THE HISTORY OF AMSAT AO-7 LAUNCHED NOVEMBER 15, 1974

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AMSAT AO-7 PROJECT MANAGER

[Note: This is Part One of a two-part article that capsulizes the highlights of the full story by Mr. King, which can be found (with detailed technical notes) at https://www.amsat.org/amsat-ao-7-a-fifty-year-anniversary/*]*

Abstract

We often hear reports that, collectively, the oldest satellites still working in space are the JPL Space Probes Voyager 1 and Voyager 2. The Voyagers were both launched in 1977 to take advantage of the planetary alignment called, back then, the "Grand Tour." But are they indeed the oldest, still functional spacecraft in outer space? Is it conceivable that the oldest still working satellite in space wasn't even designed or operated by NASA, USAF, ESA, or any other space agency? Could it be that this satellite was designed by radio amateurs, with its final assembly in a basement laboratory not far from Goddard Space Flight Center? What if we learned that 2024 is the 50th anniversary of this satellite, launched on November 15, 1974? And, as you will discover, the spacecraft AMSAT-OSCAR-7 (AO-7) is still providing service to hundreds of radio operators worldwide, as it has for a very long time. Would you believe that the oldest satellite working around our planet is a SmallSat weighing 29 kg?

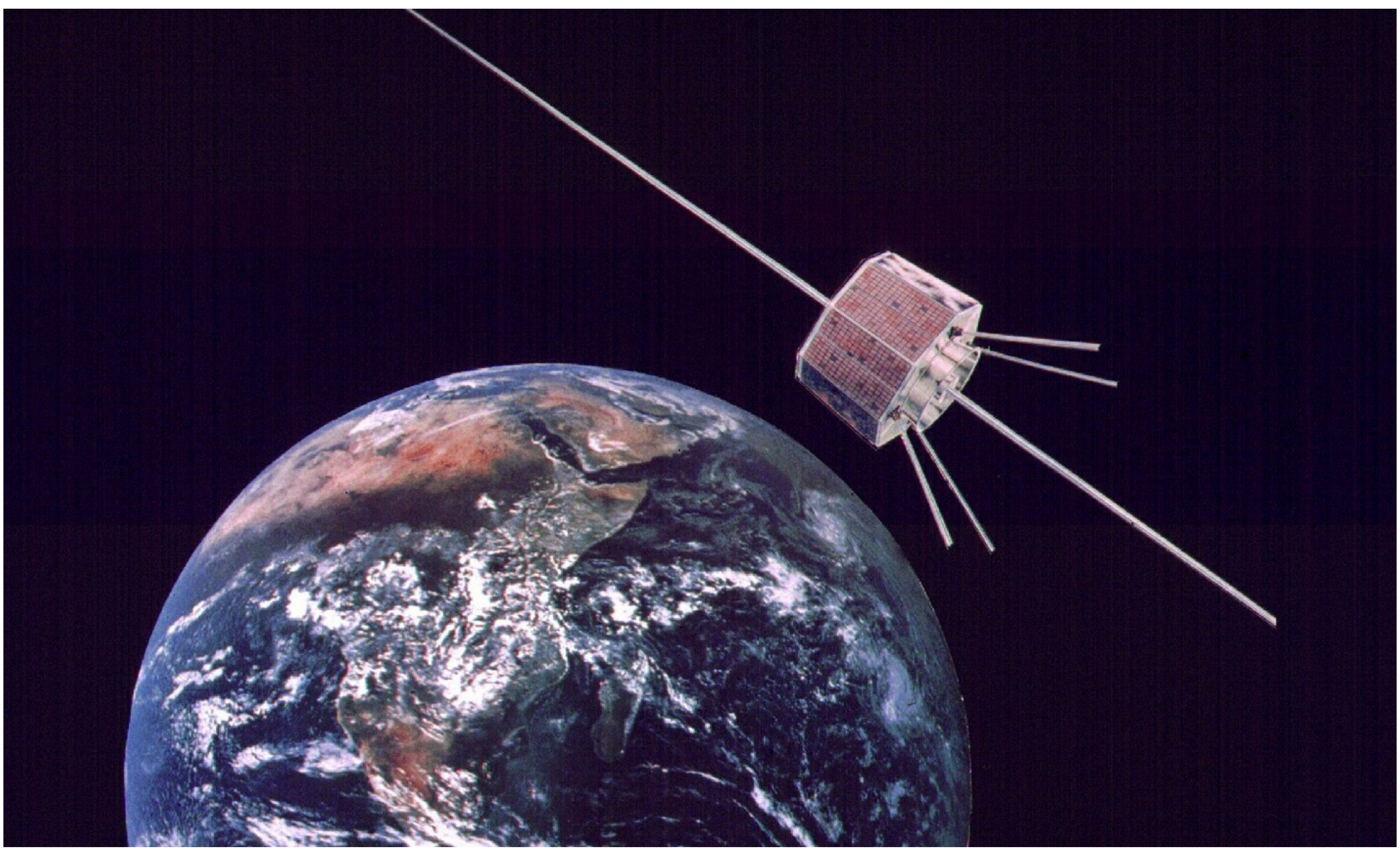
The above, as best we can determine, is all true! This is the amazing story of what made this possible and why this satellite is sometimes called the "Sleeping Beauty Satellite." The technology employed by AO-7 was advanced and, in certain aspects, was ahead of the primary spacecraft it flew with (NOAA-4/ITOS-G). AO-7 has already lived longer than many of its designers and operators. It is just possible that it will outlast all of us. In its on-orbit performance, this spacecraft did everything its designers asked it to do and outlived the other two spacecraft launched with it (INTASAT and NOAA-4). Still in its 1450 km SSO, waiting for the next generation of SmallSat engineers to learn from what it can teach them.

Introduction

In this paper, we will share a story about a well-loved piece of hardware created by a group of enthusiastic space-loving young engineers looking to do something real in space. They came from many countries and backgrounds and, for four years, worked together to create this 29 kg object. They didn't have a lot of money. But, they had enough money to buy the essential items that couldn't be begged, borrowed or stolen. It can be noted that not every person who made us such a loan believed we would be successful in getting the hardware launched. The fact is that most of the hardware worth launching did get launched by us. Two sets of components fall into this category; they've made history because they flew on AMSAT-OSCAR.

