# From the Perspective of the Pioneers: The Small Sat Revolution

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ABSTRACT: Twenty years ago, when the AIAA/USU Conference on Small Satellites began, only a handful of people in the industry were looking at reducing the size and complexity of satellites. This paper gives the backgrounds of a few of these people, as well as the story of the conference's beginnings. Included are Gil Moore, Rex Megill, Frank Redd, Rudy Panholzer, Eric Hoffman, Amnon Ginati, Bob Meurer, Ron Woll, and Bob Twiggs.

When the conference began, there were many nay-sayers who didn't see any value in small satellites. Small satellites didn't seem useful with the technology then available. Over the years, however, small satellites moved from being hobbyist projects to performing important missions. The miniaturization of electronics, smaller budgets, and the need for faster completion were all factors in that success.

Resistance to change remains today. There is still a strong desire for bigger, more capable satellites with almost perfect reliability. Another obstacle to success is access to cheap, responsive launches. On the horizon are materials advancements, commercial technology breakthroughs, and success with imaging and distributed apertures.

### INTRODUCTION

In the early days of the AIAA/USU Conference on Small Satellites, James Van Allen came to speak about the experience of putting up the first U.S. satellite, Explorer I. In those days, he said, everything was a small satellite. Five of his first eight satellites failed, but they could tolerate the failures because the satellites were relatively low-cost. This was the philosophy that the people who started the conference were trying to regain.

The small satellite concept was ludicrous to many people. Smallsats were thought of as toys, with no relevant value. Everyone thought that they required too much ground support for communications and couldn't perform useful missions.

The pioneers who believed differently showed they could overcome these objections, often with creative thinking. In fact, when people struggle to give a size definition to a small satellite, they end up saying that it is more about mindset than size. The advantages of small satellites are not only that they are cheaper, faster to build, and more tolerant of failure, but also that they represent new ways of achieving objectives.

There were many interesting people who started the smallsat movement and were involved in the early days of the Small Satellite conference. Gil Moore, Rex Megill, and Frank Redd came together at USU at the right time to start the Conference. Rudy Panholzer, working at the Naval Postgraduate School, simultaneously saw the need to get people together to talk about lightsats. Meanwhile, Eric Hoffman was working with Frank Redd on an AIAA committee that was actively discussing the advantages of reducing the size and complexity of spacecraft. In Europe, Amnon Ginati was working at the Technical University of Berlin looking to develop and launch a small satellite. Bob Meurer had just been assigned to the Office of Naval Research and a small satellite called GLOMR. Ron Woll spent his career in the Air Force Satellite Control Network, and Bob Twiggs was working at Weber State University on a joint project called NUSat. These men represent only a selection of the many people involved in smallsats at the time. There are many others who are notable for their contributions to the industry. Jan King and his international associates were already flying their amateur radio satellites when the Small Sat Conference began, and Professor Sir Martin Sweeting was leading Surrey Satellite Technology Ltd. in their innovative success. The absence of these and others from this paper should not be taken as a lack of respect or gratitude for their contributions.

### HISTORY

Advanced rocket technology came to the U.S. after the end of World War II. V-2 rockets were captured from the Germans and brought to the White Sands Missile Range in New Mexico.

#### Gil Moore

Gil Moore was a sophomore studying engineering in New Mexico when the U.S. Army began launching those V-2 rockets. He said, "My friends and I watched the rockets' vapor trails rise into the sky, across the Organ Mountains east of the campus, and became intensely interested in the new program." When they got a chance to examine a rocket on campus, they were amazed at the rocket technology the Germans had developed. In April of 1946, the basement of his dormitory was converted into a laboratory to reduce radio telemetry data from the rocket launches. Gil got a part-time job that paid 65 cents an hour and started his career in the space industry.

Gil graduated from New Mexico State University in 1949 and went to work for the university's Physical Science Laboratory. In 1962, Gil moved to Utah and established the AstroMet Division of Thiokol Corporation in Ogden, which launched several hundred sounding rockets over the next 20 years. Following his work with AstroMet, Gil worked on the Thiokol solid rocket boosters for the Space Shuttle program and became an adjunct professor of physics at Utah State University in Logan.

In 1976 he delivered a presentation in California on the topic of placing undergraduate student science experiments aboard the Space Shuttle. At that same conference, NASA announced the Get Away Special (GAS) Program. The GAS Program would provide self-contained experiment canisters that would be placed in the cargo bay of the Space Shuttle. Gil immediately announced that he would buy the first GAS canister.

The next day, Gil called Rex Megill, a professor at Utah State University (USU) and said, "I'm going to donate half of this canister to USU, what are you going to do with it?"

# Rex Megill

Rex Megill had come to USU in the early 1970s. When Rex was in high school, he read all he could about flying and vowed to become an aeronautical engineer and a test pilot. He read so much that he turned in a book report every day, and in the process, read every book in the library. Rex worked his way through college and earned a Master's degree in Physics from the University of Nebraska. After graduating, he went to work at Los Alamos National Laboratory. He then went to Boulder, Colorado for a PhD and stayed there to continue his research in atmospheric sciences. This research led him to develop small payload experiments to fly in sounding rockets. When USU eventually lured Rex away from Colorado to help with their atmospheric research, he came as a full-time teaching professor in Physics and Electrical Engineering. He also served as science advisor and then director of the Center for Research in Aeronomy, later called the Center for Atmospheric and Space Sciences (CASS). When Gil Moore called Rex to ask what he was going to do with part of a GAS canister, it only took him a couple of days to decide. He saw an opportunity to reverse the trend he saw of students graduating with degrees in Physics and Engineering "who had little or no practical, hands-on experience." He and Gil collaborated to start a program where students could build their own experiments and fly them in space. Rex was the on-campus advisor who supported and guided the students. That first GAS can orbited the Earth in 1982 on the Space Shuttle Columbia.

