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Deepak, R., Twiggs, R. (2012): JoSS, Vol. 1, No. 1, pp. 3-7
(Feature article available at www.jossonline.com)

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Thinking Out of the Box: Space Science Beyond the CubeSat

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Abstract

Over a decade ago, Professors Robert (Bob) Twiggs (then of Stanford University) and Jordi Puig-Suari (CalPoly-SLO) effected a major paradigm shift in space research with the development of the 10-cm CubeSat, helping to provide a new level of student accessibility to space science research once thought impossible. Seeking a means to provide students with hands-on satellite development skills during their limited time at university, and inspired by the successful deployment of six 1-kg, pico-satellites from Stanford's Orbiting Picosatellite Automatic Launcher (OPAL) in 2000, Twiggs and Puig-Suari ultimately developed the 10-cm CubeSat. In 2003, the first successful CubeSat deployment into orbit demonstrated the very achievable possibilities that lay ahead. By 2008, 60 launch missions later, new industries had arisen around the CubeSat, creating new commercial off-the-shelf (COTS) satellite components and parts, and conventional launch resources became overwhelmed. This article recounts this history and related issues that arose, describes solutions to the issues and subsequent developments in the arena of space science (such as further miniaturization of space research tools), and provides a glimpse of Twiggs' vision of the future of space research.

Figure 1. Prof. Bob Twiggs

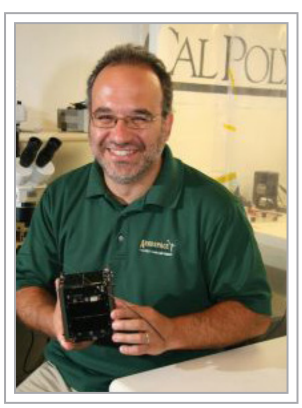

Figure 2. Prof. Jordi Puig-Suari

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Mavericks of Space Science

With the development of the Cubesat over a decade ago, Bob Twiggs, at Stanford University (now faculty at Morehead State University), (Figure 1) and Jordi Puig-Suari, at California Polytechnic State University (CalPoly) (Figure 2), changed the paradigm of space research, helping to bring a new economy to space science that would provide accessibility once thought impossible to University students around the globe. Neither intentionally set out to establish a new model for satellite design and space research; instead, it happened as a result of seeking a pragmatic solution to the question of how to best provide students with hands on satellite development skills within their one- to two-year span at the university. From this fundamental question, they disrupted the space research industry, and catalyzed new growth areas in space science, providing a foundation for attainable hands-on space research.

Twiggs describes the historical background of the development of the CubeSat concept in illustrated detail in his article "Origin of CubeSat" (Helvajian and Janson, eds., 2008). In brief, the radical departure from traditional satellite design represented by the CubeSat began after the successful 2000 launch of the Orbiting Picosatellite Automatic Launcher (OPAL), part of Stanford University's Satellite Quick Research Testbed (SQUIRT) led by Twiggs. OPAL deployed six hockey puck-sized picosatellites (1 kg weight) (Soojung-Kim Pang, 2011). Inspired by this success, Twiggs explored a larger, more cubical design to support more power and experiment capacities. According to Twiggs, he found the perfect model for his new design in a local retail store, in the form of the 4-inch cube packaging for Beanie Babies. The resulting picosatellite, measuring 10-cm cube and weighing only 1 kilogram, was the CubeSat. (Figure 3).