Ni-Cad Batteries

One fascinating program that flew from NASA/GSFC was called Radio Astronomy Explorer (2). (RAE-2). This satellite did radio astronomy measurements from around the moon. This spacecraft used a standard NiCd battery design of the day, employing standard 6 AH cells. This battery is the star of our show for the story we're telling. The particular battery pack we were given was the engineering test battery for the



RAE-2 program. It had accumulated many hours working under load before it was removed and retired. This battery became the primary battery for AO-7. As they accumulate more cycles, NiCd battery cells increase their series resistance. This causes the voltages of each cell in the battery pack to begin to sag under load. This behavior worsens with increasing duty cycles, especially with a higher drain depth. AO-7's battery did its best for 6.5 years from launch and allowed the spacecraft to carry out every element of its mission requirements before it did what all NiCd batteries do: in mid-year 1981, each cell in the battery failed SHORT. The spacecraft had failed, we thought, for good.

The spacecraft team was not too upset about this apparent demise of AO-7 as we had accomplished all of the program's goals with this very popular spacecraft. Tens of thousands of radio amateurs had used the satellite, and many specialized communications demonstrations had also been carried out. Unexpectedly, 21 years later, in mid-June of 2002, the satellite was heard again, first by a very loyal AO-7 user from the past. That seemed most appropriate. After a careful assessment, it was clear that what had occurred in the spacecraft was that one of the shorted NiCd cells had failed again, but this time, it failed OPEN. NiCd cells, simply stated, do not do that. We believe that something in the processing of these particular cells during their assembly caused a material defect, different from nominal NiCd technology, that caused at least this one cell to fail to open. The spacecraft came back to life in mid-2002, and it has remained in operation since, without a battery, running only through solar array power. As we will discuss further, there is no reason to believe this condition will not last well into the future.

Karl Meinzer (center) showing the HELAPS Mode B Transmitter.

The "Clean Room" in the basement of Jan King, W3GEY.

Solar Panels

The second gift from NASA to AMSAT was a box of old solar panels found in the attic at Goddard Space Flight Center. In this case, we didn't have to talk to any particular NASA/GFSC power engineer to obtain permission to use them because they were just abandoned. The particulars make this story more magical. In the box discovered were 16 new solar panel segments (in their original boxes - sealed and with desiccant still in place) and two panels of the same type, but these had been test articles. This was exactly the number we needed to build a 12-14-Watt small satellite. With these treasures in hand, the design we selected was an octagonal structure, just the right size for the program we had in mind. But, the panels were far more special than we realized. We couldn't have known then that these panels would be perfect for the long-lived high radiation (cumulative dose) mission that we would be conducting in the future.

This Has Been Going on for a Long Time

As the name of our satellite suggests, AO-7 was the seventh in a series of amateur satellites. If the reader is new to the world of small satellites, it may surprise you that the very first small satellite to be launched was OSCAR-1, launched in 1961. The satellite was built by Project OSCAR (Orbiting Satellite Carrying Amateur Radio) and got the USAF to approve the inclusion of this "piggyback" spacecraft as second stage ballast on the next available mission. Project OSCAR launched four spacecraft until their primary launch source went dry. That was in about 1966. OSCAR had demonstrated the value of "spare volume" in the "boot" of a rocket. So, the Department of Defense decided to use that space itself. It was 1969 when AMSAT was formed, and realized that NASA was a more likely candidate for launching secondary payloads than US military vehicles.

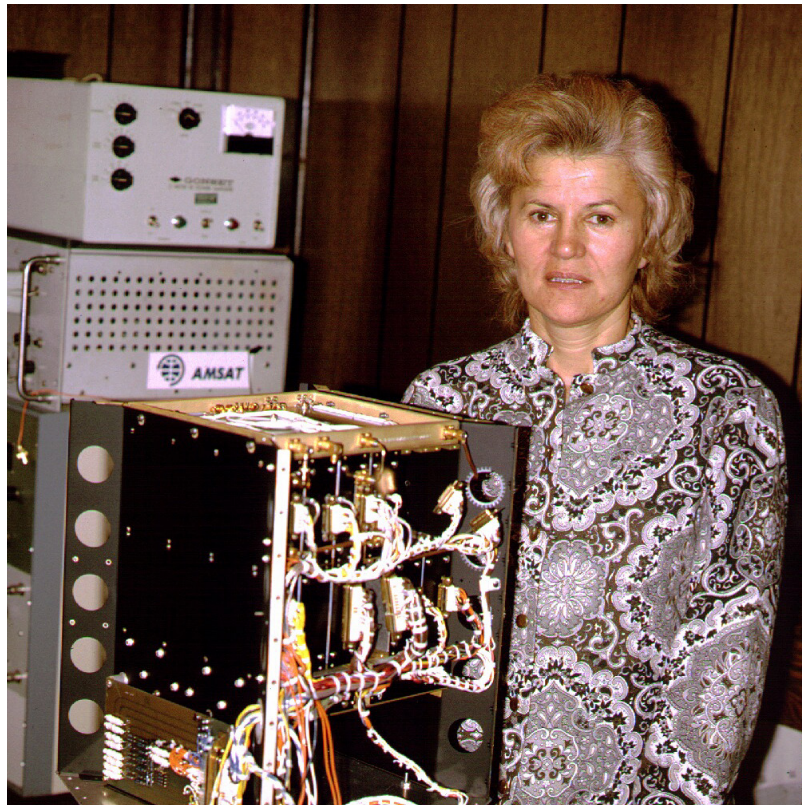
Experimenter Meetings

By 1971, AMSAT had grown to encompass enthusiastic young engineers from Australia, Canada, Germany, France, Japan, the United Kingdom, and several other hi-tech areas worldwide. We formed a working group, who met via amateur radio communications whenever possible. And, approximately quarterly, we would hold an Experimenter's Meeting. These meetings don't sound particularly interesting or important. Not everyone would come to Washington, DC, where they were held. However, everyone would come at least once a year. At first, these meetings were peer-reviewed proposal exercises, where we sorted out who would build what and how. However, as the process proceeded and these became more formal, they became design reviews, pre-test reviews, operations planning meetings, and even pre-ship reviews. AMSAT was already emulating the organizational structure, which became apparent in the real aerospace environment.