Gil wasn't satisfied with experiments that stayed in the shuttle bay, so he came up with the idea of launching a small satellite out of a GAS canister. He talked NASA into this idea and began organizing people to design what became the Northern Utah Satellite, or NUSat. NUSat was a very small satellite built by a collaboration of Weber State College with Bob Twiggs' help; USU, with support from Rex Megill; New Mexico State; 26 companies; and a few government agencies. It launched successfully in 1985.

NUSat's mission was to collect and transmit data about FAA radar patterns. There was some disappointment after launch, when the only signal received for a year was, "NUSat to Weber State Ground" but no data. No one could figure out what was wrong. After a year, on the verge of shutting down the program, they went into the ground station room at Weber State to try talking to the satellite one last time. Because the ground station wasn't in use, the room hadn't been heated and was very cold. They called up the satellite and heard, "NUSat to Weber State Ground .... " and then received a stream of data. Thrilled, everyone scratched their heads trying to figure out why it suddenly worked. Finally someone said, "I think I know what happened!" He remembered he had changed the frequency of the oscillator on the satellite right before launch, but forgot to tell the ground station. The cold in the room had by chance adjusted the ground oscillator enough to tune it to the satellite. They received six months of good data after that.

While still at USU, Rex formed a company called Globesat, with a goal "to bring small satellites to the commercial market." This unfortunately didn't happened nearly as fast as he hoped. During Rex's final years at USU he proposed the new Center for Excellence in Space Engineering with a new faculty member, Frank Redd.

### Frank Redd

Frank Redd came to USU in 1984 after a distinguished career in the Air Force. Frank grew up in Price, Utah and received his undergraduate degree from the United States Military Academy at West Point. Being in the top of his class academically, he was able to choose to go into the Air Force and become a pilot. He loved flying, but also loved engineering, so immediately applied to go to graduate school. He received his Master's and Engineer's degrees from Stanford, and then was assigned to teach at the Military Academy at West Point. He later completed his PhD at Brigham Young University.

In the mid 1970s, Frank was assigned to the Air Force Space Division where he was the program director for the Inertial Upper Stage (IUS), which was in use until 2004. During his time as director of the IUS program, he realized that despite the stress, he was involved in a really exciting project; he wanted to continue to be involved in space and space research.

Frank's final Air Force assignment was as Vice Commander of the Space Technology Center in Albuquerque, New Mexico. In that position he had responsibility for all the Air Force Laboratories and became aware of the research being done by the Space Dynamics Laboratory at USU. When Frank retired from the Air Force as a Colonel, he knew that he wanted to continue his involvement in space, but he also had a love for students and teaching. His dual assignment at Utah State in the Department of Mechanical Engineering and at the Space Dynamics Lab was a perfect fit.

Frank began teaching and discovered the need for smaller satellite projects that students "could get their arms around". He was instrumental in getting a new Center for Excellence in Space Engineering at USU. He became a member of the AIAA Space Systems Technical Committee and later served as chairman. While Frank was still a new professor in 1987, USU encouraged faculty members to celebrate the University's centennial year by having symposia on campus. The idea of a Small Satellite Conference was born and came to fruition as he talked it over with Rex and Gil.

In naming the conference, Frank decided to follow the example of a colleague from New Mexico, and somewhat audaciously titled it The *First Annual* Utah State University Conference on Small Satellites. Feeling that they needed a co-sponsor, Frank got the Utah chapter of AIAA to lend their name.

After the conference planning was well underway, and publicity was started, Frank heard about an AIAA

sponsored Light-sat conference being organized by Rudy Panholzer at the Naval Postgraduate School.

### **Rudy** Panholzer

Rudy Panholzer was born in Austria, and was a teenager during WWII. After receiving his diploma in Graz, he came to Stanford in 1953. He got an assistantship to study, and he later joined the faculty. He was there for about seven years. He was at Stanford when Sputnik was launched, and he was intrigued. His colleagues were curious about the frequency of the signal from the satellite. One of them called a friend in Moscow who gave him all the frequency information.

When Rudy got his PhD, he did his dissertation on using a loop of mercury as a gyro for a spacecraft. In 1964, Rudy went to the Naval Postgraduate School (NPS) as a professor. He was interested in integrated circuits and communications devices and got involved with MEMS. In 1982, a student had an opportunity to work on the acoustic characterization of the Space Shuttle cargo bay. None of the other professors had time to help him. When Rudy was approached, he realized that this was much too important to let go. He helped the student with his project and started his involvement in space.

In 1986, with about six months to prepare, Rudy and others (including professor Alan Fuhs) started organizing the AIAA/DARPA Light-Sat conference. They held it in the King Hall Auditorium at the Naval Postgraduate School in Monterey, and 500-600 attended. Rudy said this was a "good indicator that there was a void that needed to be filled."

When Frank first heard about the conference at NPS, he almost panicked. There was a real worry that there wouldn't be enough interest for two conferences. He printed some fliers and went to the NPS conference to advertise and meet people. When the USU conference came around, they had more attendees than expected. Frank said they had a mixed, creative group of people there. They had university people, the amateur satellite folks who had been launching the OSCAR satellites, several industry representatives, and people from the University of Surrey in England.

The conference truly was the *first annual* conference and filled a need felt by many. Attendance has grown significantly over the years, and people keep coming back. There has been a large international presence at the conference, with up to 20 different countries represented in a single year. It had also been a priority to those running the conference to keep the quality of presentations high. Frank felt it important not to try to pad attendance by soliciting as many papers as possible. The conference has never held concurrent

sessions, a policy which was actively supported by Eric Hoffman.

# Eric Hoffman

Eric Hoffman was educated in electrical engineering at M.I.T. and Rice University. After graduating, he went directly to the Johns Hopkins Applied Physics Laboratory and stayed there until 2004—a total of 40 years. He spent his last 19 years as Chief Engineer of their Space Department. The Space Department was sparked by Sputnik in its own way. One of the APL engineers looked at the Doppler data from Sputnik and thought he could extract the six Kepler elements of its orbit from that little bit of data. This was the birth of Doppler navigation.