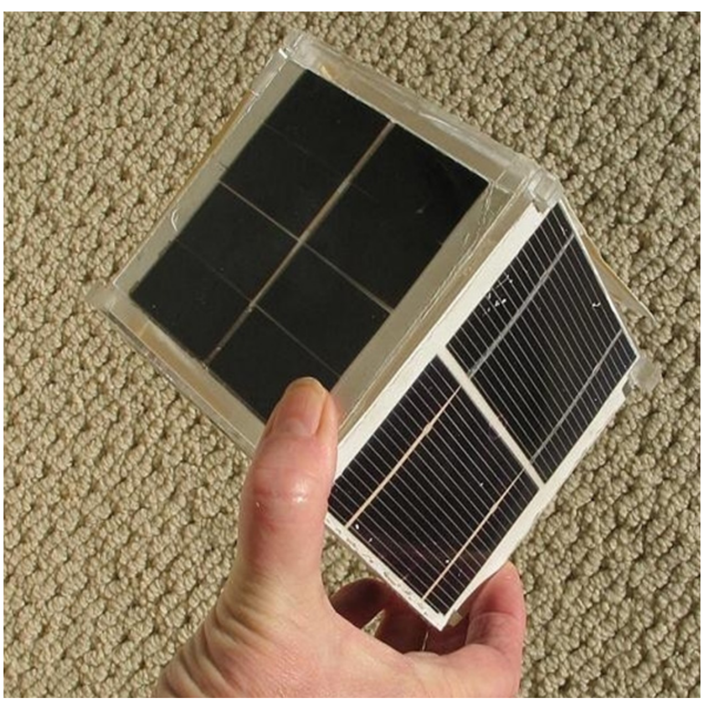
Figure 3. Original CubeSat


Figure 4. Twiggs with his PocketQub (1PQ)

Later that year, Twiggs and Puig-Suari released the specifications for the open-source CubeSat in a 10-page manual (Stephenson, 2011). By 2003, Puig-Suari and CalPoly had developed the Poly- PicoSatellite Orbital Deployer, or P-POD, for launching up to three 1-unit CubeSats; and Twiggs, at Stanford, had completed CubeSat buses and experiment designs. By its first launch, in 2003, the CubeSat had already morphed from a one-unit (1U) research tool to double-unit (2U) and triple-unit (3U) CubeSat experiments.

A Chilly Reception Thaws

Initially, when Puigi-Suari and Twiggs presented their novel idea to the Space community, they were met with harsh criticism, namely that the CubeSat could never function as more than a toy in space. However, by using the converted ICBM launcher the SS-18, Dnepr, the first successful CubeSat deployment into orbit in 2003 helped demonstrate the very real, and very achievable possibilities that lay ahead. Twiggs described how CubeSat emerged from the CalPoly and Stanford labs as follows:

"One of the first scientific applications of the CubeSat started with the first launch in 2003. A triple CubeSat called QuakeSat developed with Stanford students by Quakefinder, Inc. from Palo Alto, CA was launched to determine if they could observe low frequency electromagnetic radiation in areas prior to an earth quake. This EM radiation was analyzed after the fact from recorders near the 1989 Loma Prieta earth quake near Santa Cruz, CA. There was some evidence of this phenomena seen which may lead to new space prediction systems in the future." (Personal Communication to Deepak, 2011)

Over the past eight years since the first CubeSat launch, more than 60 CubeSat missions have been successfully launched into orbit (Stephenson, 2011). A little over half of these were U.S. missions. CubeSat missions have had a variety of stakeholders, from universities to high schools, and an increasing number of industry partners, such as Boeing, which was the first large aerospace company to form a new group to develop the CubeSat. New industries have arisen around the CubeSat, as well – such as Pumpkin in the US, Innovative Solution in Space (ISIS) in the Netherlands, and Clyde Space in Scotland, all of which have facilitated further research and innovation, and led to commercial off-the-shelf (COTS) satellite components and designs.

With this burgeoning interest, the small satellite community is now inundated with CubeSat experiments, as technologies continue to evolve in support of miniaturization, and interest in space is reignited with each success. CubeSat demand and popularity among university and government scientists, students, and other users have, at this point, overwhelmed conventional launch resources. This is partly attributable to heightened interest from government agencies and private industry; but also, in large part, to the sheer magnitude of research and educational projects for which a low cost CubeSat platform is ideal.

NASA has responded to the demand for more low-cost launches for universities through its new Educational Launch of NanoSatellites (ELaNa) mission led by Garret Skrobot at the NASA Kennedy Space Center in Florida. This endeavor is scheduled to provide 22 launch missions by the end of 2012, with more launch opportunities to be made available in the years that follow.