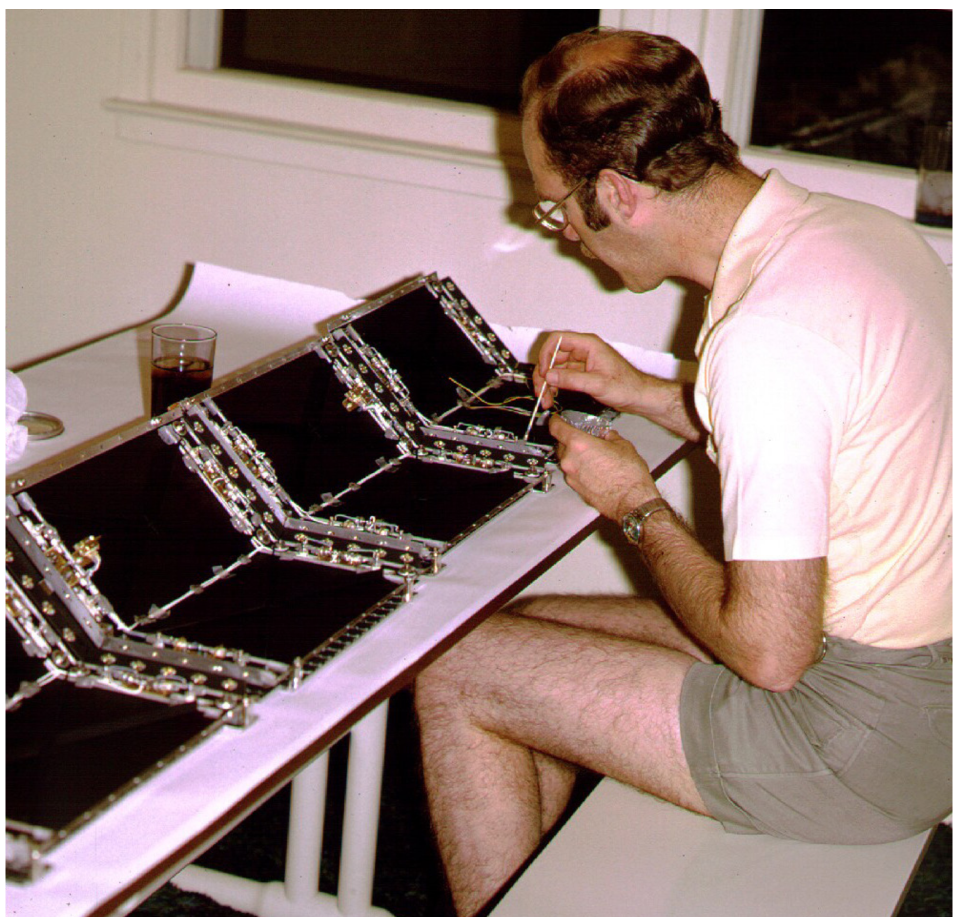
Experimenter's Meetings continued unabated. We were learning from AO-6, now in orbit, about the hardware we had only dreamed of before. Now, we had some hard data. We corrected our designs where we needed to based on what AO-6 was telling us. At this epoch, we found the RAE-2 battery pack and the OGO-5 solar panels. This event created a turn in the road, particularly regarding our thoughts on the AO-7 structural design.

Comparative Models and Methods

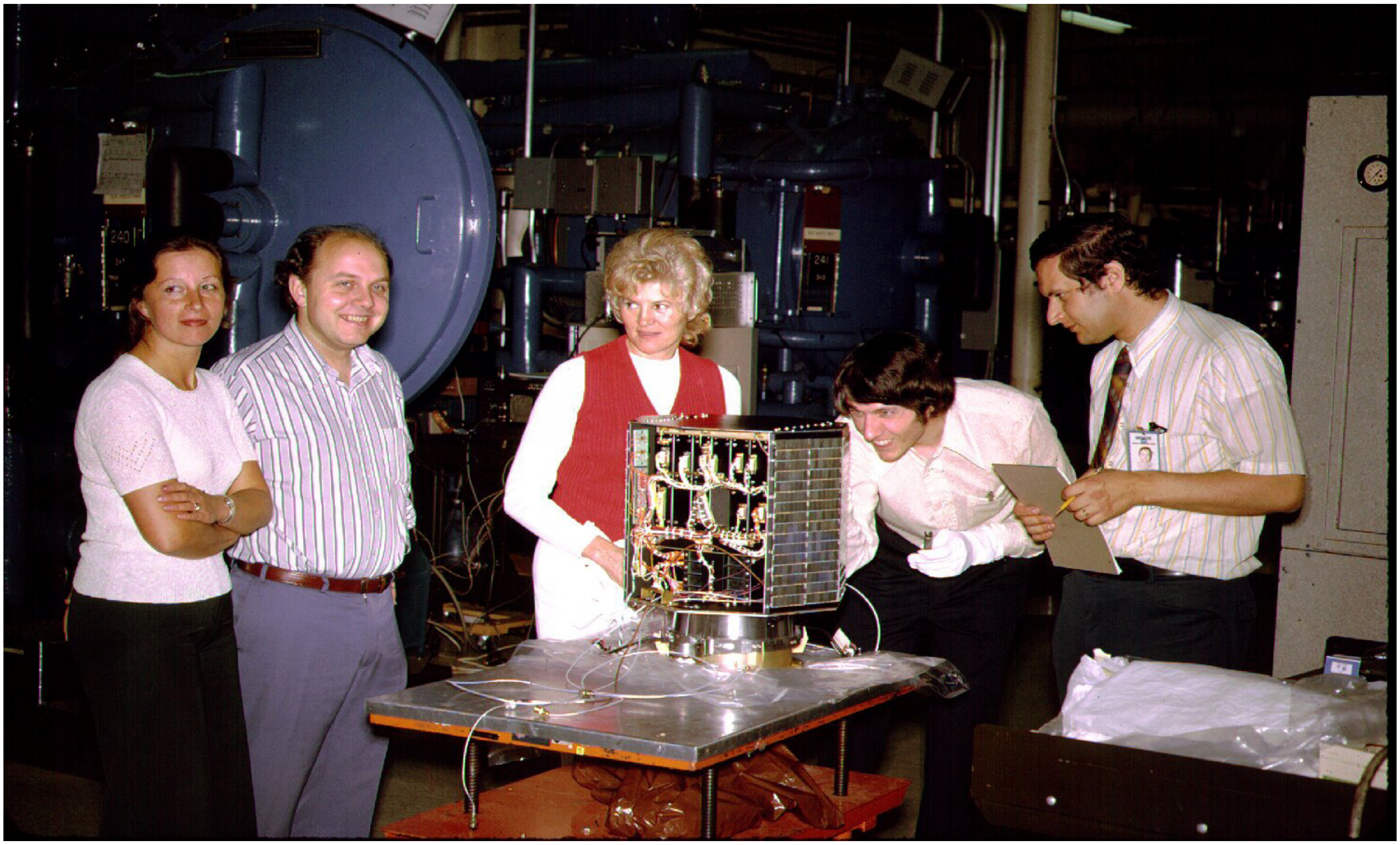
We were excited about the new octagonal cylinder design we'd thought of based on having taken possession of the 16 OGO panels. And in making our decision, we looked to other smaller-sized Goddard programs for inspiration. After completing the mechanical structure design, an octagonal cylinder, we immediately built a prototype mass engineering model. The spacecraft was mechanically centered around the aforementioned 10-cell NiCd battery pack. The electronics were divided into 16 modules (12 large and four small); these standardized modules force uniformity. The modules slid into the structure frame on small rails and were



Marie Marr shows off her latest wiring work-of-art installed in AO-7.