Sputnik is a reminder that satellites started out small. Launched in 1957, it was about the size of a basketball, with a mass of 83 kg. Explorer 1, launched in 1958, was only 14 kg. Eric noted that if you plot the sizes of satellites over the years, they increase until the mid 1980s, with Cassini and other "Battlestar Gallactica" class spacecraft. Then you can watch the dry mass steadily decrease again. What happened in the mid 1980s?

In 1986, Eric met Frank Redd on the AIAA Space Systems Technical Committee (SSTC). This committee was incredibly active with Frank as chairman. Eric proposed a position paper on small satellites to the SSTC in 1987, and a draft was available a couple of months later. Helped by Frank and Ed Senasack of NRL, he pushed this through the AIAA bureaucracy. The AIAA issued it as an official Position Paper in 1989, a record time for AIAA approval. Such papers are distributed widely to Congress, the military, etc. The paper begins:

"America has produced the most sophisticated space projects in the world, as exemplified by the shuttle, the Tracking and Data Relay Satellite, and the Voyager spacecraft. Many of our goals in space can be met only with large, complex, and, therefore, costly spacecraft. But somewhere along the way this nation seems to have forgotten the important role played by smaller, low cost systems. Neglect of these smaller satellites has weakened our space technology base, reduced the number of launch opportunities, and left our military vulnerable to loss of a few key satellites.

"Historically, small spacecraft have permitted timely access to space for a wide range of scientific researchers to perform advanced—and sometimes high-risk experiments. More recently, however, high cost and infrequent launch opportunities have imposed a conservative and lengthy selection process that may result in a space scientist participating in only two complete programs in the course of a career. More junior scientists may be excluded altogether, and may move on to other fields."

Concurrent with the AIAA position paper, the first Small Sat Conference was held, and a whole group of people began looking smaller again. One of their biggest obstacles was overcoming the mindset of most people in the industry.

## THE NAY-SAYERS

One early Small Sat Conference key-note speaker was a friend of Frank's who was prominent in the Aerospace Corporation. He stood up to give his speech and explained why smallsats had no value. He said that the Aerospace Corporation would never sink a bunch of money into them, and said that small LEO satellites were too expensive to track. It was quite a surprising key-note address considering the purpose of the conference.

# Amnon Ginati

Amnon Ginati was raised in Israel and attended Tel Aviv University, studying physics. He then got his master's degree at the Technical University of Berlin, in Germany. As a research assistant there in 1985, he started the development of TUBSat, a small satellite intended for a GAS can launch.

TUBSat's purpose was to test 3-axis stabilization in a 50 kg satellite. Before this time, all of the satellites in this class used gravity-gradient stabilization. The satellite's reaction wheels were also designed at the University. The TUBSat team wanted to demonstrate a remote joystick controlled satellite with a camera. This was right after the Chernobyl nuclear disaster in Russia. The people in Europe didn't know about the nuclear fallout for two weeks. The TUBSat idea was that with inexpensive ground-controlled satellite pointing, similar disasters could be detected sooner.

When Amnon went to a GAS conference at Goddard Space Flight Center in 1986, he made an appointment to meet Gil Moore and Rex Megill. After the conference. Amnon and his student Hans Koennigsmann flew to Logan with Gil, Rex, and their student Andew Sexton. While there, Amnon got acquainted with Frank Redd, and cooperation was established between the Technical University of Berlin and USU.

While in Utah, Amnon remembers being invited to a party at Gil's house in Ogden. Amnon drove with his student Hans, followed by Rex and his wife. He admits that he likes to drive fast, and the speed limit at the time was only 55 mph. A police car pulled over Rex

and then Amnon. When the policeman came up to Amnon's car, he spoke mostly German to him, pretending he didn't know much English. The policeman finally said, "there is no Autobahn here," and let him go without a ticket. When they arrived at Gil's house, Amnon asked Rex what happened. The policemen said that he'd clocked Amnon at 80 mph and Rex at 79. Since Amnon was going faster, and was let off without a ticket, the policeman had to let Rex go, too.

When Amnon came to the first Small Sat Conference a year after his first visit to Utah, he had already been presenting the TUBSat design to various people. When he presented the design of a 50 kg satellite with 3-axis stabilization, people laughed at him. The idea seemed impossible to most of the space community.

Amnon says of the early years of the conference, "I think the Small Satellite [conference] was very stimulating. It was some kind of shock for the classical industry. They all came to Utah, I remember, sitting on the last row observing what these crazy guys are doing—how it will impact their business in the future." He says that he thought about 50% were "crazy guys" with new ideas—students and people starting new small companies. The other half were there observing what impact these ideas could have on their business. He says, "I remember a lot of interesting corridor discussions with those guys."

There is a story that at the first Small Sat Conference, Jan King chided the military for using only the most expensive parts instead of anything commercial off-theshelf (COTS). Some of AmSat's OSCAR satellites, built of off-the-shelf parts, had been functioning successfully on-orbit for years. Jan was insistent enough that he angered the military contingent, who were threatening to leave until Gil smoothed things over.

Another memorable moment reported by Ron Woll happened at a panel discussion at the AIAA/DARPA Light-Sat Conference. One of the people on the panel was from Martin-Marietta. He said he didn't know why he'd been invited because his company had no intention of getting into the "Cheap-Sat" business. It took several years to overcome that name.

The Air Force was a strong voice against small satellites in the early days. Eric Hoffman explained that for the missions they were doing—geo-stationary satellites such as the Milstar communications satellites and spy satellites—they felt they needed size to accomplish their mission. Gil Moore also said they "stoutly maintained that too many ground stations and too much infrastructure would be required to control and receive data from constellations of small satellites."

## **Bob** Meurer

Bob Meurer was involved in the military in those days. He had a 15 year career as a Naval Flight Officer doing anti-submarine activities. He got his education while in the Navy, and then was sent to National War College. In 1986, he was assigned as Program Manager for Aerospace Technologies in the Office of Naval Research (ONR). Among the many interesting technologies he inherited was a small satellite named Global Low-Orbit Message Relay (GLOMR), which had been launched from a GAS can in 1985, shortly after NUSat. It was GLOMR that really caught his interest.

