Michelle D. Thompson, W5NYV

5379 Carmel Knolls Dr, San Diego, CA 92130;
mountain.michelle@gmail.com

Howie DeFelice, AB2S

804 Fall Place, Herndon, VA 2010;
howied231@hotmail.com

Evolutionary Engineering for Revolutionary Satellites — AMSAT Next Generation

Next generation AMSAT satellites are faced with new challenges in uncertain launch schedules, development schedules and justification for the project.

AMSAT must shift from a reactive to a proactive engineering philosophy. In general, AMSAT waits for a launch opportunity and then starts recruiting volunteers to design satellites and payloads. This strategy is no longer viable due to three fundamental changes in the way the space industry works: (1) uncertainty in launch schedules, (2) lead time between launch availability and satellite development, and (3) justification for launching a satellite.

1 — Launch Uncertainty

There is increased uncertainty in launch schedules. Launch opportunities have fundamentally changed over the history of the organization. The impression is that launches were easier to obtain and less expensive in the past because Amateur Radio was familiar to the more military-minded launch authorities that approved the inclusion of Amateur Radio payloads. Launches were described as more experimental, less commercial, and more controllable within a hierarchy that was less sensitive to cost and more familiar with Amateur Radio. With the increasing industrialization and commercialization of satellite launches, amateur payloads were no longer privileged. They were expected to pay their way just like any other payload. Quotes were prohibitively high, ranging into the millions of USD. Amateur Radio's uncertain role in the commercial space industry makes it harder to recruit teams and raise funds.

There is an impression that lead times for launches have shortened, further challenging the AMSAT volunteer corps with shortened engineering schedules. However, there are some counterexamples. SumbandilaSat started in 2005 and did not launch until late 2009. FUNcube began around 2007 and didn't launch until 2013. Having a long launch window can be as negative as one that is too short, since it may be very difficult to keep a volunteer team together and motivated for 4 to 6 years, especially if the launch dates are unspecified for the majority of the design effort.

Launch opportunities have been offered with very short windows. Launch opportunities currently accepted and pursued by AMSAT have exhibited high probabilities of being delayed or cancelled or transformed. The modern launch opportunity landscape is dominated by uncertainty. Schedules might be short or long. Launches might be a sure thing or they might be very tentative. Coupling work to a launch means work stops and starts, or never starts in the first place because the launch isn't a "sure thing". Making payloads the priority instead of waiting on a launch to organize the work around is the right way to respond to increased schedule uncertainty. Suppressing publicity, marketing, recruitment, and fundraising because modern launches aren't a "sure thing" is detrimental.

2 — Design Time and Launch Lead Time

We can no longer afford to wait for a launch and still hope to finish modern designs. The lead time for development of highly desirable digital designs is unavoidably lengthy when compared to lead times for established analog designs. The increased functionality and flexibility of digital design comes at the direct cost of increased complexity. Complex things take longer to engineer, especially the first time through. The promise of re-usability through modular digital design and software is real. That promise is delivered through solid systems engineering and clear documentation.

AMSAT is working to build up a volunteer corps with expertise in digital design. The number of people with this expertise is still small compared to the industry demand. As a result, the number of people with the spare time to donate to AMSAT is limited. However, even if AMSAT was fully staffed and in possession of a working library of digital designs that could be efficiently adapted to the specifics of individual payloads, the increased complexity of digital design may still mean longer schedules when compared to simpler analog designs. Software is most often the biggest schedule risk in digital design.

3 — Justifying the Need for a Launch

Communications services alone are no longer a justification for launching a satellite. The continuing commodification of communications is something AMSAT, and all of Amateur Radio, must adapt to and confront so as to remain relevant. This means that if we want to continue concentrating almost exclusively on satellite communications, then we must pick truly challenging space-based communications projects and provide designs, justification, and documentation. We must be prepared to opportunistically lobby for inclusion in nontraditional niches.

An example of this is AMSAT's participation in the NASA CubeQuest Challenge. AMSAT volunteers devised a method to determine satellite range and range rate using modest antennas out to a distance of over 750,000 km. This is challenging engaging work that needs full recruitment publicity support from AMSAT.

What are the things that we are already doing within AMSAT that would be the best fit for a proactive strategy?