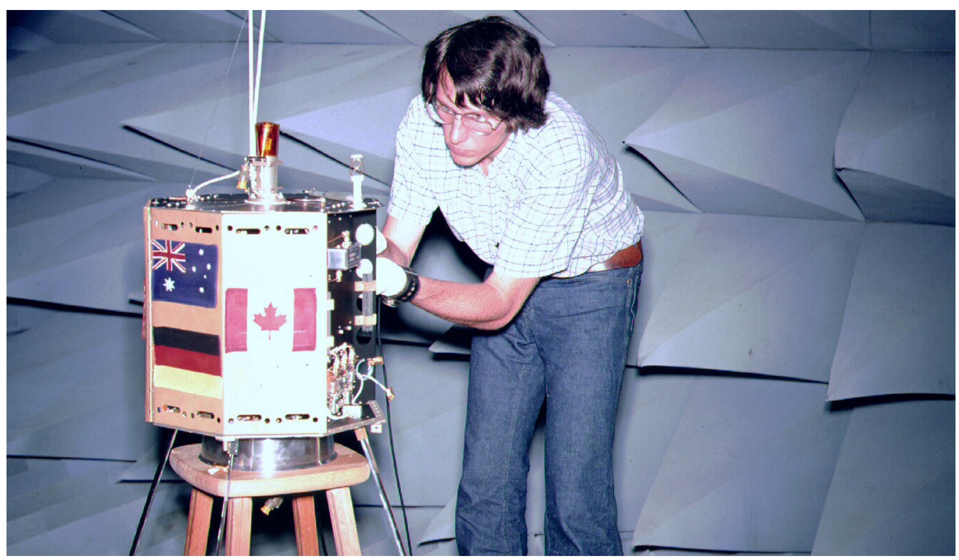
Dick Daniels, W4PUJ, finishes work on the exterior panels holding the solar panels.



Karin and Karl Meinzer, Marie Marr, Jan King and Perry Klein ready AO-7 for vacuum chamber testing.

then bolted in place. We were able to find radio amateurs who owned and operated aluminum-machining shops. These volunteers donated the finished modules and the rail assembly, which was made for our design, at no cost to AMSAT.

At about this time, over in the Delta Program, we heard that another secondary payload was looking for a launch opportunity. The spacecraft was to be known as INTASAT, and their project was looking for a launch in the same time frame as we were. NASA HQ was keen to support such an international opportunity, and the NASA Administrator immediately approved the program. For the first time, I began to think about the meaning of the word competition. However, before I even had time to worry about the possibility we might have to stand down for another secondary payload, my by-now good friend at the Delta Project, John Tomasello, called to let me know there would be room for three on this launch! Relief! The INTASAT program team became "great mates." We attended several secondary payload meetings together. We shared ideas. There was some strength in numbers to be had.



AO-7 Project Manager, Jan King, W3GEY prepares the spaceframe for RF testing in the anechoic chamber.

Amateur Radio Experiments and Their Implementation

It is possible to think of the inventiveness that occurred during this period (and the ideas that were ultimately implemented in flight hardware) as being of two flavors:

A) Telecommunications Experiments - primarily using amateur radio frequencies and methods, yet applicable to other telecom systems/satellites and
B) Spacecraft Technology Experiments - new ideas applicable to all future satellites, especially small ones.

The VHF/HF Transponder (Mode A)

This linear communications transponder was developed by Dr. Perry Klein (K3JTE). Perry was the founder and first president of AMSAT. This transponder concept had been completed in time for flight on AO-6, so it was the shooting star for that spacecraft program. Indeed, this was to become the first long-lived communications payload ever to have flown on a small satellite. This transponder was built again for AO-7. Some minor frequency adjustments were made based on user feedback from AO-6. This transponder receives in a 100 kHz-wide passband in the 2 m amateur frequency band (145.85-145.95 MHz), and the TX downlink is in the Amateur Radio 10 m band (29.40-29.50 MHz). A telemetry beacon transmitter is also at the downlink band edge (29.50 MHz). The output power of this transponder was about 2 Watts PEP.

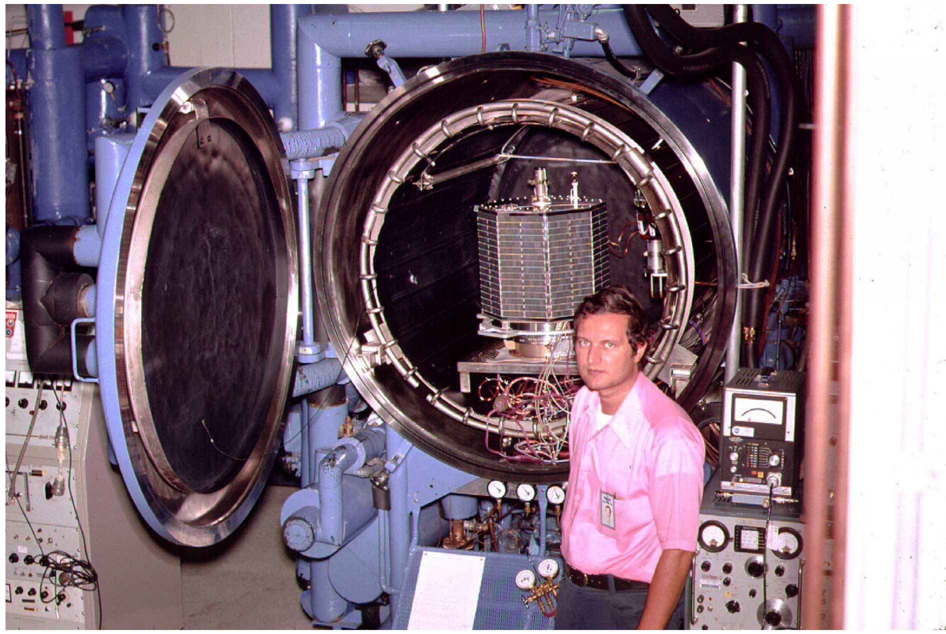
The receive antenna is a circularly polarized canted turnstile, while the downlink antenna is a proper-length dipole antenna resonant on 29.5 MHz. This was the first SmallSat antenna deployed using a pair of pyrotechnic devices known as "reefing line cutters." This deployment is another first. It is the first ICC Class 2 ordinance used by any secondary payload in orbit.