GLOMR was a DARPA project designed to demonstrate the ability to collect, store, and forward data from remote ground-based sensors. Bob said, "GLOMR was interesting in that it demonstrated a real military mission could be performed using a satellite bus machined from nautical brass and employing amateur radio transceivers and a Tandy TRS-80 Model 100 (32K) computer as a control station." GLOMR was controlled using one of the earliest portable computers.

During Bob's first year at ONR, his interest in what small satellites could do for the fleet became a key focus of his work. He went on to create multiple small satellite projects in the next four years. These were known collectively as SPINSats (Single Purpose Inexpensive Satellites)—the forerunner to what are now called TacSats (Tactical Satellites).

Bob says, "Back then, the idea of flying dedicated small satellites in support of the tactical warfighter was treated with significant disdain. The 'big space' mafia routinely disputed the efficacy of such systems, most probably because they were a threat to the bigger systems in development or on the drawing board." To Bob, this was a red cape he couldn't shy away from, and his life's challenge became to "prove the traditionalists wrong and bring small satellites into the mainstream."

Bob, like Amnon, says that in those days, you were either an advocate or an opponent of small space systems. Many of the advocates banded together for support in an ad hoc SPINSAT technology working group with officers from all of the military services. "While the Navy led, the Army and Marine Corps took active roles in this group. It remains unknown today whether the very few Air Force junior officers that participated were there as visionary leaders or spies for their senior leadership." He said the question then, as now, was what small satellites could do that provided military utility or scientific merit. The prevailing attitude back then was that smallsats didn't have enough capability, could not do any significant missions, or were simply toys for students. Most didn't want to divert funds to see if there was really any merit in them. Bob Twiggs expressed the prevailing attitude toward smallsats as, "This is a bunch of boloney." It would not be because of military or industry support that smallsats would succeed.

### WHAT BROUGHT SUCCESS

Despite the many objections, smallsats have become not only legitimate, but also a major part of the space industry. What made this happen? Rudy put it simply as "Low cost, faster completion, increasing capability." These were, of course, the industry's goals from the beginning.

### Electronics

Gil said that probably the biggest factor in the success of smallsats has been the quantum leap in electronics technology. The miniaturization of electronics has been accompanied by an increase in capability. There has also been a dramatic increase in both solar cell and battery efficiency, increasing the capability of smallsats dramatically.

Amnon said that he likes to compare this to the computer industry. Just as computers changed from something that filled a room to being a more capable PC on your desk, he envisions a PS—a personal satellite in the realm of 50 kg that can do much more than the older huge ones, but is also accessible to more people.

### Decreased Budgets

Bob Twiggs said the driving factor in smallsat success was the end of the cold war; suddenly everyone didn't have a bunch of money to spend on huge systems. This made the simpler, less expensive smallsats more attractive.

Amnon mentioned that in Europe there isn't one unified system, so there is less money. "If you have no money, you build something with more risk, or with more calculated risk." This truth began to apply more to the U.S. and Russia as budgets decreased.

Bob Meurer also commented on the economics of small satellites. He said, "Just as the U.S. and Russia began their exploration in space with small satellites, the economically challenged nations of the world find small satellites the only means to access space that fits within their national budgets."

### Technology Demonstration

Because of the rapid improvements in technology, there is a lot of new hardware that can't be used in expensive missions until it is proven. Bob Meurer says that "small satellites have proven to be a highly economical means of validating new technologies in space without putting an otherwise expensive asset at risk."

### Flexibility

Ron Woll believes that one of the reasons for smallsat success is their flexibility. They can be constructed in a shorter time-frame, and have more launch flexibility because they can launch as secondary payloads.

For military missions, responsiveness has become critical. Bob Meurer says we "need to be able to put systems up in a very short period of time to support the war fighter." Small satellites with limited objectives are much more able to meet this need.

### **Development Speed**

Faster completion is a very attractive aspect of small satellites for more than one reason. For students involved in a project, it is very desirable to be able to see a project through from start to finish. "Gone are the days where a student can begin a space project only to hope that they will see it fly within a decade," claims Bob Meurer.

The attractiveness of a shorter mission life applies to professionals too. When engineers have the satisfaction of seeing their projects succeed, they stay in the industry.

Bob Meurer also says that the military is experimenting with building very capable small satellites within a 12month period. "Odds are they will succeed," he comments.

Eric Hoffman brought up an example of the increasing need for fast mission completion. In 1983, President Reagan made his "Star Wars" speech and started the Strategic Defense Initiative (SDI). Suddenly, there was an urgency to get a demo of an in-space intercept to silence the critics. All the big names bid to do it, but their programs were overly complex, requiring at least five years and hundreds of millions of dollars.

As a new branch of the military, SDI didn't have as many pre-conceived notions. They selected a space intercept demonstration dreamed up by APL system engineers John Dassoulas and Mike Griffin. APL launched two small spacecraft on Delta-180 in 1986. The program was so successful and visible that it was written up in Reader's Digest. NASA studied this success and began its Discovery program.

## Intangibles

There are also some less tangible causes for success mentioned by Amnon and Ron Woll. Amnon credits the "innovation of young people." He says "they come with brilliant ideas that sometimes look ridiculous [compared to] all the classical approaches." Ron credits persistence.

# Ron Woll

Ron Woll arrived at Vandenberg AFB, California in 1962 on his first Air Force assignment. He had enlisted in the service, received technical school training in ground radio repair, and then was assigned to a place no one had even heard of yet called Vandenberg (California maps still identified the base as Camp Cooke) and to an 'Instrumentation Squadron' (whatever that was). Most of the others in his class went to Turkey. He was lucky enough to get the assignment that put him in a career he has enjoyed for 45 years.

When Ron arrived, he had no idea what they did at Vandenberg. He had to wait several months for a security clearance before anyone would tell him what he would do there. After he was there for a couple days, they all watched John Glenn's famous flight on TV. The next day, some co-workers called him outside for something he had to see. He watched a rocket launch, then explode spectacularly at about 3000 ft. He later learned that it was essentially the same booster configuration on which John Glenn had flown the day before.

