Amateur Radio and the CubeSat Community

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Abstract
This paper will explore the relationship between the AMSAT and CubeSat communities, including gained educational experiences, collaboration on an International Ground Station Network, and future Amateur Radio payloads on CubeSats.

1. Introduction
CubeSats are a class of picosatellites built primarily within a university setting to get students interested and educated in the science of building small satellites. Multidisciplinary teams of students work on designing and fabricating the satellite structure, electronics, communication system, and payload. Formal procedures for building and testing satellite components are written by students and used throughout the process. While some schools choose to outsource aspects of fabrication, such as milling the structure and fabrication of PC boards (due to time constraints or lack of adequate equipment), most of the building and assembly of the satellite is done in house.

One of the greatest concepts within the CubeSat project is the very short conception-to-operation time, usually two to three years. This allows first and second year students the opportunity to be involved with the satellite from the planning stages to operation of their satellite while it is orbiting this planet.

CubeSats are defined by a very simple specification: 10cm on a side with a total mass of less than 1 kg. There are other specifications in the standard, such as separation springs and deployment switches, but those two are the main ones. The CubeSat standard was started by Bob Twiggs at Stanford University in 1999, but was fully developed and kept up-to-date by students at Cal Poly.

The common CubeSat standard was designed so that satellites can be loaded into a CubeSat deployer, such as a P-POD, T-POD, or XPOD, and launched into space on a whole range of launch vehicles. A CubeSat deployer is used as the interface between the launch vehicle and CubeSats, to protect the primary payload from our satellites and provide a common set of mounting holes for the launch vehicle. A deployer also allows CubeSats to switch launch vehicles if the situation should arise.

Currently, there are 4 CubeSats working in orbit right now (Table 1), with another 6 not functioning in orbit. University designed and built CubeSats typically have a 60% success rate of turning on when deployed into space. While this success rate may seem extremely low, remember that the primary purpose of this project is education. The objectives of the project have been fulfilled whether the satellite works in space or not.

Satellite	School	Launch	Frequency	Payload
XI-IV	University of Tokyo	30 June 2003	437.490 MHz	Camera
QuakeSat	Stanford/Quakefinder	30 June 2003	436.675 MHz	VLF receiver
XI-V	University of Tokyo	27 October 2005	437.345 MHz	Camera
CUTE-1	Tokyo Institute of Technology	21 February 2006	437.505 MHz	Attitude determination

Table 1: Operational CubeSats as of September 2006

One might comment on how much space junk we are adding to space. While this has been true in the past, due to the FCC's new orbital debris mitigation plan [1], things are changing. Methods to de-orbit spacecraft are being developed and tested; these ideas will be discussed later in this paper.

As can be seen in Table 1, most CubeSats operate in the 70cm Amateur band. Simplex systems are used to decrease complexity and reduce required frequencies. Most CubeSats uplink codes are not published, and therefore can't be used by the general public, although Japanese Amateur Radio operators can use XI-IV to take and download pictures.

2. Collaboration between AMSAT and CubeSat Communities

If regular Amateur Radio operators cannot uplink to a CubeSat, then what could possibly be the benefit to the Amateur Radio community? There are numerous benefits to the community, among them the education of another generation of satellite builders and users, and the ability to work satellites with new and interesting payloads.

Education is the reason why this program was started. Students working on CubeSats are already interested in satellites, and with a little push many of them get their Amateur Radio license. At Cal Poly, more than three-quarters of the students working on the CubeSat project have their Amateur Radio licenses. About half of the team has talked with XI-IV, and about a quarter of the team has talked on regular AMSAT satellites.

These students are the future of AMSAT, and will one day be building and designing the next generation of Amateur satellites. The complex problem solving they learn in the lab will help them with the new technologies.

The CubeSat community thrives off of interaction with experienced satellite builders. Students in these programs need mentors to help them with the complexities of building an object destined to orbit this planet. The AMSAT Area Coordinator list is great place to begin looking for mentors around a particular university.