The UHF/VHF Transponder (Mode B)

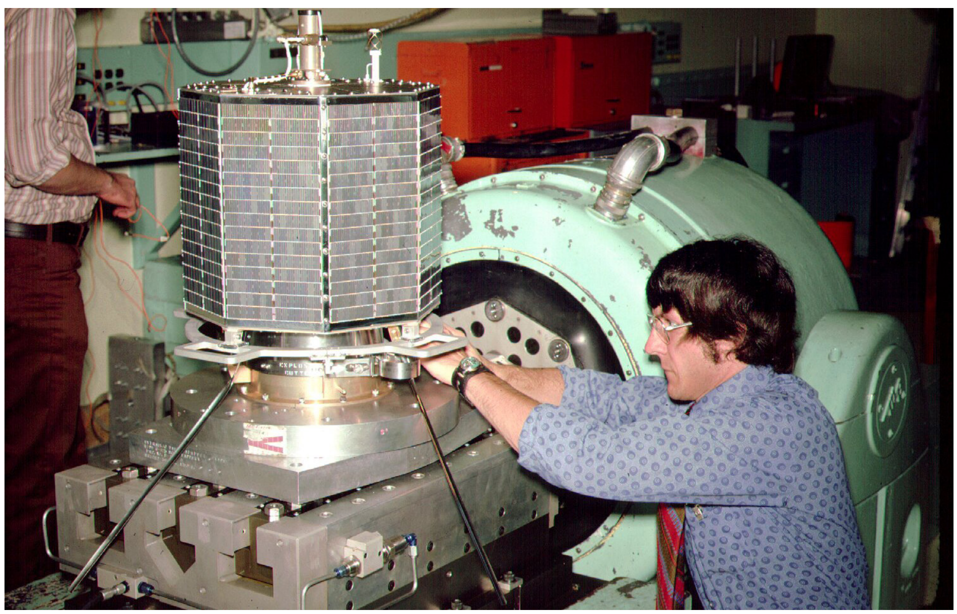
By any measure, this transponder is the star of the show for AO-7 and certainly deserves to be. This transponder was developed by Dr. Karl Meinzer (DJ4ZC). In the space-flight world, it has been a long-term goal to continually improve the power efficiency of all communications satellites, not just those that transmit in the amateur satellite frequency bands.). Dr. Meinzer aimed to develop a power-efficient means to re-transmit an SSB signal. Karl's total "bag of tricks" ultimately became known as HELAPS = High-Efficiency Linear Amplification via Parametric Synthesis.

The 435 MHz Beacon Transmitter

During this time frame, AMSAT wasn't just building spacecraft. We participated extensively and, we might say, aggressively in the preparatory work associated with the ITU 1972 WARC (World Administrative Radio Conference). This effort created a new satellite service for the world: the Radio Amateur Satellite Service. Employing a new ITU footnote



Perry Klein and the vacuum test chamber holding AO-7.



Technicians mount AO-7 to the table of the shake test device.

[FN 5.2.8.2; now ITU FN 664], this new service was allowed to use five new frequency bands on a secondary basis. Other bands have since been added on a primary or a secondary basis.

AMSAT was keen to begin using these valuable resources as soon as possible. A team of Canadian radio amateurs anxious to implement a UHF beacon experiment on AO-7 realized the first real opportunity. The 435.1 MHz beacon occupied one of our large modules. It transmitted in two modes: on-off keying and FSK. The on-off mode was used for transmitting CW (Morse Code) telemetry, and the FSK mode was used to transmit 850 Hz shift RTTY (50 baud standard) telemetry.

The 2304 MHz Beacon Transmitter

The story about this particular experiment, among the many comprising the AO-7 mission, doesn't have a happy ending. Despite the hard work on this part of our project, in this single instance, the new footnote we had managed to get through the ITU did not work in our favor. The footnote moved the S-band Amateur Radio Satellite allocation from 2300-

2350 MHz to 2400-2450 MHz. Despite our best efforts and a final request to consider the payload only experimental, the FCC denied our application. Thus, our first microwave beacon transmitter was stillborn.

The Morse Code Telemetry System

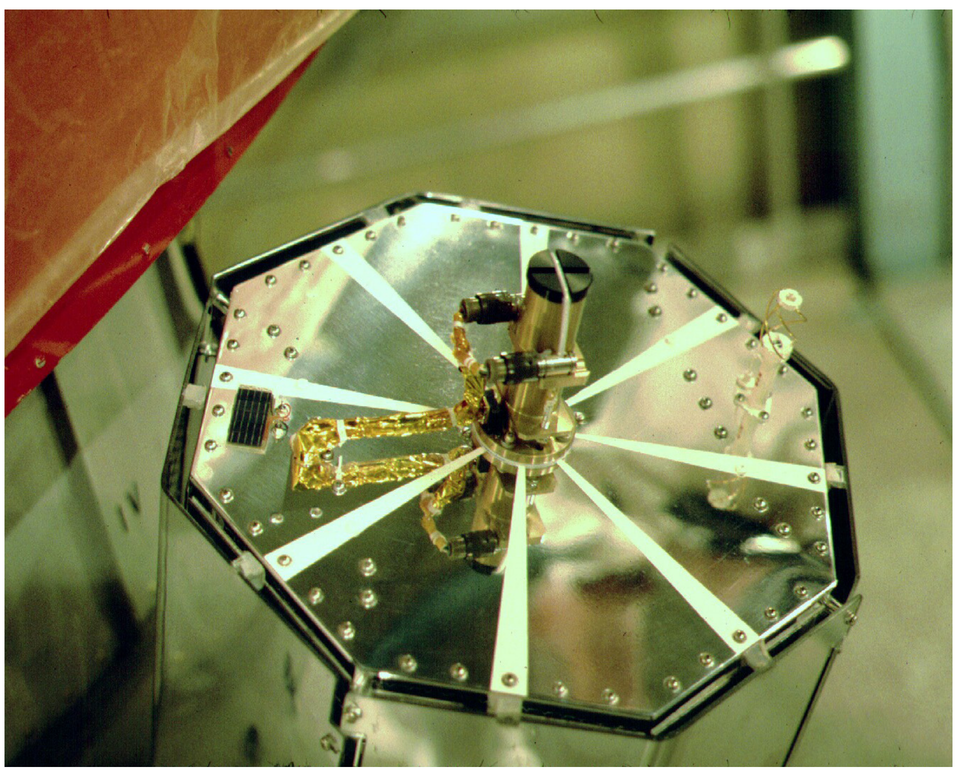
There is something about Morse Code and modern times that don't go together. Let's think about Morse in another way. In addition to a few spacecraft and pursuing a WRC radio allocation, AMSAT was also busy developing an educational curriculum. We thought it would be exciting to allow grade-school through high-school students to understand the basics of a spacecraft, not by reading about it in a book but rather by using an actual spacecraft in class.