Proactive Strategy

The "Five and Dime" digital microwave approach is a good candidate. The 4A, 4B, and CubeQuest payloads, terrestrial Groundsats, and Phase 4 Ground radios are all reconfigurable by design. The idea of building to a published air interface that relies on a well-known open standard (DVB) serves a proactive payload principal very well. If this approach proves to be as successful as we think it will, other international AMSAT groups may adopt this proven standard making larger numbers of satellites available for use with a common ground station.

The FOX designs are excellent candidates. The FOX LEO design has shown to be reliable and robust.

What Amateur Radio centric designs are unquestionably attractive as payloads, besides the successful FOX program? What could we as amateur experimenters build and demonstrate that would be worth the cost to launch?

Engineering Challenges

An engineering challenge that could be worth a subsidized launch would be to build a practical HEO CubeSat in a 1U form factor. This would be an extremely rewarding endeavor requiring creativity in mechanical, RF, analog and digital design. AMSAT could be the record holder for the smallest HEO ever orbited. This is the kind of engineering challenges that will attract creative thinkers with the possibility of seeing their ideas actually placed into orbit.

Table 1.
Maximum expected power that can be generated from various size CubeSats.

Size	*Fixed solar panels*	*Fixed plus deployable panels*
1U	2 watts	10 watts
2U	5 watts	12-23 watts
3U	7 watts	21-30 watts
6U	14 watts	40-60 watts

AMSAT has not had a high altitude satellite since AO-40 stopped functioning in 2004. The economics and politics of replacing AO-40 with *any* sort of HEO satellite has relegated AMSAT to LEO satellites of the CubeSat variety in the form of the Fox series of satellites. The commercial success of the CubeSat platform has created opportunities to reach higher orbits as a ride share. Creating a practical Amateur Radio satellite that is operable from HEO altitudes of over 40,000 km is extremely challenging. The biggest problem is generating sufficient power from the available satellite real estate.

The Table 1 summarizes the maximum expected power that can be generated from various size CubeSats based on data from the Clyde Space web site (**https://www.clyde.space/**).

To put this in perspective, AO-13 generated 50 W of solar power and had a 50 W VHF downlink linear transponder. AO-40 could have generated in excess of 600 W of solar power. The 2.4 GHz downlink had 50 W of RF power. Both satellites used omni directional antennas. Anyone who operated those satellites remembers the difference in antenna size required to make a contact. AO-13 required long boom or stacked VHF/UHF beams where AO-40 could be worked with a small (0.6 meter) dish for downlink and a single 10 element WA5VJB "cheap Yagi" (**www.wa5vjb.com/references.html**). For the same level of RF power, higher frequencies mean smaller antennas on the ground.

Ground Station Antennas

Smaller antennas on the ground are another reality that has become increasingly important over the past 13 years since AO-40. More Amateur Radio operators and potential Amateur Radio operators live in antenna restricted areas. A practical Amateur Radio ground antenna needs to be not more than 1 meter in diameter. This establishes another criteria for our HEO CubeSat. It must be able to complete a downlink to a 1 meter antenna without exceeding the dc power limits of the satellite. The RF power of the transmitter is the largest consumer of power but it's not the only power consumer on the spacecraft. Power must be allocated for satellite monitor and control, on board signal processing, environmental control, attitude control and any potential scientific experiments that may be required to qualify for a launch.

Conservation of Satellite Power

Conservation of power is critical for a HEO CubeSat so the best place to start is with the transponder. General guidelines for an efficient and effective downlink are as follows.

1.— Use a single carrier for downlink with the SSPA operating close to saturation.

2.— The downlink should be PSK digitally modulated with robust FEC.

3.— Directional antenna with gain should be used to increase EIRP.

The desire to use directional antennas impose other requirements on the satellite, attitude control. The satellite attitude must be controlled with enough accuracy to keep the Earth within the beamwidth of the antenna. This should not be too difficult for the size and gain of the typical CubeSat antenna. Another advantage of attitude control is the possibility to maximize Sun angle to increase solar panel output.

All previous Phase 3 satellites used attitude control. AO-10 (see Figure 1) and AO-13 were spin stabilized. AO-40 had the ability to be three axis controlled using momentum wheels but due to other issues it too was spin stabilized. Spin stabilization is an effective means of controlling satellite attitude when used in conjunction with *magnetorqueing*. For spin stabilization to work, the satellite frame must be constructed with a high width to height ratio, with the satellite weight equally distributed so that the satellite is balanced about the axis of rotation.

This type of structural symmetry is difficult to achieve with a CubeSat. Other forms of stabilization such as gravity gradient boom, miniature reaction wheels and relocatable mass need to evaluated for effectiveness.