Miniaturization of Space Science Tools

The CubeSat developers focus on enhancing and improving current models of the picosatellite -- advancing the attitude control, miniature magnetic-torquers, and star trackers, for example; the Payload developers facilitate improving CubeSat research with enhanced spectral imaging and astrophysics devices and experiments. Meanwhile, Twiggs looks to the future of space research, noting that within the past decade, space research has been condensed exponentially to fit CubeSat size and form-factor requirements. Synergistic miniaturization by innovative technology companies from all industries has developed and enhanced the current capabilities of the CubeSat—making it possible to conduct bigger space research experiments with smaller systems.

This trend towards smaller size shows no signs of stopping in the near future, as components continue to become smaller and more powerful. For example, Twiggs' PocketQub, a collaborative effort with Morehead State University and Kentucky Space, is a palm-sized satellite that can fit into your pants pocket! (Figure 4.) A 5-cm side cube, it further shrinks small satellite technology. Approximately eight (8) PocketQubs can fit within one CubeSat -- a new model for the future of education in space science! (See Figures 5 and 6.)

Twiggs believes that the PocketQub will be a key tool in re-igniting Science, Technology, Engineering, and Mathematics (STEM) education at high schools throughout the U.S. and around the globe. The STEM education subject matter in the field of space research is often easily lost on students because of its inherently almost abstract application in space research. By providing high schools with a two-year course outline along with hands-on experience in design, build, launch and telemetry of small satellites, it has far greater potential to keep students' focus and interest on these more at-

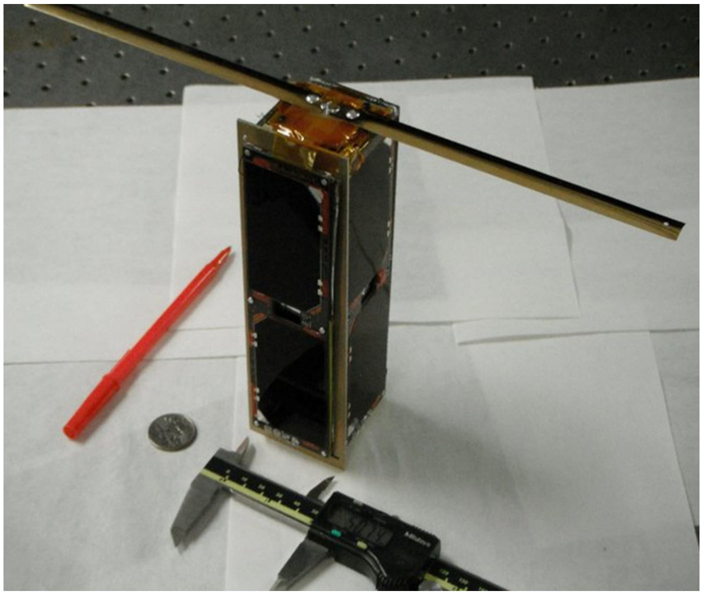

Figure 5. A 2PQ satellite

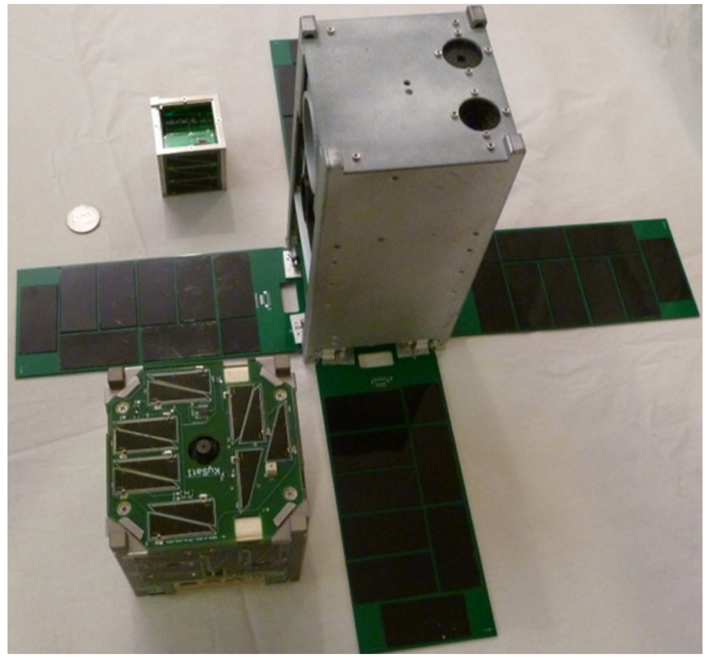

Figure 6. 1PQ next to 1U and 2U

tainable project goals, especially after they hear their first signals from space!