Another area where the AMSAT and CubeSat communities work together is trying to find the CubeSats just after launch. Each university wants to know as quickly as possible whether their satellite is working or not, but there are many obstacles. For example, the first pass over the earth station might be several hours after deployment, NORAD can't differentiate between individual CubeSats in the days after deployment (so they are just going to release one Keplerian element for multiple satellites), or the elements might be slightly wrong. The Amateur community can help out with all of these problems, and has done so in the past.

The SSETI Express mission is a great example of the help that Amateur Radio operators are willing to give the CubeSat community. SSETI Express was a 62 kg satellite, with 3 CubeSats inside, that was launched in October 2005. Unfortunately, the satellite failed just 14 hours after launch, but the Amateur community provided crucial data to the SSETI Express team when the satellite was out of range of the primary and secondary earth stations [2].

3. Ground Station Network

A ground station network is a collection of earth station networked together for the purpose of sharing data. The main benefit of this approach is it dramatically increases amount of data that can be downlinked or uplinked to a satellite, as well as increasing control of operations for satellite owners. While there are some legal issues that still have not been resolved, using other earth stations to uplink commands to your satellite allows events to take place around the world and owners to react to potential problems quickly.

Currently, there are two independent ground station networks. One is the Mercury Ground Station Network [3], designed by James Cutler of Stanford University. At the height of its use, there were several stations in California and one in Alaska that were connected to the network. However, the network is no longer being actively used or maintained.

The second ground station network is the Ground Station Network built by various technical universities in Japan. While currently there are 13 Japanese universities using the Ground Station Network [4], there are plans to expand the network to include users outside of Japan within the next year. Currently, the Japanese Ground Station Network is only dealing with digital data packets, but there is no reason why it could not be adapted to use VoIP or similar protocols for voice.

Figure 1: Picture downloaded from XI-IV in 7 hours

A great benefit of linking earth stations is that more data can be downloaded. While this may not seem very beneficial to the average voice satellite operator, this can be helpful for hams that use store-and-forward or BBS satellites.

A test conducted on 26 April 2006 between the University of Tokyo and Cal Poly San Luis Obispo demonstrates just how much more data can be downloaded with just two stations [4]. The test, using the Japanese satellite XI-IV (Figure 2), was to download a full 32kB picture as fast as possible. Normally, it takes 1 day at Cal Poly to download a picture (or a little less than 10kB per good pass), and 1-2 days at the University of Tokyo. It takes them the extra time because of local RF interference on their Amateur bands. During this test, it only took 7 hours to download a full picture. About one-third of the picture was downloaded at Cal Poly, and the rest was downloaded at the University of Tokyo. The picture was stitched together by students at the University of Tokyo, and can be seen in Figure 1.

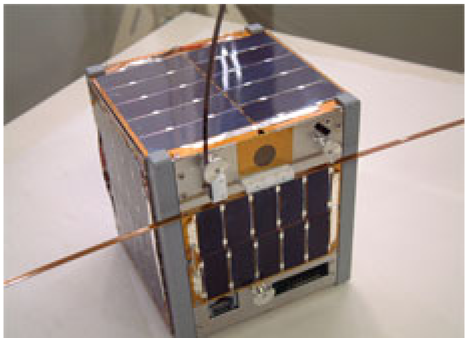

Figure 2: XI-IV satellite

During the beginning of August 2006, a test was conducted [5] between earth stations at Cal Poly San Luis Obispo, University of Tokyo, and Luleå University of Technology in Kiruna, Sweden. This test used both the CUTE-1 and XI-IV satellites. The main purpose of these experiments was to test an arctic ground station on the network. The station at Kiruna, Sweden is at 67.7° north, and can communicate with satellites in polar orbit almost every pass. Another test was to see how the satellites would react to very frequent transmissions (large power load), and also see how much data could be downlinked from both satellites. The earth stations involved with this test were too far apart for true handoffs.