One of our members, Dr. Marty Davidoff (K2UBC), decided to write a curriculum at the secondary education level. He received a grant to write it from DOE. The ARRL and AMSAT distributed the Satellite Experimenters Handbook 2 to anyone wanting to teach others about spacecraft technology. The book especially targeted secondary school educators. Key among the concepts was the idea of giving a teacher, who may or may not be a radio amateur, the information necessary to assemble a receiving system, which could act as a student demonstration tool in school. This receiver and antenna would allow a class to receive and decode telemetry. This process required the students to think through some orbital mechanics, the technology of antennas and receivers, and finally, the principles of demodulation and decoding.

This is where Morse came in. For just the numbers 0-9, Morse can be learned in 10 minutes by just about anyone. And, so, it is a perfect tool for any eighth grader!

Our Morse Code Telemetry Encoder System was designed and fabricated by John Goode (W5CAY). This unit was built in one of our small modules. It used fixed logic: 34 ICs, which were +10 V CMOS (RCA CD4000-AD series). One LM108A operational amplifier was used for the A/D converter. This little box, which used CMOS, was amazingly efficient. It required two ma of current at 10 V DC from the power bus. That is a whopping 20 mW. This TLM encoder had 24 analog input channels. The 24 channels, organized in 4 columns and 6 rows, were divided into current, voltage,

Transporting AO-7 to the Western Test Range: Marie Marr, Arthur Feller (leaning on the spacecraft!), and Perry Klein on the right. Martha Saragovitz, AMSAT Office Manager, purchased a dual seat ticket for the spacecraft and Art is carrying it. It was "Mr. Oscar Satellite"! The captain is quoted as saying "There is nothing in the book about this!" A perfect position was found for it in the hold.



This close-up photo shows the proximity of AO-7, with protective covers on, to the primary payload – barely centimeters apart.

and temperature channels. All were scaled to a 1.0 V full-scale input to the A/D converter. The encoder produced decimal values and was organized into two Morse characters between 0 and 99. The first number of each word is a digit, which gives the row number of the datum. This reduces the ambiguity of where in the frame the encoder was, in case the decoding person gets a bit lost.

The RTTY Telemetry System

The closest thing the amateur radio community had to standardized digital, high-speed communications in the 1970s was a Teletypewriter. Peter Hammer (VK3ZPI), one of the original Australis-OSCAR 5 team members and a University of Melbourne graduate, had long been enthusiastic about creating both telemetry and command capabilities for the new satellite system. Edwin Schoell (VK3BDS) assisted him in the circuit design and construction. Their RTTY telemetry system was not for the faint of heart. It also contained over 100 CMOS integrated circuits and analog operational amplifier ICs. This unit required two of our large-size modules to accommodate this much hardware.

The data format for this encoder is reasonably apparent. Each analog data value is three decimal digits (so values range from 000-999). The two-digit channel number precedes each analog value. The RTTY TLM system had a second major mode. The idea for this second mode, we can say, humbly, was a really good idea we learned from NASA. This second mode is a dwell mode. This allows a particular channel to be sampled repeatedly for faster, continuous data. It was believed that this would assist in diagnosing a spacecraft malfunction that might be caught by more rapid measurement of particular telemetry data.

With all three satellites loaded, the launch team begins installation of the fairings that will protect the payload on its way to space.

CodeStore

Radio amateurs have always been fascinated with digital modes of communication. When thinking about the timeframe—where this spacecraft sits in electronic history—it is easy to forget that we're at T-3 years and counting from the first 8-bit microprocessor. The notion of packet communications was still nearly 10 years into the future. Our experiment team wanted to demonstrate that we could store data at will on a spacecraft in transit across the sky and then download it at another location. We already wanted to demonstrate non-real-time digital communications to ourselves and the world. So, with the energy we had left, we developed one last simple communications experiment.

CodeStore probably wasn't the best design choice then, but we chose the command frequency for the uplink. This meant we didn't have to implement yet another receiver. However, this made the experiment far less general than it could have been. AMSAT did not want to share knowledge of the command frequency and codes with anyone who didn't need to know them. Thus, CodeStore (its uplink in particular) was not an experiment shared with everyone, as were the communications transponders described above. It could, realistically, only be used by authorized command stations.

CodeStore was the brainchild of and was designed and fabricated by John Goode (W5CAY). In one small module, he housed an AFSK decoding system, which allowed uplink data to be clocked into a "long" shift register. To be precise, the shift register contained 896 bits. This was done with the memory ICs of the day. What one could manage then was 14 ICs, each containing 64 bits of serial data storage. The contents of the shift register were sequentially downlinked (FIFO) to the selected beacon when we commanded CodeStore to go into RUN mode.

Environmental Test Program

We had lots of help from NASA and NOAA. Both agencies wanted to be sure we wouldn't cause damage to ITOS-G, the primary satellite. It is worth explaining the government's concern in this instance. Secondary payloads were now, for the first time, winning this little battle to get launched regularly with expensive satellites. In 1970, the AO-5 satellite rode in the engine compartment of the Delta second stage - perhaps 3.5-4.0 meters removed from the primary satellite. In 1972, the AO-6 secondary payload was moved up to a site about 30 cm away from the primary payload. A significant aluminum plate was placed between the two spacecraft to protect ITOS-D from contamination from AO-6.