Eventually, Ron found out that he was at the Vandenberg Tracking Station, working for the Air Force Satellite Control Facility (now known as the Air Force Satellite Control Network, AFSCN). They would support one satellite for 3-4 days and then wait a couple of months for the next launch. They did more pre-launch testing than on-orbit support. When his four-year assignment was up, he quit the Air Force so that he wouldn't get transferred, and stayed in the same job for another nine years as a Lockheed contractor. He then relocated to Sunnyvale, California to work at the Satellite Test Center.

Ron went to the AIAA/DARPA Light-Sat conference hosted by the Naval Post Graduate School in Monterey in the spring of 1986. While there he saw fliers for the USU conference and decided to attend. Ron has come to every Small Sat Conference since. One of the things Ron has liked about the conference is the spectrum of people showing up. With his Air Force/DoD background, it was interesting to him to see how the amateur, foreign, commercial, and university people could put something together on a shoestring budget. Watching from the back of the room were the 'big-budget' NASA and DoD representatives. There was a lot of skepticism about 'cheap-sats'. But the conference exposed him, and others, to the academic parts of the industry. He remembers USU, Weber State, Arizona State, Colorado State and others who were focused on the research end of things. The people who kept showing up and exchanging ideas had the persistence to keep trying and accomplish things that many thought were impossible.

# **REMAINING RESISTANCE**

Despite the success demonstrated by small satellites, there is still some resistance. Gil says that many people still think of small satellites as toys for college kids. Rudy also commented on the persistence of the "bigger is better" philosophy. If someone "only" has a small satellite, they think they are settling for something less.

# Fear of Risk

Another paradigm still getting in the way of progress is what Bob Meurer calls the "necessity of four-nines". In other words, people still want a 99.99% chance of success. This kind of certainty adds expense, time, and size to any project, which is the antithesis of the smallsat philosophy. However, in a world that takes any failure very hard, it is difficult to give up on this expectation.

Amnon also discussed this situation. He commented that universities are used to looking at higher risk situations, and thus they succeed more with small satellites. At NASA, high risk has negative political connotations.

# Fear of What's New

Related to the fear of risk is the hesitancy in the industry to try anything unproven. NASA used to build Application Technology Satellites to demonstration technology, but they don't anymore. Eric Hoffman said that even with the growth in smallsats, it is still hard to get new technologies tested so they can be used more widely.

Just as untested hardware is never used on an expensive asset, untested ideas are also suspect, even within the smallsat community. At one Small Satellite conference, Motorola first publicly announced their plan to put up a constellation of small satellites to be used for communications—Iridium. Even with the open minds at the Small Sat Conference, Eric says no one believed they could do it. But they did succeed in their technical goals, if not their business ones.

Bob Twiggs has experienced skepticism with some of his new ideas too.

# Bob Twiggs

Bob Twiggs had a varied career before he got into the space industry. He was raised on a potato farm in Idaho, enlisted in the Air Force to get an education, and studied electrical engineering. Bob worked in the microwave industry with high-powered amplifiers, wrote software using a teletype machine over the phone, and ended up at National Semiconductor developing software for cash registers. Wanting to move back to a more rural area, he moved to Ogden, Utah to work for TRW doing software. He also started to teach microwave topics at Weber State College in 1981.

In 1982, Bob was introduced to an exciting project to build a small satellite launched from a GAS can: NUSat. He'd been going to school during the days of the moon landings, and building spacecraft sounded exciting. NUSat was the beginning of space experiments at Weber, where Bob established the Center for Aerospace Technology. They built a strong team that included many different technology experts and industry partners.

In 1993, he left Utah to start a small satellite program at Stanford University in California. Stanford was a new type of challenge, with more academics and less industry involvement, but he successfully started the Space and Systems Development Laboratory there. They've had several launches, including OPAL and QuakeSat. OPAL was interesting because it was a micro satellite (20 kg) that launched several picosats about the size of Klondike bars.

Bob got involved in the space industry with small satellites and has only looked smaller. During his experience with the "Klondike Bar" satellites, he realized that they were too flat. If they were turned the wrong way, they lost much of the sun on their solar arrays. He started thinking about other designs, and went to the store looking. He found a 4 inch cubic beanie-baby box, took it home, and started designing on the dining room table. He eventually came up with CubeSats.

He met with a lot of resistance. People said that CubeSats—tiny 10 cm square satellites—were just toys. NASA and industry had no interest in the idea. Even people like the AmSat group, who had been involved in small satellites longer than anyone, wouldn't at first allocate ham frequencies to CubeSats because they didn't take the idea seriously. It was an echo of the earlier resistance to small satellites. No matter how much success is seen with smaller satellites, it is still hard to get minds around new paradigms and ideas.

## **REMAINING OBSTACLES**

Unfortunately, even though smallsats have demonstrated their usefulness on a smaller budget with a shorter development time, there is still the problem of getting launched. When asked what the greatest obstacles to the industry were now, Gil said, "1. Lack of Access, 2. Lack of Access, 3. Lack of Access."

### Launch Opportunities and Cost

Almost everyone interviewed mentioned the need for cheaper, more responsive launches. As Bob Meurer put it, "Regrettably, while we have significantly shortened the development cycle for small satellites, getting them launched remains as the tall pole in the tent."

Rudy observed that with the current state of things, the launch is many times the cost of the whole ground operation.

Eric Hoffman noted that we used to have the Scout launch vehicle, which provided a reliable \$6 million ride. Scout disappeared when parts could no longer be obtained for its subsystems. Eric commented that there have been numerous "paper launch vehicles" meant to reduce launch costs but they haven't been built. There are currently few launch options, and they aren't very inexpensive.

Limited launch options are a threat to the flexibility of a program. When Amnon was designing TUBSat in Berlin, they planned for a GAS can launch. After the Challenger disaster, this option was lost. Amnon said he was afraid that the students would have white beards before the satellite was launched. They eventually secured a Russian launch.