During the test with CUTE-1, approximately 2.2kB of temperature, voltage, accelerometer, gyro, and current data was downloaded during one pass over each earth station. The transmitter was on for 25 minutes, and the battery voltage stayed above 3.75 volts, which is slightly below nominal voltage for their particular Li-Ion batteries but well within the acceptable range. CUTE-1 can be seen in Figure 3. The test with XI-IV yielded 60.3kB of data downlinked to earth stations.

There are many legal aspects to think about when using an internet-based ground station network. However, they may not be as large as one might anticipate. On the receive side, there is no problem at all; a station does not even need any Amateur Radio involvement to receive satellite signals and put them on the internet. However, on the transmit side, the situation becomes more complex.

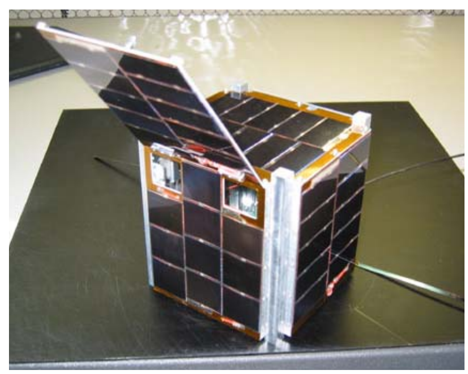

Figure 3: CUTE-1 satellite

Domestically, there should not be any legal problem for transmitting through a ground station network because both Amateur Radio operators fall under FCC rules and regulations. Also, the FCC does not care where the data being transmitted originates; it is up to the control operator of the station that actually transmits the data to monitor the data and ensure it follows the rules [6]. This is no problem for unencrypted communications, but most satellite commands are encrypted and cannot be inspected by a control operator. Legally, satellites uplink commands can be encrypted (§97.211), but the transmitting control operator might not like this idea.

A good example of transmitting on RF using another Amateur's station can be found within the Echolink system. Within this system, any Amateur Radio operator with a computer and microphone can talk on Amateur Radio repeaters across the country. This system is used all the time and currently has the backing of the FCC [7].

Bigger legal issues occur when the Ground Station Network goes international. While the same principles still apply (the FCC only cares about the station), some heads might turn if a station from a country without a reciprocal licensing agreement started transmitting from the middle of this country. The International Ground Station Network community will need some legal help (from AMSAT and the ARRL) in this regard before the system can be fully deployed.

4. Future

The future is looking bright for the CubeSat community. There are several CubeSat launch opportunities in the near future, and many new schools and companies are starting CubeSat programs. There is also real science being developed by these universities.

As for future launches, there is another Dnepr launch of 7 CubeSats from Kazakhstan this winter, organized by Cal Poly. In November 2006, GeneSat, with E. coli bacteria aboard, is scheduled to be launched aboard a Minotaur. The University of Toronto is organizing a launch of 5 CubeSats from an Antrix PSLV on 30 June 2007. Cal Poly is in talks with SpaceX and Space Access Technologies for launching CubeSats aboard their launch vehicles.

Universities are also flying interesting experiments on their CubeSats. Delft University of Technology, in their Delfi-C^3 mission, is performing tests of thin-film solar cells, internal wireless networks, and high-efficiency power amplifiers [8]. It will have a Mode U/V linear transponder for use when the science mission is complete.

Experiments are also being flown to flight qualify de-orbit mechanisms, in response to the FCC's recent guidelines [1] requiring that satellites de-orbit themselves within 25 years of end of life. These de-orbit devices range from tethers to balloons to deployable panels. Future AMSAT satellites will need to incorporate a de-orbit device.

5. Conclusions

While CubeSats may seem small and uninteresting to the average AMSAT member, they are a growing force within the satellite community. These CubeSat programs are enabling a whole new generation of satellite builders and operators to learn about systems integration, Amateur Radio, orbital mechanics, and communications systems. Both communities work together to track CubeSats during their first few days, and AMSAT mentors are always needed guide students through the design and build process, and to teach the art of Amateur Radio.

6. References

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