AC 2011-1151: SIGNIFICANCE OF STUDENT-BUILT SPACECRAFT DESIGN PROGRAMS IT'S IMPACT ON SPACECRAFT ENGINEERING EDUCATION OVER LAST TEN YEARS

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Significance Of Student-Built Spacecraft Design Programs – It's Impact On Spacecraft Engineering Education Over Last Ten Years

Abstract

For nearly 30 years, student-built space missions have provided an unique opportunity to launch small spacecraft with a small budget. Among the technical and educational merits of such projects, one significant outcome is the cross disciplinary training for undergraduate science and engineering students that prepares them for a future career in industry. The experience of many schools in the U.S. and around the world indicates that hands-on, project-based education is very effective for recruiting, retaining and training engineering students. In the last decade, programs such as the AFRL-sponsored University Nanosat Program, the CanSat program, and especially the CubeSat standard have dramatically changed spacecraft engineering education. In an incredibly short period of time (especially by aerospace standards), such activities have helped foster strong aerospace education programs in schools with no history of space activity. In fact, it can be shown that the 'success' of these programs was a direct result of their satellite-building activities. In this paper, we will discuss three related topics, (1) the status of the student-built space missions over last ten years, (2) the significance of these programs and their contributions to spacecraft engineering education and opportunities looking ahead, and (3) the broader impact of these programs on research, innovation and entrepreneurship.

Introduction

One of the main issues facing the space sector is an aging workforce, and attracting the young people that will build, launch and operate the rockets, satellites and communications networks of the future has proven difficult. Organizations and companies around the globe are working on improving the situation, and with many, it begins by spurring interest in science, technology, engineering and math (STEM) in the youngest generations and keeping that interest alive as they pursue college and then careers. Many government and industrial leaders point at the acute need to improve space-related education as a major challenge for the American space enterprise [1-4].

In seventies and eighties, few U.S. universities were involved in spacecraft design and research, predominantly involving only graduate students; only 10 student-built satellites were launched worldwide between 1981 (the first-ever launch) and 1994. There was a drastic change in early to mid nineties with the introduction of several "student design centered" programs and competitions by federal and defense organizations, as well as university initiatives; ten more student satellites were launched between 1995 and 1998; while 30 more were launched from 1999 to 2003. The one-hundredth student-built satellite was launched in 2008, and an average of more than 10 satellites per year have been launched in the last half of this decade.

Recent literature discusses the critical need of astronautics and spacecraft design/systems engineering programs at universities and the response to the growing shortage of space workforce. Gruntman, et al [1, 2] discussed the needs to improve space-related education that had emerged as a major challenge for space enterprise. The authors pointed out that development of the future space workforce requires a concentrated effort from government, space industry and academia. Pelton, et al [4] presented their findings about the quality, vibrancy and appeal of science and technical education, particularly in space education. They recommended the need for a robust link between academia with a well defined space education and research agenda supported by space industry, NASA and other federal agencies to reinvigorate and expand the quality of space education programs. Hunyadi, et al [19] described the first federal program, started in 1999, to competitively select flight spacecraft among a dozen university entrants. Originially, this University Nanosat Program (UNP) was scoped for shuttle secondary flights, but has since been targeted for ESPA-class secondary launch opportunities. This program provided unique opportunities for capability demonstration. Particular points of interest included the symbiosis of government and academia on a flight program; the training of the next generation of aerospace professionals; and the opportunity to infuse existing aerospace institutions with out-of-the-box methodologies and technologies. As AFRL's UNP was a competitive program, only a handful of universities were participating in the design activities. At the same time, the CubeSat standard was jointly developed by Stanford University and Cal Poly with the intent to accelerate development and flight opportunities for student programs. The CubeSat program was adopted by many of the organizations, educational and amateur groups that were already interested in building low cost picosatellites [20], but it is noteworthy that many of the CubeSat-launching schools had no identifiable spacecraft program before 2003. The consortium of CubeSat developers is now wide ranging with universities from four continents having launched missions, and dozens more CubeSats in development worldwide. The CubeSat community lists more than 70 programs building 1-kg-class spacecraft worldwide, and 27 U.S. universities have participated in the UNP.

While none can deny that student-built spacecraft are an established fact, there is little discussion in either the education or engineering literature about the merits of this fact. Should universities be in the practice of building and launching their own spacecraft? Given the tremendous costs of building and operating student-built spacecraft – measured in student hours, faculty hours, dollars spent, items donated and, especially, the long times between flight operations – are student-built spacecraft worth the cost? In a related issue, we have identified two broad categories of schools building flight hardware: "flagship" schools and "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. There is a growing disparity in both launch rates and mission success between the two classes; generally speaking, flagship schools build bigger satellites with more "useful" payloads, and tend to have sustained programs with multiple launches over many years. By contrast, the satellites built by independent schools are three times more likely to fail, and for most of these programs, their first-ever spacecraft in orbit is 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. Thus, if student-built spacecraft are worth the cost, how can independent schools build sustained satellite programs? [5 - 9].