In 1974, the AO-7 secondary payload was mounted so that there was approximately 10 cm between the two spacecraft. It is not too surprising that NOAA wanted AMSAT-OSCAR-7 to be clean. They did not want outgassing products from our cheap little satellite on their radiation coolers. So, not only were we able to have a thermal vacuum test once, but we also had to have one twice. From NOAA's and NASA's standpoint, the second test was a "bake-out" test to drive off all contaminants from the spacecraft before they were shipped to the launch site. Never have there been more willing supplicants to environmental tests.

AO-7 leaves on its historic flight aboard Delta-104 on November 15, 1974, fifty years ago.

Functional Testing of AO-7

You've heard it every year, and you will hear it again this year: the best way to assure the reliability of any small satellite is to test, test, and test. We hope this paper will once again reinforce this behavior. No spacecraft this author has worked on could be functionally tested like AO-7. The additional environmental tests imposed by NASA gave us the time we needed, and we used it for more functional testing.

We established a ground rule for our experimenters based on our experiences with AO-6 and AO-7. The rule was that we wanted every component (module) in every satellite in the future to experience at least 1000 hours of "burn-in" time before launch. The time could be accumulated at ambient conditions and/or during environmental testing such as thermal vacuum tests (TVAC). The notion was quite simple. If a module wasn't needed at a particular time, and it would be just sitting on the shelf, it should be under test sitting on the shelf. However, our rule was that this should amount to 1000 hours, and a log was required from each experimenter to demonstrate that this milestone had been accomplished. Large, professional spacecraft, at that time, only required about 100 hours of similar testing before launch. Even now, we believe this is a good SmallSat rule to follow. We also believe this testing offsets some aspects of using COTS piece parts instead of qualified devices.

AMSAT AO-6 had failed the first proto-flight vibration test. The lesson learned there was fresh in 1973 when we were just designing the structure for AO-7. We did build a prototype model of this spacecraft. We made it as representative as possible and vibration-tested it to qualification levels. All of it worked fine. Ultimately, the test model, prototype, and spacecraft weren't identical to the flight unit. However, it was representative. Perhaps, most importantly, it gave us confidence that we knew what we were doing. None of us were mechanical engineers.

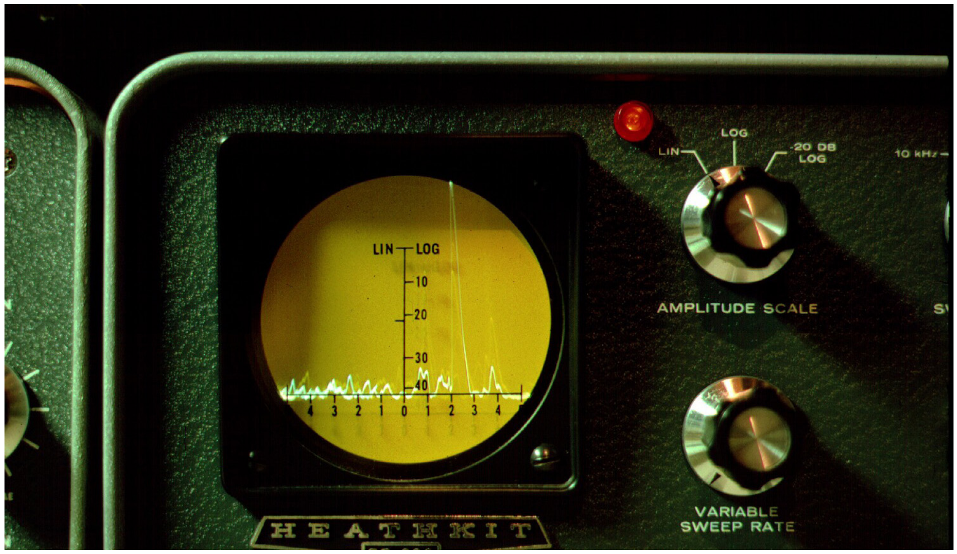
The individual experiment builders performed many subsystem tests, and more than a few home ovens and refrigerators were used to give our team the confidence they needed. In this phase of AMSAT's development, this growing team of small satellite engineers was learning a lot.

Before the fight test program, the transponders were put into vacuum bell jars to check the high-power amplifier performance under a hard vacuum. We found some difficulties with the UHF/VHF transponder, which did experience corona discharge. This couldn't be corrected but did not cause the experiment's failure. We knew the spacecraft would outgas within 24 hours of launch. At these pressures, the corona could no longer sustain itself. So, the precaution to remedy this problem was to wait a few days after AO-7 was in orbit before turning that experiment on. Corona was never a problem for AO-7 after launch.

Let's Launch It

By the end of September 1974, AO-7 was ready for transport to the Western Test Range. We kept doing functional tests, even when we reached the test range. The initial part of the launch campaign went smoothly. We completed our final long-form functional testing. We had an excellent opportunity at the launch site to meet again with the Spanish INTASAT team. We were then able to exchange many stories regarding our common SmallSat experiences. The two secondary spacecraft were mated on October 10, 1974, and the fairing was installed a few days later.

Fate was not through with us yet. At the Flight Readiness Review held for the Delta, the NASA Review Committee found that they were not happy with a failure that had occurred on the assembly line for the Delta Inertial Guidance System. The two secondary payload satellites were removed from the vehicle for repairs. This was done without summoning the AMSAT team back to the test range. This was dangerous to AO-7 because it had four live pyros set to be fired four seconds after spacecraft separation. They were to deploy the 10 meter dipole antenna. Had the technicians not remembered to remove the SAFE/ARM plug from the spacecraft before de-mating, the gantry would have been filled with copper antenna material very shortly after the de-mate would have occurred. Fortunately, the technicians didn't forget. The spacecraft was safe.



A sight to behold! AO-7's telemetry beacon is heard for the first time! Temp-0198

A few weeks later, our team returned, this time at our own expense since AMSAT was running out of cash. We re-mated our spacecraft, and the launch team put the fairing back on the vehicle. Now, we said our goodbyes to AO-7 one last time. Delta-104 was launched on November 15, 1974, into a 1460 km circular sun-synchronous orbit. This took place with no anomalies.

AO-7 Primary Mission (First Life)

AO-7 lived a very healthy lifetime of 6.5 years. Not to overstate the case, however, AO-7 outlived both co-passengers launched by Delta-104 during its primary lifetime.

Significantly, the three AMSAT satellites, AO-6, AO-7, and AO-8, had long, overlapping lifetimes. The first two were in sun-synchronous orbits, while AO-8 was in a lower Landsat-type orbit, approximately 800 km. These overlapping conditions resulted in continuity of service, making the Amateur Satellite Service a real and viable service.