# Launch Paperwork

One of the advantages to Russian launches that Amnon pointed out is the easier paperwork. NASA's riskadverse mindset makes the paperwork of getting a launch often harder than building the satellite to be launched. The university Nanosat program might be demonstrating this. Although there have been 30 programs funded through the generosity of AFRL and DARPA, only two have managed to get launched so far. Because the launches are provided as part of the program, the failure to get on orbit doesn't seem to be because of expense. It appears that in the life of a graduate student, they have time to build the spacecraft, but not to get through the paperwork required for launch.

### Lack of Responsiveness

The long time frame required for launch opportunities isn't only a university concern. Responsiveness is the current buzzword and challenge for all space endeavors. Ron Woll says that even though we've tried, we are not yet succeeding in being responsive. Although there is a current focus on the launch vehicle end of development, there are many other aspects to be considered, including satellite buses, payloads, launch ranges, and ground systems.

Responsiveness problems remain in spacecraft development, even in the smallsat industry that proposed to solve the problem. Although standard bus projects have been attempted several times since the 1970s (continuing the highly successful Agena concept of the 1960s), they have yet to demonstrate success. The responsive goal is to build a generic bus so that you can plug in your payload, place it on a rocket, and launch. Ron says the SBIRS (Space Based Infrared System) program is a good/bad example of responsive space. If it takes 10 years to design a satellite, then it is 10 years out of date at launch.

#### Loss of Expertise

Eric Hoffman brought up an obstacle to progress that has just begun: the retirement of the first generation of people in the space business. If they started working in about 1959, they began retiring in 1999. There is a lot of knowledge on the verge of being lost. Knowledge capture and knowledge transfer have become popular terms.

### Money

Another obstacle to further smallsat success suggested by Amnon is economics. He believes that some companies haven't gotten involved in smallsats because there is not as large a profit to be made from an inexpensive spacecraft or a cheap launch. To a company focused on dollar amounts, smallsats haven't looked very desirable. This situation could be changing, however. As the smallsat industry grows, larger companies are trying to penetrate this niche. If companies with more resources enter the market, they might initially under price their offerings. There is a question whether such low pricing could be sustained, and it remains to be seen if the smaller players who started the industry could survive such competition.

Ron brought up the related obstacle everyone fights with: funding. Bob Meurer says that funding "has

traditionally been the biggest obstacle to advancing the cause of small satellites." However, as funding is obtained, as it has been in the TacSat program, we must deliver on our promises. Bob says, "The number one challenge to industry is to deliver the performance we have promised for small satellites, on schedule and on cost."

### THE NEXT BIG THING, PART 1

When this group of pioneers was asked what the 'Next Big Thing' would be in the small satellite industry, there were two sorts of replies. First, there is the prediction of what will come next, or what we'd all invest in if we could see the future.

Gil Moore says he expects big advancements in materials science. Carbon nanotubes, micro machines, and nanotechnology will all make small satellites more capable in a smaller space.

Bob Twiggs also expects the commercial technologies to aid small satellites. The small but capable parts for cell phones, laptops and wireless communications are very applicable to the smallest satellites.

Gil and Rudy Panholzer both expect constellations, formation flying, and distributed apertures as one of the next big things we'll see deployed.

Amnon mentioned how useful smallsats are in Earth observation, where they can respond quickly to a need for information after a disaster or a need for specific scientific data. Smallsats give us the ability to respond quickly to the needs of our planet.

Bob Meurer agrees, stating that "the ability to image one's own territory, watch your neighbors and monitor world events will continue to lead as a principal use of small satellites." More capable modern smallsats can collect high quality imagery on a regional basis.

Bob referred to a study done by Forecast International, which projects that 139 imaging satellites will be delivered over the next 10 years, with the majority (97) slated for production in the next five. Imaging has been one of the primary missions of small satellites. Bob points out that imagery is the only commercial market that has even come close to turning a profit, and that if nations can only afford a little bit in space, they usually pursue an imaging satellite.

# THE NEXT BIG THING, PART 2

The second sort of response about the 'Next Big Thing' was more about what it should be. There were many suggestions for what we should do in this industry to advance it. Not surprisingly, many of the suggestions

are ideas aimed at solving some of the obstacles to success which have already been discussed.

## Faster, Better, Cheaper Launch Vehicles

Everyone hopes for a breakthrough in launch opportunities. Bob Twiggs mentioned the hope of commercial enterprises like SpaceX. Despite their recent launch failure, they have a goal to reduce the cost of access to space "by a factor of ten". Amnon also mentioned this launch and said that even though the first launch didn't succeed, it shook the system. The people at SpaceX are injecting positive energy into the system.

The launch problems Amnon experienced with TUBSat pointed out to him another weakness in the system. Germany didn't have any launchers. At that time in Europe, there were none. He commented that it's very, very dangerous for you to make plans which include a single source for anything. Choice in launches would help, but Amnon had an additional idea. He envisions building launch partnerships so that when a customer buys a satellite from a company, the price is for a satellite in orbit, not a satellite on the ground.

Amnon said of his TUBSat launch experience, "If you are in a difficult situation, then you start to develop an idea." When they couldn't get a GAS can launch, they flew to Russia and said, "You're launching a rocket almost every week," and asked for a ride. Those were in the days before the wall came down, and there was a KGB man in every meeting. They got their Russian launch, and over the years have maintained a positive relationship with the Russians. He says that it was "always good business" with the Russians.

Another related option is what Bob Twiggs sees happening at California State Polytechnic University (Cal Poly). They are offering and managing Russian launch opportunities through their school. They are trying to deliver a more "Fed-Ex" style launch, where you drop off your satellite two weeks before launch and away it goes. Achieving this would accelerate innovation, because you could look at what's on orbit, decide to change something, and launch again in six months.

# Students and Allocation of Launch Space

Bob Twiggs lists students themselves as the next big thing. He says, "Students are absolutely the most innovative group." He says they have what NASA lacks; they don't have a fear of failure. He foresees a whole new group of people coming into the aerospace industry, with knowledge growing exponentially over the next 10 years. He wants to see his goal achieved of having it possible to design, build, and launch a satellite in the life of a Master's degree student.