Before we can proceed, we must first clearly define what we mean by a university-class satellite, which we will also call student-built. This specification is needed because the "student" label has been applied to $15 million NASA science missions and 3-kg Sputnik re-creations. For the purposes of this discussion, a university-class satellite has these 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 (students) performed a significant fraction of key design decisions, integration & testing activities, and flight operations.
3) The training of these people was as important as (if not more important) the nominal "mission" of the spacecraft itself.

Therefore, a university-class satellite is defined by programmatic constraints and is different than a space mission with strong university participation. The purpose of university-class missions is to train students in the design, integration and operation of spacecraft, and this is accomplished by giving students direct control over the progress of the program. Exclusion from the university class does not imply a lack of educational merit; it simply means that student training was not a design driver.

Status of the University-class Spacecraft

A list of university-class spacecraft launched from 1981 until the present is split between Tables 1 and 2. The process for compiling this table was as follows: First, a list of all university-related small satellites that reached orbit (however low) was assembled from launch logs, conference proceedings (especially the AIAA/Utah State Conference on Small Satellites), the author's knowledge and several satellite databases [10-14]. Because of the difficulty in compiling and verifying information about the many student missions that were never launched, we have only included projects with a verifiable launch date. Furthermore, missions that did not meet our definition of "university-class" 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.

Table 1: All University-Class spacecraft Manifested Through 2005 [10-14]