Small Footprint, More Capable Satellites

The orbital parameters of the launch could have an impact on the satellite design as well. If launched as a secondary payload on a GTO (Geosynchronous Transfer Orbit), the perigee may be too low to prevent premature orbit decay. Thrusters using volatile fuels are usually prohibited on secondary payloads so some form of non-volatile propellant needs to be investigated.

While we have been focused on improving our expertise in digital design, an over-arching challenge to AMSAT is to build more capable satellite in smaller footprints. The smaller the satellite, the greater the challenges. A HEO CubeSat will require thinking outside the cube.

P4 is an unusual exception in that the most common launches we can expect which will most likely be 6U or 3U CubeSats to HEO. Therefore, AMSAT should declare work on a family of HEOs that included 1U, 3U, and 6U packages. Each of these projects would be expected to go above and beyond the current status quo. The vision would be to exceed expectations and attract launches by demonstrating successful designs worth launching. The payloads must be more than commodity communications or they must provide value-added service to a scientific package. Identifying synergy between a science package or experiment and the radio communications requires being able to communicate with a wide variety of scientists and engineers.

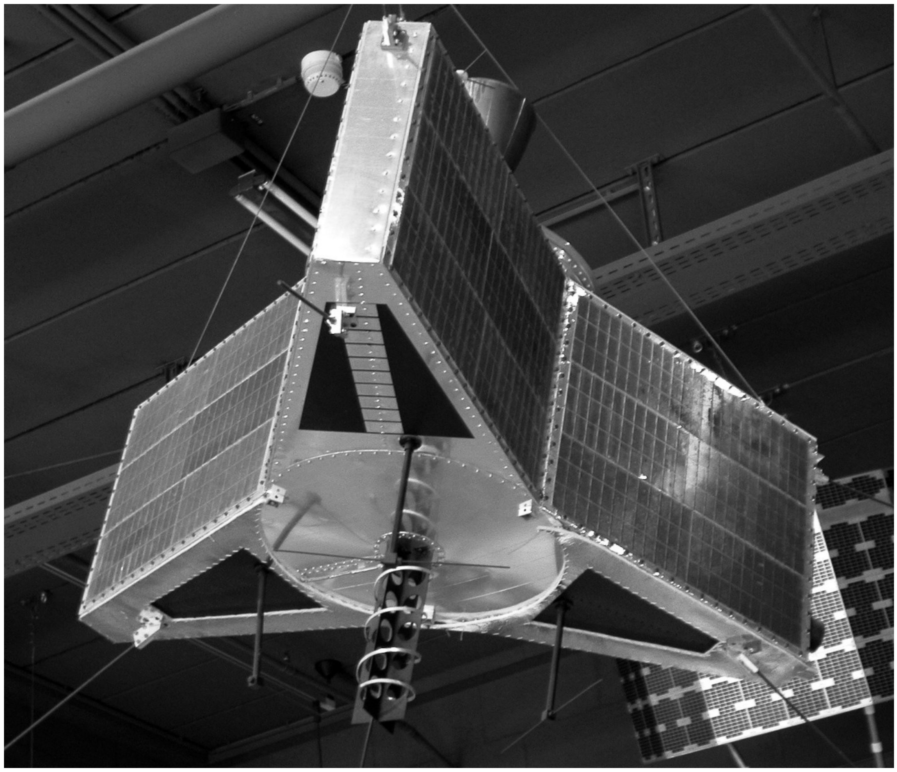

Figure 1 — A model of AMSAT OSCAR 10.

AMSAT Needs

AMSAT must have a volunteer corps of digital and analog designers that are willing to work, independent of launches. AMSAT must identify a family of payload projects, independent of launches. AMSAT must find the money to build and test those payloads, independent of launches. In parallel, AMSAT must opportunistically and aggressively pursue launches and missions where these projects can be deployed.

Culturally, AMSAT has biased itself towards appealing to operators instead of technical experimenters. This was fine in the early days when a large part of the membership were highly technical, that got on the air just to see how well their new modification or home-brew antenna worked. Chasing awards was an anomaly. The recruitment of operators was a way to grow membership beyond the highly technical crowd. However, in the opinion of AMSAT leaders such as Howie DeFelice, AB2S, we “went too far.”

The typical AMSAT member is portrayed as an FM LEO operator chasing grid squares. AMSAT emphasizes and celebrates the operating skills and dedication of the people enjoy this aspect of satellite communications. Is this a large and diverse enough community to ensure the viability of AMSAT moving forward?