At present, the small satellite community seems hesitant to embrace the PocketQub -- as hesitant as it was about the CubeSat in the past. But Twiggs is confident in the development of micro-miniaturization of technology, and believes that in the not-too-distant future, CubeSat-like experiments will be possible on the 5-cm cube scale of the PocketQub. He is even preparing for another order of magnitude reduction with SliceSat/ChipSat inventions. Both of these are flat, panel-like space experiments with limited power, but simpler experiments capable of data transmission, using the five-cm-cube dimensions of the PocketQub. Over 24 small matchbox-sized FemtoSats can be stacked inside a CubeSat, and possibly released towards the Moon, and as such, Twiggs aptly named "Moonbeams." There is also significant progress being made on the Cornell University ChipSat. This is bringing new attention to the smaller- than- PocketQub class of spacecraft that performs important space science functions using swarms of these ChipSats. These types of relatively inexpensive experiments are excellent research tools for providing hands-on experience for the benefit of encouraging younger space enthusiasts and to help breach the current STEM education stagnation.

Out of the Box

Reflecting on launched CubeSat mission research, Twiggs recognizes that space microgravity research in particular is significantly limited. In his vision for the future, he foresees companies such as NanoRacks opening up exciting new possibilities for doing microgravity research. Twiggs and Jeffrey Manber (of NanoRacks) believe this opportunity will revolutionize astrobiology research. They have devised a NanoLab (Manber, 2011) to fit in a rack system to be attached to the International Space Station (ISS), based on CubeSat form-factor; the NanoLab has the same dimensions and relative weight as the CubeSat. The Rack provides "hassle-free," plug-n-play research for 32 NanoLabs. Most notably, the Rack has USB adapters for the Labs to plug into for data storage/transmission and for powering the NanoLab. The NanoLab can stretch to accommodate up to four units, and can be any variation of 4U x 2U in size.

Overall, from a practical standpoint, the saturation of the CubeSat market (due to its economical and ready access to space) has put a pinch on progress in the area of space science, as there are only a select few launch opportunities for experiments per year. However, Twiggs feels that the politicking behind the growing

CubeSat market should not limit the research opportunities available for education. NanoRacks, for example, provides a new tool, a new paradigm for the conduct of space research - one where the experiment is not space-limited by battery or solar cell production. He believes it will be invaluable to continuing University-led research, especially in the chemical and biological fields, and in new ones, such as exo-medicine, where it is not necessary to have free-flying space experiments. The Valley Christian High School in San Jose, California, was one of the first to benefit from the STEM education experience on the ISS, using the NanoRacks system, with a plant-growing experiment in early 2011.

Space Fingerprints

This is an era of miniaturized space research, heralded by the CubeSat. As a technological innovation that presents a radically different level of versatility and accessibility to enthusiasts, educational and professional facilities, the CubeSat/small satellite phenomenon has been likened to the development of the personal computer (Stephensen, 2011). Computer enthusiasts and technologists were able to build their own machines and gain invaluable hands-on experience to contribute and advance the community's knowledge. Similarly, the CubeSat enthusiasts/developers share the common goal to leave their "fingerprint on the ceiling" of space through their own hands-on experience with small satellites.

As a point of illustration, Twiggs makes reference to a recent HackerSPACE workshop hosted by Kentucky Space in Lexington, Kentucky, USA: "This workshop was directed towards a broader audience than the normal university or government engineers. The workshop attracted double the expected attendance of 25 to learn about what it takes to do space experiments. At least three more of these workshops are planned for early 2012. It is believed that there could be a community of developers for space experiments like the apps developers for smart phones."

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