Launch	Launch ID	Launch Date	Mission	Primary School(s)	Nation	Mass (kg)	Mission Duration (months)	Status	Type	Multi	Flag?
1981	1	10/6/81	UoSAT-1 (UO-9)	University of Surrey	UK	52	96	N	S	y	NF
1984	2	3/1/84	UoSAT-2 (UO-11)	University of Surrey	UK	60	281	N	C	y	NF
1985	3	4/29/85	NUSAT	Weber State, Utah State University	USA	52	20	N	T	y	NF
1990	4	1/22/90	WeberSAT (WO-18)	Weber State	USA	16	96	N	C	y	NF
1991	5	7/17/91	TUBSAT-A	Technical University of Berlin	Germany	35	188	N	C	y	F
1992	6	8/10/92	KITSAT-1 (KO-23)	Korean Advanced Institute of Science and Technology	Korea	49	77	N	T	y	F
1993	7	5/12/93	ARSENE	CNES Amateurs (?)	France	154	4	F	C	n	NF
	8	10/26/93	KITSAT-2 (KO-25)	Korean Advanced Institute of Science and Technology	Korea	48	96	N	C	y	F
1994	9	1/25/94	TUBSAT-B	Technical University of Berlin	Germany	45	1	F	T	y	F
	10	3/2/94	BremSat	University of Bremen	Germany	63	11	N	S	n	NF
1995	**11**	**8/28/95**	Techsat 1-A	Technion Institute of Technology	Israel	50	-	LF	C	y	F
			UNAMSAT-A	National University of Mexico	Mexico	10	-	LF	C	n	NF
1996	12	5/9/96	UNAMSAT-B (MO-30)	National University of Mexico	Mexico	10	0	F	C	n	NF
1997	13	10/25/97	Falcon Gold	US Air Force Academy	USA	18	0.5	N	T	y	F
	14	10/30/97	YES	ESA/ESTEC-led partnership	Europe	187	0.1	N	E	y	NF
	15	11/3/97	RS-17	Russian high school students	Russia	3	2	N	E	n	NF
1998	**16**	**7/7/98**	TUBSAT-N	Technical University of Berlin	Germany	8	46	N	T	y	F
			TUBSAT-N1	Technical University of Berlin	Germany	3	20	N	T	y	F
	17	7/10/98	Techsat 1-B (GO-32)	Technion Institute of Technology	Israel	70	51	N	S	y	F
	18	**10/30/98**	PANSAT (PO-34)	Naval Postgraduate School	USA	70	60	N	C	n	F
			SEDSAT (SO-33)	University of Alabama, Huntsville	USA	41	33	F	T	n	NF
1999	19	2/23/99	Sunsat (SO-35)	University of Stellenbosch	South Africa	64	23	N	C	y	F
	20	**5/27/99**	DLR-TUBSAT	Technical University of Berlin	Germany	45	120	N	S	y	F
			KITSAT-3	Korean Advanced Institute of Science and Technology	Korea	110	55	N	T	y	F
2000	**21**	**1/27/00**	JAWSAT (WO-39)	Weber State, USAFA	USA	191	1.0	F	T	y	NF
			Falconsat 1	US Air Force Academy	USA	52	1.0	F	E	y	F
			ASUsat 1 (AO-37)	Arizona State University	USA	6	0.0	F	E	y	NF
			Opal (OO-38)	Stanford University	USA	23	29	N	T	y	NF
		2/10/00	JAK	Santa Clara University	USA	0.2	0	F	E	n	NF
		2/12/00	Louise	Santa Clara University	USA	0.5	0	F	S	n	NF
			Thelma	Santa Clara University	USA	0.5	0	F	S	n	NF
	22	6/28/00	Tsinghua-1	Tsinghua University	China	49	30	N	E	y	F
	23	**9/26/00**	TiungSAT-1 (MO-46)	ATSB	Malaysia	50	39	N	S	y	F
			Saudisat 1A (SO-41)	King Abdulaziz City for Science & Technology	Saudi Arabia	10	36	N	C	y	F
			Saudisat 1B (SO-42)	King Abdulaziz City for Science & Technology	Saudi Arabia	10	27	N	C	y	F
			UNISAT 1	University of Rome "La Sapienza"	Italy	12	24	N	E	y	F
	24	11/21/00	Munin	Umeå University / Luleå University of Technology	Sweden	6	3	N	S	n	NF
2001	**25**	**9/30/01**	Sapphire (NO-45)	Stanford, USNA, Washington University	USA	20	36	N	E	y	NF
			PCSat 1 (NO-44)	US Naval Academy	USA	12	106	S	C	y	F
	26	10/12/01	Maroc-TUBSAT	Technical University of Berlin	Germany	47	106	A	S	y	F
2002	**27**	**12/20/02**	Saudisat 1C (SO-50)	King Abdulaziz City for Science & Technology	Saudi Arabia	10	91	A	C	y	F
			UNISAT 2	University of Rome "La Sapienza"	Italy	17	24	N	E	y	F
2003	**28**	**6/30/03**	QuakeSat	Stanford University	USA	3	61	N	S	y	NF
			CUTE-1 (CO-55)	Tokyo Institute of Technology	Japan	1	85	S	E	y	F
			XI-IV (CO-57)	University of Tokyo	Japan	1	85	A	E	y	F
			CanX-1	University of Toronto	Canada	1	0	F	E	y	F
			AAU Cubesat	University of Aalborg	Denmark	1	3	F	E	y	NF
			DTUsat	Technical University of Denmark	Denmark	1	0	F	E	n	NF
	29	**9/27/03**	STSAT-1	Korean Advanced Institute of Science and Technology	Korea	100	82	A	T	y	F
			Mozhayets 4 (RS-22)	Mozhaisky military academy	Russia	64	82	A	C	y	F
2004	30	4/18/04	Naxing-1 (NS-1)	Tsinghua University	China	25	75	A	T	y	F
	31	**6/29/04**	SaudiSat 2	King Abdulaziz City for Science & Technology	Saudi Arabia	15	73	A	S	y	F
			SaudiComsat-1	King Abdulaziz City for Science & Technology	Saudi Arabia	12	73	A	C	y	F
			SaudiComsat-2	King Abdulaziz City for Science & Technology	Saudi Arabia	12	73	A	C	y	F
			UNISAT 3	University of Rome "La Sapienza"	Italy	12	73	A	T	y	F
	32	**12/21/04**	3CS: Sparky	ASU/NMSU/CU Boulder	USA	16	-	LF	E	y	NF
			3CS: Ralphie	ASU/NMSU/CU Boulder	USA	16	-	LF	E	y	NF
2005	33	8/3/05	PCSat 2	US Naval Academy	USA	12	13	N	C	y	F
	34	**10/27/05**	XI-V (CO-58)	University of Tokyo	Japan	1	57	S	E	y	F
			Mozhayets 5	Mozhaisky military academy	Russia	64	0	F	E	y	F
			UWE-1	University of Würzburg	Germany	1	1	F	E	y	NF
			Ncube II	Norwegian Universities	Norway	1	0	F	E	n	NF
			SSETI Express (XO-53)	European Universities	Europe	62	0	F	C	y	NF

