cases, NASA is no longer in the business of launching university-class spacecraft. Payloads of interest to the DoD are ranked by the Space Experiments Review Board (SERB), and then STP places those payloads onto available launches depending on their ranking and whether the opportunities match up with payload requirements. This is one instance where the mission truly matters: university-class missions tend to sit on the lowest rungs of the SERB list because of their lack of DoD-relevant payloads. While many low-ranked student spacecraft have made it onto an STP rocket (including MidSTAR-1, FalconSat 1-3, ANDE, RAFT, MARScom, PCSat 1-2, 3CornerSat, Sapphire, Opal, ASUSat-1, and JAWSAT), delays between a spacecraft being flight-ready and finding a launch can stretch into the years. And mission (or lack thereof) drives that delay.

On the other hand, the last four years have seen a sharp increase in CubeSat-class launches. And while it appears that universities are finding a faster path to orbit in a P-POD, the unfortunate truth is that many of these flights have been delayed by months or even years from their original schedule. (The 2006 Dnepr launch was originally scheduled for 2004, for example. And the June 2007 PSLV launch carrying six CubeSats has been postponed indefinitely. In these instances, the mission had no bearing on the timeliness of launch.

There are some signs of hope for timely CubeSat launches. U.S. launch providers (e.g. SpaceX and NASA's Expendable Launch Program at Kennedy Space Center) have expressed interest in outfitting their launch vehicles with P-POD launchers. Unfortunately, the student CubeSats may start competing for launch slots with professional spacecraft built by Boeing, the Aerospace Corporation and others. So, again, the presence of relevant missions may give university-class spacecraft an edge over their counterparts.

Suggested Missions

What kinds of missions would best serve the universities wanting to break in to the satellite world? Broadly speaking, few university-class programs are going to be capable of the precise pointing and long-term functionality of modern remote sensing systems; those that are capable of such performance levels will invariably be flagships. Similarly, it will be difficult (but not impossible) for independent schools to "compete" against flagships for the payloads that need a well-designed, moderate-performance spacecraft bus (e.g. MidSTAR and the TUBSAT family).

Thus, independent universities need to seek out the relevant missions that professional programs can't or won't try – especially if they're trying to find launch sponsors. Examples include:

- **Communications**. The author is at a loss to explain the near-absence of Amateur communications services provided by university-class spacecraft over the past 7 years. Certainly, Amateur radio service does not improve ones standing on the SERB list, and has proven exceedingly difficult to close any sort of medium-rate data link with CubeSats, but the disconnect between the Amateur community and the university-class community is a cause for concern. Both groups could benefit from one another.
- **Biology**. NASA's GeneSat series of spacecraft prove that worthwhile science can be done on a CubeSat-class platform. It remains to be seen whether a student group could build a CubeSat capable of worthwhile science, but it is an extremely worthwhile question to pursue. At present, this is an untapped area for space missions, and a chance for schools to make real impacts.
- **Multi-spacecraft operations**. Given the risks associated with maneuvering many vehicles in close proximity, NASA and the Air Force are understandably hesitant to spend a lot of time on money (although they did fund DART and Orbital Express, among others). But with the higher risk-tolerance of a university program, it would make sense for a school or teams of schools to launch multiple CubeSats to perform a common task.
- **High-risk, high-reward**. Missions like Tethers Unlimited's MAST benefited from early collaboration with student projects. Doubtlessly, there exist clever people at every university who have wild ideas about space technologies – ideas that probably won't work, but have tremendous implications if they do. University-class missions are the perfect avenue for such research

THE SUM OF THE MATTER

When all is said and done, does the mission matter? Or is it a chasing after wind? First, let's examine our *a priori* assumption: sustained programs are better than one-shot programs. We believe this to be true, because of the opportunity for improvement in the education and orbital missions; if every program is a one-shot satellite, then students continue to make the same mistakes and we see no real progress in the design and operation of spacecraft (at least no progress coming from the schools).

Clearly, flagship schools can and do build sustained programs that support "real" missions. But this question isn't for the flagships; by definition, flagships have the support necessary to sustain a program and find launches. For the independent schools, it's an uphill battle, trying to complete a spacecraft in a few years' time and get a launch.

Perhaps out of the second wave of CubeSats will emerge a few sustainable, independent programs – or one or more independent schools will hit upon a novel set of missions they can build into a sustained program. At the moment, though, neither of those cases has come to pass. We wait with great anticipation.

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