Gil Moore says that the next big thing we need is "The industry's realization that allocating space for student satellites on all civilian, military and commercial launch vehicles is in the industry's best long-term interest." The space required for student satellites is small, but provides so much good, including technology demonstration, true science, and the training of the upcoming generation of space enthusiasts.

Gil's idea of allocating space for student experiments is similar to an idea put forth a long time ago by the SSTC and Eric Hoffman. They once pushed the idea that on every satellite, some space and power be set aside for technology demonstration. This "tax" would have to be mandated by the sponsor organization. If it were an absolute requirement, then the space would be set aside, and new technologies would be tested in space more regularly.

# Achieving Responsiveness

Faster technology demonstration helps with the critical issue of space responsiveness. Ron Woll talked about responsiveness as an obstacle, but also as the future of the industry. He said the next big thing would be, "Pavload development responsiveness, Bus responsiveness, development Launch Vehicle responsiveness, Launch Range responsiveness, Ground C2 responsiveness (there is a theme here somewhere)." He says that we could succeed if we can ever get to the Model-T Ford assembly line model where you can have any color as long as it's black. When anyone says, "I want it my way," the result is a higher-cost and typically less-responsive item.

Bob Meurer looks at the TacSat program—the answer to the U.S. Congress' call for "Operationally Responsive Space"—as a major prospect for success in responsiveness. The goal here is to make the satellite bus a commodity. Instead of trying to build a standard bus, which everyone has failed so far to do, the government would require that the bus be built to a standard. Bob mentioned ten parameters needed to define the bus, including power, mass, payload mass fraction, pointing knowledge and control, data throughput, propulsion capability, etc.

Once the bus is designed to this standard, the U.S. government could make a block buy of buses (at lower cost) to support a range of payloads. Given launch vehicles, a payload could be quickly designed to the bus and launch vehicle. Bob says, "If this materializes, it will be a significant milestone in the history of small satellites..."

### Sharing Information

Rudy suggests that the future of small satellites is in following the Surrey approach. They perform multidisciplinary research at the academic center and have commercial success in producing low-cost, rapid response spacecraft, often using COTS parts. They use a modular approach, and have a team of very enthusiastic PhD students. Rudy says they also encourage the transfer of technology and sharing of information.

Bob Twiggs mentioned this sharing of information in the CubeSat community. CubeSats have attracted not only college students, but also customers like the Taiwanese and Japanese governments. The CubeSat community is built on a philosophy of shared information. The payload can be kept private, but everyone who builds one shares information and help about the bus.

These suggestions emphasize how useful it is to work together, and how knowledge gained and shared can benefit everybody. That has probably been the greatest contribution of the Small Satellite Conference—it has brought people together to talk, share successes, and open minds to new ideas.

### CONCLUSION

Eric Hoffman worked on his first small satellite in 1964. He was given the job of designing the master oscillator for NASA's Direct Measurement Explorer A. He says he was just a kid, but he was put under a senior engineer who watched over him in the job. In like manner, as this generation of senior engineers retires, it would be ideal to have them mentor the new crop of students in which Bob Twiggs and Amnon Ginati have so much hope.

Over the years, the AIAA/USU Conference on Small Satellites has had a variety of activities and speakers. James Van Allen came as one of the "Legends of Space" that used to speak on the first night of the conference. Others who came included Konrad Dannenberg, one of the engineers from the V-2 experimental center at Peenemuende who came to the U.S. to work on the American rocket program; General Bernard Schriever, an Air Force general revered for successfully shepherding the development of the intercontinental ballistic missile program and establishing a framework for the Air Force's space program; Jacque Blamont, who was the father of early efforts that led to France's preeminence in launch vehicles; and Clyde Tombaugh, who discovered Pluto. For many, these speakers were the highlight of the conference.

Gil Moore, who was responsible for bringing these legends, said he brought them to keep everyone from getting too cocky about all their new ideas. He said, "You can stand a whole lot taller if you stand on the shoulders of those who came before." As this generation of pioneers looked to the legends before, the next generation should look to these pioneers and stand taller.

## **EPILOGUE**

Gil Moore retired from Thiokol in 1987 to join Utah State University's Space Dynamics Laboratory as a research scientist and to work for Globesat with Rex Megill. In 1994, he retired from the Space Dynamics Laboratory to accept the General Bernard A. Schriever Chair in Space Systems Engineering at the United States Air Force Academy. He once brought some of the Air Force Academy cadets to the Small Sat Conference in grand style; the cadets parachuted into the quad during lunch and presented their registration forms. He was the technical chairman of the conference for the first ten years and was responsible for bringing many of the big names to the conference.

Gil and his wife, Phyllis, have donated multiple GAS canisters to multiple universities. Gil continues to advocate the accessibility of space for students. He and Phyllis started Project Starshine in 1996. The Starshine satellites are built with many reflective mirrors. These mirrors reflect sunlight to the ground, which enables the satellite to be easily tracked by students without specialized equipment. The satellites were designed by the U.S. Naval Research Laboratory and were built by an informal, volunteer coalition of member organizations, schools, and individuals. The project receives no formal funding and operates on the donation of materials and labor from its members. Including the three launched satellites and the fourth under construction, the Starshine Project involved tens of thousands of students from 43 countries. Students have polished the thousands of sun-reflecting mirrors, which were essential to the project's mission, and they have tracked the satellites across the night sky. The three completed satellite missions were placed into orbit as secondary payloads on available launch vehicles, including the Space Shuttle and an Athena rocket, at no cost to Project Starshine.

Rudy Panholzer is still at the Naval Postgraduate School. He served as the dean of the Graduate School of Engineering and Applied Sciences and is now the Chairman of the Space Systems Academic Group. He has built up an excellent program at NPS that turns out consistently high quality master's theses from its military officers. Rudy has been the principal investigator on PANSAT, the Petite Amateur Navy Satellite, launched in 1998. This small satellite was designed as a proof of concept store-and-forward communications satellite. Its main objective, however, was to support the space systems engineering and operations curricula at NPS by providing a hands-on hardware experience.

Rudy has been very supportive of the Small Satellite Conference, and has attended every year since it began.