Table 2: Manifested University-Class Spacecraft, 2006-2010

2006	35	2/21/06	CUTE-1.7 (CO-56)	Tokyo Institute of Technology	Japan	10	1	F	C	y	F
	36	3/24/06	Falconsat 2	US Air Force Academy	USA	20	-	LF	S	y	F
	37	7/26/06	UNISAT 4	University of Rome "La Sapienza"	Italy	12	-	LF	E	y	F
			Ncube	Norwegian Universites	Norway	1	-	LF	E	n	NF
			KUTESat	University of Kansas	USA	1	-	LF	E	n	NF
			CP2	Cal Poly San Luis Obispo	USA	1	-	LF	E	y	NF
			CP1	Cal Poly San Luis Obispo	USA	1	-	LF	E	y	NF
			ION	University of Illinois	USA	2	-	LF	T	n	NF
			ICE CUBE1	Cornell University	USA	1	-	LF	T	n	NF
			ICE CUBE2	Cornell University	USA	1	-	LF	T	n	NF
			PiCPoT	Politecnico di Torino, Italy	Italy	2.5	-	LF	E	y	NF
			SEEDS	Nihon University	Japan	1	-	LF	E	n	NF
			SACRED	University of Arizona	USA	1	-	LF	E	n	NF
			Rincon	University of Arizona	USA	1	-	LF	E	n	NF
			MEROPE	Montana State University	USA	1	-	LF	S	n	NF
			HAUSAT-1	Hankuk Aviation University	S. Korea	1	-	LF	E	n	F
			Baumanets 1	Bauman Moscow State Technical University	Russia	92	-	LF	E	n	F
	38	9/22/06	HITSat (HO-59)	Hokkaido Institute of Technology	Japan	2.7	5	N	C	n	NF
	39	12/21/06	RAFT-1 (NO-60)	US Naval Academy	USA	1	5	N	C	y	F
			MARScom	US Naval Academy	USA	1	5	N	C	y	F
			ANDE (NO-61)	US Naval Academy	USA	75	12	N	C	y	F
2007	40	1/10/07	LAPAN-Tubsat	Technical University of Berlin	Germany	56	43	A	C	y	F
			PEHUENSAT-1 (PO-63)	National University of Comahue	Argentina	6	3	N	C	n	NF
	41	3/9/07	Falconsat 3	US Air Force Academy	USA	54	41	A	S	y	F
			MidSTAR-1	US Naval Academy	USA	120	41	A	T	y	F
	42	4/17/07	Saudi ComSat-3	King Abdulaziz City for Science & Technology	Saudi Arabia	12	39	A	C	y	F
			Saudi ComSat-4	King Abdulaziz City for Science & Technology	Saudi Arabia	12	39	A	C	y	F
			Saudi ComSat-5	King Abdulaziz City for Science & Technology	Saudi Arabia	12	39	A	C	y	F
			Saudi ComSat-6	King Abdulaziz City for Science & Technology	Saudi Arabia	12	39	A	C	y	F
			Saudi ComSat-7	King Abdulaziz City for Science & Technology	Saudi Arabia	12	39	A	C	y	F
			CP4	Cal Poly San Luis Obispo	USA	1	5	N	E	y	NF
			CP3	Cal Poly San Luis Obispo	USA	1	5	N	E	y	NF
			Libertad-1	University of Sergio Arboleda	Columbia	1	1	N	E	n	NF
			CAPE-1	University of Louisiana	USA	1	5	N	E	n	NF
	43	9/25/07	YES2/Floyd	ESA-led partnership	Europe	30	0	N	T	y	NF
			Yes2/Fotino	ESA-led partnership	Europe	6	0	F	T	y	NF
2008	44	4/28/08	Cute 1.7 + APD II (CO-65)	Tokyo Institute of Technology	Japan	2	27	A	E	y	F
			CanX 2	University of Toronto	Canada	2	27	A	T	y	F
			AAU-CubeSat II	University of Aalborg	Denmark	1	27	A	T	y	NF
			SEEDS 2 (CO-66)	Nihon University	Japan	1	27	A	E	n	NF
			COMPASS 1	Fachhochschule Aachen	Germany	1	27	S	E	n	NF
			Delfi-C3 (DO-64)	Technical University of Delft	Netherlands	3	27	S	T	n	F
2009	45	1/23/09	SpriteSat (Raijin)	Tohoku University	Japan	50	0	F	S	n	NF
			PRISM	University of Tokyo	Japan	8	18	A	T	y	F
			KKS 1	Tokyo Metropolitan College of Industrial Technology	Japan	3	0	F	T	n	NF
			STARS 1	Kagawa University	Japan	8	0	S	T	n	NF
	46	4/20/09	ANUSAT	Anna University	India	38	15	A	C	n	F
	47	5/19/09	CP6	Cal Poly San Luis Obispo	USA	1	4	N	E	y	NF
	48	7/15/09	BEVO-1	University of Texas	USA	5	0	F	T	y	NF
			AggieSat2	Texas A&M University	USA	3.2	8	F	T	n	NF
	49	9/17/09	SumbandilaSat (SO-67)	University of Stellenbosch	South Africa	81	10	S	T	y	F
			UGATUSAT (RS 28)	Ufa State Aviation Technical University	Russia	35	10	A	T	n	F
	50	9/23/09	UWE-2	University of Würzburg	Germany	1	1	F	E	y	NF
			SwissCube-1	Ecole Polytechnique Fédérale de Lausanne	Switzerland	1	10	A	S	n	F
			BeeSat	Technical University of Berlin	Germany	1	10	A	T	y	F
			ITU-pSat	Istanbul Technical University	Turkey	1	10	A	E	n	F
2010	51	5/20/10	UNITEC 1	University Space Engineering Consortium	Japan	16	0	F	T	n	F
			Waseda-SAT2	Waseda University	Japan	1.2	0	F	E	n	NF
			Negai*	Soka University	Japan	1	3	N	E	n	NF
			K-Sat	Kagoshima University	Japan	1.5	3	N	S	n	NF
	52	7/12/10	STUDSAT	Indian university consortium	India	1	1	A	E	n	NF
			Tisat 1	Scuola universitaria della Svizzera italiana	Switzerland	1	1	A	E	n	NF
	53	9/30/10	FASTRAC-A	University of Texas	USA	15	n/a	-	T	y	NF
			FASTRAC-B	University of Texas	USA	15	n/a	-	T	y	NF
			RAX	University of Michigan	USA	3	n/a	-	S	n	NF
			FalconSat-5	US Air Force Academy	USA	100	n/a	-	S	y	F