AMSAT’s newest satellite is an FM repeater. There are two or three more FM repeaters scheduled to follow. More linear LEOs are not the answer either. There are now at least four linear LEOs in orbit and the biggest complaint among the people who operate them is that there are not enough people to talk to.

AMSAT, Maker Movement, and ITAR/EAR

Howie and others feel that AMSAT has a unique opportunity with the resurgence of the Maker Movement. There is a renewed interest in experiencing the satisfaction that comes with using something you built yourself. AMSAT provides a conduit that the Maker Movement can’t get anywhere else. This requires AMSAT to have ongoing engineering projects with lots of people working in small teams as either part of a bigger project or as a research team for a particular goal, similar to the way Phase 4 Ground is constructed to serve multiple payloads.

Decoupling the work from launch schedules and increasing our presence in communities such as the Maker Movement will require a major change in the way AMSAT thinks about engineering communication and where it spends volunteer time, energy, effort, and funds. The ITAR/EAR (International Traffic in Arms Regulations / the Export Administration Regulations) problem has to be clearly and publicly resolved. The lack of a clear, consistent, public policy from AMSAT on ITAR/EAR has been a major ongoing impediment to amateur satellite engineering communications in the United States. Silence in the face of need stands in very stark contrast to the open innovative nature of Amateur Radio in general and the open source Maker Movement in particular. Being afraid to communicate comes from the perception of enormous legal risk if one guesses wrong on what to say or not say. Any policy must come from AMSAT’s board of directors. The continuing damage done to amateur satellite service engineering by ITAR/EAR is an existential crisis to AMSAT and should be treated as such.

One way forward is to continue and expand the practice of teaming up with universities and other research institutions. This organizations often demand clear guidelines on what communications are legally allowed, and very often have departments or human resources tasked with managing ITAR/EAR constraints. This spreads the risk and increases collaboration at the cost of having a centralized and consistent AMSAT policy. Leadership in establishing a clear pro-volunteer ITAR/EAR policy provides substantial long-term benefits to Amateur Radio and the larger science, engineering, and technical fields.

Summary Remarks

Launch uncertainties cannot be used as a gating item to halt or delay or suppress work on digital designs. There's just too much work that needs to be done. If work stopped and waited for a rock-solid launch opportunity, then the work would literally never be completed. This is the reality of large complex digital designs and the challenge of smaller footprints. If we accept the conventional AMSAT wisdom that people won't volunteer without solid launch schedules, then the obvious implication is that AMSAT can't do challenging and complex designs. If AMSAT can't execute challenging and complex designs, then we cannot participate in current, let alone future, space-based communications projects. If we want to keep Amateur Radio in space, then we have to execute challenging and complex designs. In order to engineer these designs, we have to decouple launches from our schedule and design optimistically, speculatively, and flexibly. This means a big step up in volunteer corps expertise and a change in communications, fundraising, and recruiting focus.

How to Help

Join the membership organizations that help achieve the goals you want to see in Amateur Radio. Join AMSAT, ARRL, TAPR, ATN, your local or regional amateur technical organization. Support efforts that advance the state of the art. Have expectations. Ask questions. Active members of a community set the agenda. Become active.

Michelle D. Thompson, W5NYV, enjoys thinking and doing — not necessarily in that order! Book learning includes BSEET, BSCET, math minor, MSEE Information Theory. Actual doing includes engineering at Qualcomm, engineering at Optimized Tomfoolery, Amateur Extra class license, AMSAT Phase 4 Ground lead, Organ Donor Pipe Organ lead, DEFCON, IEEE, Burning Man, and community symphony.

Howie DeFelice, AB2S, was employed in wireless communications continuously since 1974, starting as a test technician at Communications Associates, Inc., working with HF-SSB commercial marine transceivers. This led to employment in land mobile radio, then as a field engineer for Magnavox Marine and Survey Division, and then various positions in California Microwave designing and building INMARSAT transportable earth stations, fixed earth stations and designing and delivering multi user VSAT networks. He attended SUNY Farmingdale and received an Electrical Engineering Technology degree, and currently works with wireless security. Howie has a Commercial Radiotelephone license, earned the Novice license in 1976, upgraded to Advanced class in 1977, and to Amateur Extra in 1979. He joined AMSAT around the time AO-13 was launched. Howie enjoys building and experimenting more than operating and looks forward to help make the next generation of HEO satellites a reality.