Eric Hoffman retired from the Applied Physics Lab in 2004. During his career there he performed systems engineering for many of APL's space communication and navigation systems, as well as for entire spacecraft. Eric has also taught space systems design topics in numerous places, including the Naval Academy, Johns Hopkins University, National Taiwan University, and various NASA centers. He still consults and teaches a course for the Applied Technology Institute that he started with Frank Redd.

Eric was also involved in the early days of the Small Sat Conference. He would provide post-Conference critiques that materially improved the Conference. He talked APL into donating the lights that are used to keep speakers to their time limits, and argued for keeping the Conference to only one session at a time.

When asked about the early days of satellite development, Eric said that it was much different. Suppliers felt that it was their patriotic duty to supply parts. Organizations would have 500-600 people all using the same charge number. There was enough slop in the accounting that if you thought of something you wanted to try, you could just pursue it.

Bob Twiggs is passing on the torch at Stanford. He is now semi-retired and last year turned his spacecraft design class over to one of his former students. In June 2003 his team launched QuakeSat, a triple length CubeSat with foldout solar panels. It had a 2-foot extendable boom with a magnetometer to measure the electromagnetic waves that might be propagated before an earthquake. If such waves were found, it could lead to early earthquake warning. The satellite cost less than \$1 million and had a Russian launch costing \$120,000.

Bob is currently advising a group of universities in Kentucky who are starting a CubeSat program. He's been thrilled to see how their collaboration on the satellite has already helped them learn about each other's programs and get excited about future projects. This is another example of why he is so optimistic about what students have to offer. In 1999, Ron Woll retired from Lockheed and went to work for Scitor Corporation, continuing his AFSCN career. He calls it "a most interesting, enjoyable and rewarding experience." He has good memories of 20 years of the Small Sat Conference, especially of the "Legends of Space." He also has hope for the opportunities being offered by the Air Force Space Test Program.

Amnon Ginati worked at the Technical University of Berlin until 1990, when the president of OHB Systems, Manfred Fuchs, approached him with a job offer. Amnon said to him, "But you don't build small satellites," to which professor Fuchs replied, "Ok, then we will build small satellites." Amnon worked at OHB for 10 years as Director of Satellite and Launch Business Development. Amnon built up their business of scientific, telecommunications, and Earth observation satellites. The company is notable because they were traded on the stock market at an early stage and have been very successful.

In 2000, Amnon went to work for the European Space Agency (ESA). In the last five years at ESA, Amnon developed the Earth Observation Future Science and Applications programs. He is now working for the director general of ESA preparing an exciting new interdisciplinary program.

Amnon is also a professor at the University of Applied Science in Bremen, Germany, where he teaches and spends his weekends. He says he is still teaching because he "likes to keep a link to young people." Amnon says that they need to educate everyone about space more in Europe. The kids there have heard of NASA, but most have not heard of ESA.

Amnon compared his career to a sandbox. A sandbox has huge creative potential to a child. You never know what a child might build there. He said that he is like a child with a sand box. When he was at the university, he had a nice 2 meter x 2 meter sandbox in which to be creative. In industry, he had a 20 meter x 20 meter sandbox. At ESA, he has a whole beach on which to develop new ideas.

Bob Meurer retired from the Navy in 1991 and went to work for Orbital Sciences as badge number 245. He started by selling Pegasus and Taurus rockets, then worked on Orbital's first satellites. In 2001 he move to AeroAstro as their Space Systems Business Director. He increased their struggling sales dramatically. In July 2004, after considering consulting, Bob moved to Swales Aerospace, where part of their strategic plan was to develop a microsat program. Swales was just awarded the contract for TacSat-3. Of his success, Bob says, "I was doing TacSats when it wasn't cool." Bob took over being Technical Chairman of the Small Sat Conference when Gil Moore moved to Colorado, and has served in this position for 10 years.

Rex Megill had an international reputation in studies of the middle atmosphere. He published extensively in this area, and served as a program director for the NSF in 1974-75 as well as serving on various national and international committees related to upper atmospheric research. After taking early retirement from USU, he worked in his company Globesat. With candor, he said that they didn't do very well because they were "too far ahead of the stream," but they got some interesting developments going. Rex went on to consult for another small satellite company, Final Analysis, Inc.

Rex never became the test pilot he dreamed of being as a child, but he had his private pilot's license and loved flying. He and his wife opened their home to many people. Rex passed away in 1998, leaving a loving, multi-faceted family behind.

Frank Redd continued at Utah State until retiring in During his tenure he was instrumental in 2002. building USU's aerospace program and was a mentor to students and colleagues. He had a remarkable capacity to build peaceful relations and stimulate cooperation. He created a space systems design class that gave valuable design experience to many students, including this author. He was editor-in-chief of AIAA's Journal of Spacecraft and Rockets. He served as the head of the Department of Mechanical and Aerospace Engineering for five years before stepping down to devote his time to the Space Dynamics Laboratory as Deputy Director. While at the Space Dynamics Lab, he joked that he was the CCO (Chief Complaint Officer), because people trusted him to solve their problems. This talent endeared him to many.

Frank's wife, Myrna, says that the Small Satellite Conference was dear to his heart. It grew from its humble beginnings, when he had one part-time student to help, until he turned over the reins of a thriving conference. He is probably still involved in spirit, Myrna says.

The Small Satellite Conference has always had a personality of its own. At one point Frank took a poll to see if the attendees would like it moved to a larger metropolitan center, and the firm vote was to keep it in Logan. Many people along the way added their creativity to the planning of the conference, making it unique, but Frank felt it was the attendees that made it exceptional. He was always impressed with those who attended the conference and the amount of business and camaraderie taking place in the halls and between sessions. Frank was delighted when the Small Sat Conference's Student Scholarship competition was named for him in 2002. The competition, conceived by Bob Meurer, Gil Moore, and Jane Schnaars (who garnered so many generous donations for it), was a hallmark addition to the conference.

Frank passed away in 2003. He is remembered as a superior Air Force commander, an admired leader, and an accomplished engineer. His integrity in all he did left a legacy in his career and home.