Impact of University Spacecraft Programs in Improving Space Education

It has been argued and very well documented by professional organizations, federal space research programs and the experience of many schools in the U.S. and around the world that hands-on, project-based education is very effective for recruiting, retaining and training engineering students [1-4, 15-18]. Since early eighties to mid-nineties, only a handful of universities worldwide had even a token amount of student involvement in real spacecraft engineering. This trend changed dramatically in the new millennium with programs such as the AFRL-sponsored University Nanosat Program, the CanSat/BalloonSat program, and especially the CubeSat standard with its P-POD deployment system. In an incredibly short period of time (especially by aerospace standards), such activities have helped foster strong aerospace education programs in schools with no history of space activity. In fact, it can be shown that these programs provided opportunities for "second tier" aerospace education programs to improve the quality of their programs. It can also be shown that the 'success' of these programs was a direct result of their satellite-building activities.

AFRL's University Nanosatellite Program

The University Nanosatellite Program is a competition hosted by the Air Force Research Laboratory's Space Vehicles Directorate (AFRL/RVSV). The program receives sponsorship and funding from the Air Force Office of Scientific Research (AFOSR). It is a multi-university competition aiming to develop next generation of aerospace engineers to lead the development of space technology in the future. The stated goals of the University Nanosatellite Program are to, "educate and train the future workforce through a national student satellite design and fabrication competition and to enable small satellite research and development (R&D), payload development, integration and flight test."

Within the context of past program successes and challenges, there exist unique opportunities for capability demonstration using the University Nanosat Program structure. Particular points of interest include the symbiosis of government and academia on a flight program; the training of the next generation of aerospace professionals; and the opportunity to infuse existing aerospace institutions with out-of-the-box methodologies and technologies which incorporate the use of next-generation deployables and science instrumentation, autonomous controls, MEMS, distributed architectures, as well as advanced communications, power systems, and sensors. Particular attention is paid to evaluating program success based on such aspects as cost-sharing advantages, education and training, program flexibility and responsiveness [19].

The CubeSat Program

The CubeSat Program began in 1999 at Stanford University by Professor Bob Twiggs and California Polytechnic State University with Professor Jordi Puig-Suari. The fundamental purpose of the program was to meet an educational need to have a satellite that could be developed within two years, be very-low cost and be very low weight for reduced launch costs. The vision of the CubeSat Program was to provide a low-cost platform, promote rapid development, and train students as responsible engineers in industry's multidisciplinary environment. Since its inception, the CubeSat Program has become a worldwide program that is comprised of over 70 universities, government organizations, and private companies [20].

The CubeSat Program is designed so that space missions can be completed in two years or less. This accelerated schedule allows students to be involved in the complete life cycle of a mission. A unique feature of the CubeSat Program is the use of a standard deployment system. Through the Poly Picosatellite Orbital Deployer, or PPOD, standardization is used to reduce mission cost and accelerate development time [21]. The success of this program over the last ten years has provided a unique flexibility in the aerospace industry, opening up quicker and cheaper mission opportunities than ever before. More than 40 CubeSats from both academia and industry have been flown in the past 7 years.

CANSAT Program

CanSat is an international student design-build-launch competition organized by the American Astronautical Society (AAS) and American Institute of Aeronautics and Astronautics (AIAA). The competition is also sponsored by the Naval Research Laboratory (NRL) and the National Aeronautics and Space Administration (NASA). The CanSat competition is a space-related program for college, university and high school students. The objective of the CanSat competition is to complete space exploration missions by designing a specific system for a small sounding rocket payload according to a set of yearly objectives, such as landing in a designated area, performing remote sensing observations during flight, and incorporating lander and/or rover payloads. The competition spans the complete mission life-cycle (mission definition to flight operations) in nine months. Roughly 20 schools per year begin the competition, and around a dozen complete the mission [22].

BalloonSat Programs

The BalloonSat category is comprised of a number of independent organizations involving introductory-level engineering and science students in near-space experiments in a cost-effective manner. The “launch vehicle” is a high-altitude weather balloon that carries student payloads to altitudes as high as 30 km before bursting and parachuting back to ground. The BalloonSat provider typically provides the balloon and tracking systems, while the student teams provide their own self-contained, self-powered payload packages. Student-built payloads include cameras, temperature sensors, pressure sensors, solar cells, etc. Examples of BalloonSat providers are: the Colorado Space Grant Consortium, Edge of Space Sciences, and Near Space Ventures, Inc. Many BalloonSat missions are run completely within a school or in partnership with a local Amateur Radio Club, including the more than 80 members of the Amateur Radio High Altitude Ballooning organization [23].

Significance and Contributions of University Spacecraft Programs

A popular notion among universities is that they can provide significant impact and contributions into the naturally risk-adverse professional spacecraft industry using a “University-class” spacecraft on account of the significant level of mission risk that a student program can accept. The most obvious example of innovation is the CubeSat standard, which has not only transformed the process by which most universities approach spaceflight (bringing many new schools into the fold), but gained the attention of professional industry, the National Science Foundation and even NASA.

Introduction of the CubeSat standard in 1999 resulted in launch of first CubeSat in 2003, which is an astonishingly short time in spacecraft terms. The next seven years have shown a radical increase in CubeSat launches. As shown in Figure 1, the significant increase in manifests noted in 2004 and 2007 can be called a full-blown trend, and credit must be given to the CubeSat/P-POD launch system; as shown in Figure 2 (and especially in Figure 3), the smallest spacecraft account for the large increase in missions. In 2007, there was a speculation that, with the backlog of first-generation CubeSats launched; there might be a drop-off in the number of CubeSat missions. This has not happened. Instead, new international players have emerged with at least a dozen university-class spacecraft per year expected for the indefinite future, including six to ten CubeSats.

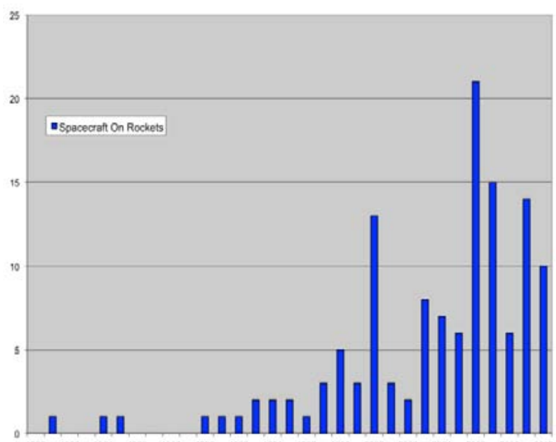

Figure 1: Total Number of Manifested University-Class Spacecraft per Year

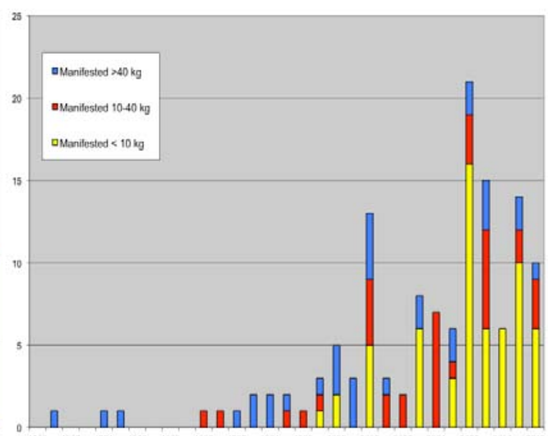

Figure 2: Spacecraft Launch Mass by Year

Another important continuing trend is the emergence of flagship schools in the manifest (Figure 4), in India, Russia, Turkey and Switzerland. Flagship schools represent 54% of the 119 manifested spacecraft through the end of 2009 (roughly the same percentage as from previous years). In terms of space missions, innovation means a significant improvement in cost, timeliness, performance or risk. As noted in the introduction, many university participants believe that they are on the cusp of innovative breakthroughs. Next section provides some examples of operational and to be launched university missions testing innovative concepts.

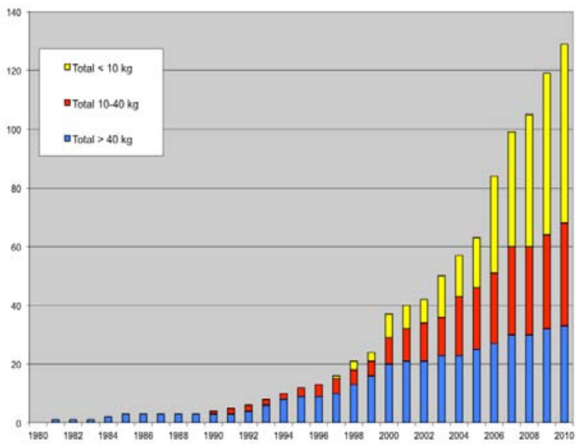

Figure 3: Aggregate Totals of Spacecraft Launched per Year

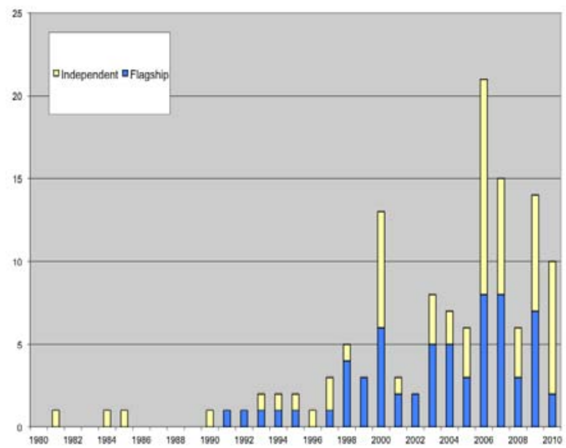

Figure 4: Flagship vs. Independent

Educational Value

The university spacecraft program has provided all the students involved with numerous educational benefits in multiple areas. Overall, the knowledge gained from such a large and in-depth project can be divided into two areas: technical and project management. These projects have helped students improve their engineering competencies.

The most challenging aspect of designing a satellite in a university setting is the collaborative effort with students from multi-disciplinary engineering programs. Constraint-based design requirements drives the students to be more creative and efficient in decision making and designing complex systems that has enabled them to be increasingly competitive in the global market. Some of the "systems engineering" outcomes that the students benefit from these programs are listed below.

Multi-disciplinary Teamwork

Students must learn to work effectively with people that do not necessarily think or talk like themselves. They must learn to understand and value the skills that each team member provides, and then employ these various skills in an optimal way to realize the final design goal. The challenges of working within a multidisciplinary team environment include team problem-solving, project management, and team communication.

Team Communications

Communications among various subsystem team members is a crucial facet in successful completion of a complex project. Students must be able to share ideas within the team, as well as clearly articulate, justify, and defend ideas with the team, external customers, and reviewers.

Additionally communication is essential to ensuring that the project will be continued on in future years and hopefully be completed. To make certain this happens, the team must seek out underclassmen to include them in the design and decision making processes. Therefore, when the upperclassmen leave school there will be other students with a vested interest in the project, increasing the probability of project completion. So far, teams have not been successful in this endeavor, causing a new project to be started each year.

Multi-disciplinary Engineering and Realistic Design Constraints

Students must incorporate engineering standards and design constraints that impact engineering solutions across all disciplines. Thus, students gain an appreciation for how/why other subsystem members may be constrained in their design solutions.

Innovation and Entrepreneurship

This section highlights the technological innovation and entrepreneurial outcomes from small satellite industry in general and university/student-built spacecrafts in particular. Table 3 shows several examples of CubeSats and Nanosats that are already operational or to be launched in future. The list includes spacecraft missions from universities, private space companies and NASA research centers.

The success of the CubeSat and university nanosat programs has spurned the growth of several entrepreneurial-mined small businesses across the globe, specifically targeting this niche market. Many of the traditional spacecraft engineering companies have started developing specific components and subsystems for small satellite community.

In addition to university programs, the CubeSat standard has led to professional missions from the Aerospace Corporation and Boeing, among others. These programs have developed CubeSat-scale technologies including: miniature, low-power star trackers, multithruster propulsion modules, nano-reaction wheels assembly for precision attitude control and electrical power systems.

Table 3: CubeSats and Nanosats Operational or Ready for Launch

Spacecraft	University/Company/Research Center	Mission Objectives	Year of Launch/ Operational Status
UoSat-1	University of Surrey	Carried research, technology demonstration and educational payloads	1981/De-orbit
NuSat-1	Weber State University and Utah State University	Demonstration that satellites could be built small, simple, and at low cost for special applications	1985/De-orbit
Sapphire	Stanford University	To train graduate students in the design, assembly, test and operation of spacecraft by	2001/Operational
QuakeSat	Stanford University	Earth observation nanosatellite based on 3 CubeSats. It was designed to be a proof-of-concept for collecting ELF earthquake precursor signals from space	2003/Last heard in 2007
Cute-1	Tokyo Institute of Technology	Test platform based on COTS components	2003/Operational
XI-IV	University of Tokyo	Test platform based on COTS components	2003/Operational
GeneSat-1	Santa Clara University/NASA Ames Research Center	The satellite is the first CubeSat to carry a biological payload into space.	2006/Operational
AeroCube-2	Aerospace Corporation	Mission is to test a communication system and the system bus plus a suite of CMOS cameras	2007/Not operational
CSTB-1	The Boeing Company	Evaluate miniature satellite technologies	2007/Operational
Cape-1	University of Louisiana	Educational Mission with Camera payload	2007/Partly Operational
CanX-2	University of Toronto	Will test instrumentation for future CanX missions including a propulsion system, momentum wheel, sun sensors, gps receiver, CMOS camera (star tracker), and	2007/Unknown
Delfi-C3	Delft University of Technology	Novel payloads – Thin Film Solar Cell Experiment, Advanced Transceiver (ATRX) payload	2007/Operational
Seeds-2	Nihon University	Rebuild of the SEEDS cubesat which had launch failure	2007/Operational
Pharmasat	Santa Clara University/NASA Ames Research Center	To measure the influence of microgravity upon yeast resistance to an antifungal agent	2007/Operational
AggieSat-2	Texas A&M University	To test a novel dual-GPS system (dubbed DRAGON) engineered by the Johnson Space Center (JSC) Aeroscience and Flight Mechanics Division (AFMD)	2009/De-orbit in 2010
BeeSat	TU-Berlin	It's mission is the on-orbit verification of newly developed micro reaction wheels for pico satellite applications.	2009/Operational
ITUPSat-1	Istanbul Technical University	Educational Mission	2009/operational
UWE-2	University of Wurzburg	Educational Mission, demonstration of ADCS capability	2009/Operational
SwissCube	Space Center at EPFL	Carries a small telescope which will allow obtaining images of the nightglow, a luminescence phenomena occurring at 100 km of	2009/Operational
OUFTI-1	University of Liege	Innovative feature of using the D-STAR amateur radio digital communication protocol	To Be Launched
AtmoCube		Scientific payload includes Radiation flux (soft X-rays, protons) Silicon Detector to monitor radiation environment	To Be Launched
e@Star		Testing of miniaturized fuel cells and an active ADCS system	To be Launched
Goliat		Dose-N – determining the total dose of radiation using a PIN diode and a scintillating material SAMIS – micrometeorites detection in orbit using a	To be Launched
PW-Sat		A mission to test a deployable atmospheric drag augmentation device for de-orbiting CubeSats	To be Launched

Research and Federal and National Laboratory Involvement

The success of the CubeSat standards in driving technological innovation and in significantly reducing the cost of entry into space has attracted the interest of several federal agencies. In 2007, the National Science Foundation started the "CubeSat-based Space Weather Program" under the Atmospheric Sciences Division. This objective of this program is to perform scientific research in space weather and related phenomena on university-built CubeSats. The first NSF CubeSat (RAX) is slated to launch in September 2010, and four more NSF CubeSat missions are funded for development.

The recent Air Force SBIR solicitation has several topics on component and subsystem developments for CubeSats, and the National Reconnaissance Office has a similar solicitation, with the stated objective of launching several dozen CubeSats under the Colony program (see Table 4). The U.S. Army has completed the first round of development on its SMDC-ONE CubeSat constellation.

Table 4: CubeSats and Nanosats Past and Current Federal Solicitations

Agency	Topic Number	Topic Description
US Army	A11-057	Lightweight Nanosatellite Constellation Communications System
US Air Force	AF103-083 (SBIR)	Attitude Determination and Control System (ADCS) for CubeSats
US Air Force	AF103-085 (SBIR)	Agile Space Radio (ASR)
US Air Force	AF103-089 (SBIR)	Improved Solar Cell Power for Cubesats
US Air Force	AF103-091 (SBIR)	Miniaturized Star Tracker for Cubesats
National Science Foundation	NSF-10-537	CubeSat-based Science Missions for Space Weather and Atmospheric Research
US Navy	N101-105	High Performance UHF Antenna for Nano-satellites
NRO	COLONY_II_CubeSat	Design, documentation for later payload integration, build, test and qualification of a quantity of CubeSat buses in order to maximize
DARPA	SB092-016	Networked Cubesat Clusters
US Air Force	AF-93-088	Modular Cubesat Architectures and Components

Conclusions

A student run satellite program can be very challenging, but the rewards are great for the students and institutions that participate in the project. These programs provide university students with practical, hands-on experience in the design, analysis, test, fabrication, integration, and operation of space systems. Anecdotal evidence suggests that there is a significant improvement in quality of the students entering space workforce who have been involved in student-built spacecraft design projects. Statistical evidence also suggests that there is a considerable increase in the number of students entering space workforce just by observing that a vast number of universities are involved in spacecraft design activities. It is also worth noticing that several second tier universities have embarked on this opportunity to improve the quality of their aerospace educational programs.

Universities, especially student-run spacecraft design programs have enormous freedom to fail, which makes it possible to executive high risk missions and also to test innovative space components and subsystems. The CubeSat revolution has not played out yet. In fact, it can be argued that CubeSats are still in their infancy. Still, it must be noted that with NASA, NSF, NRO, and DOD are putting or has started to invest significant resources into CubeSat developments, and with several recent and upcoming P-POD flights on US and international rockets, the future of CubeSats looks significantly different than it did even two years ago.

CubeSat launch opportunities are significantly increasing over the years, not only in US, but also in Europe and Asia. With the Minotaur launch vehicle in US, the first Vega Launch from Europe and several CubeSat launches from ISRO's PSLV, the future of CubeSat programs is very promising not only in US, but also worldwide. On the manifest in next 12 months (2010-2011) are nine CubeSats with strong science/technology projects—arguably the first university-class CubeSats to be more than limited-functioning "BeepSats". In addition to NSF CubeSat missions, the other eight will ride on ESA's first Vega flight; their results will be very indicative of the potential scientific benefits of university-class CubeSats, and CubeSats in general.

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