Tens of thousands of licensed radio amateurs used these satellites, many regularly. These three LEO satellites weren't quite a constellation. However, a definite pattern of passes allowed users to count on the spacecraft being there for communications. Those who know a bit about the hobby of amateur radio know that these folks love to set goals for themselves. Examples include the longest communications, the largest number of regions of the Earth contacted, the most countries contacted, the most US States contacted, the lowest power used to make communications, and so on.

The list is virtually endless. Awards are issued to those achieving the best results in each category. All of this continues to occur, but now, also via satellite. In this category, two are particularly noteworthy:

Longest Communications: During the lifetime of AO-7, two stations using the Mode A (VHF-to-HF) transponder completed the longest two-way LEO communications. One station was in Columbia, MD, and the 2nd station was in Oahu, Hawaii. This communication's reported ground surface distance was 7900 km. The elevation angle involved on both sides of the link was 0 deg. What may have given some assistance, in this case, is that the downlink on 29.5 MHz is in the HF frequency region of the spectrum, and these two stations may have gotten a small boost from the ionospheric diffraction.

First Earth-Space-Space-Earth Communications Relay Demonstration Ever: The downlink spectrum of AO-7's UHF/VHF transponder overlaps with AO-6's VHF-to-HF transponder.

The overlap of the two is approximately 50 kHz wide. The two orbits are the same - almost. AO-7's mean motion is slightly higher than that of AO-6. This means that AO-6 will "lap" its younger brother in space once every year or so. During the time when the two spacecraft are in closer proximity, it was already known to be theoretically possible (if AO-7 has its UHF/VHF transponder on) for one user to communicate through two spacecraft in succession, with the downlink of AO-7's transponder being relayed through AO-6's VHF/HF transponder uplink, and then, with the doubly relayed signal arriving on 29.5 MHz to another user on the ground. This could be done in specific geometries, in both directions, making two-way double-hop communications possible.

The first successful Earth-Space-Space-Earth relay of this type occurred on January 6, 1975, early in AO-7's lifetime and during the first occasion when AO-6 approached AO-7 in their very similar orbits. The two stations were both located in the state of Texas. In 1975, 55 user stations from 12 countries also conducted and reported this method of communication. These events were documented in the IEEE Proceedings in October 1975.

Support to Space Education

Earlier, it was explained how using a Morse Code telemetry system could help to enable a novel Satellite Educational Program. By 1975, Morse Code telemetry was being downlinked in abundance from two spacecraft, both available during class time, and the spacecraft educational program went into full swing. From the early 1970s through the late 1990s, many revisions of The Satellite Experimenters Handbook were published by the ARRL. In 1996, this document was largely replaced by a broader publication, The Radio Amateur's Satellite Handbook. This documentation became the first source for teachers who wanted to introduce a spacecraft technology section into science curricula. Dr. Martin Davidoff, K2UBC, was the author of both of these useful and practical texts. Hundreds of classrooms in several countries participated in this program. The United Kingdom and Germany both implemented their own independent versions of this program. The AMSAT Satellite Educational Program has merged with the ARISS (Amateur Radio International Space Station) program. It is understandable why students would want to talk to an Astronaut rather than take telemetry data as a means of being introduced to spacecraft and space science. Radio amateurs still provide the ground station equipment and the educational environment for the newer ARISS program.

COSPAS/SARSAT Experiments

Few joint US/USSR space programs existed in the late 1970's. However, COSPAS (Russian acronym for "Space System for the Search of Vessels in Distress) and SARSAT (Search and Rescue Satellite) was one of them. As envisioned by spacecraft engineers from both countries, the concept was to relay signals from beacon devices, ELTs (emergency location transmitters), already installed on large and small aircraft and ships and smaller vessels equipped with EPIRBs (Emergency Position-Indicating Radiobeacon Stations). These one-way beacon transmitters, originally intended to be received by surface rescue parties, could also be received and transponded by a LEO spacecraft, greatly extending the rescue potential.

The signals could also be tracked one-way by Doppler by processing the beacon uplink signal onboard the spacecraft. This would allow the spacecraft to find the source beacon's location immediately. This would allow the emergency beacon to be identified and located and the position stored for immediate downlink at the next available ground station. (NOTE: We know it is hard to remember, but this era was just before GPS.) This concept, immediately before cooperation with the Russians occurred, had been the idea of Dr. Dan Brandel of the Communications & Navigation Division at NASA/Goddard Space Flight Center.

The transmit frequencies were already established by the existing population of ELT and EPIRB beacon devices already distributed worldwide. The relevant frequencies were 121.5 MHz (civil beacons), 243.0 MHz (military only) and 406.0 MHz (civil; newer technology). There was a need to test and demonstrate the feasibility of this concept. The eventual home for such COSPAS/SARSAT transponders would be as operational payloads on NOAA/ITOS polar spacecraft and Soviet equivalent spacecraft (COSPAS). NASA no longer had available spacecraft in LEO orbit with any form of VHF transponder or equivalent payload. AMSAT did.

After considerable discussion and analysis, AMSAT and NASA made arrangements to conduct a series of measurements of transponder signals (simulating ELTs) via the VHF/HF transponder on the AO-6 and AO-7 spacecraft. The difference here is that while Brandel expected to track the one-way uplink Doppler onboard, the experiments conducted were two-way and so included both the uplink and downlink Doppler. The HF downlink added an error source to the measured Doppler since the ionosphere can add a range error.

The tests were highly successful, and it was possible to get good estimates of the uplink transmitter's original location despite the measurement error in subtracting out the Downlink Doppler value. The COSPAS/SARSAT program went ahead at NASA/GSFC and Roscosmos in the USSR. This program has been operational since 1982. From that time until 2021, when the program merged with others providing similar capability via LEO, MEO, and GEO spacecraft, the program saved the lives of 57,413 people in 17,663 rescue events involving downed aircraft and ships at sea.

AMSAT proudly played a critical role helping to validate the technology for the COSPAS/SARSAT program. Most would agree that small satellites significantly contribute to helping others in need.

Radio amateurs using AO-6 and AO-7 during the 6.5 years of AO-7's primary lifetime carried out many other experiments. For a short while, radio amateurs who work at the National Institutes of Health (NIH) conducted some data transfers from ambulances to hospitals via the AO-7 spacecraft to demonstrate that EKG data could be transferred in this manner. These were successful; however, such demonstrations might not be considered particularly practical. Members of the amateur radio community, who were working with other civil authorities, conducted other emergency communications demonstrations. [Next issue: The "Second Life" of AO-7 and its scientific discoveries.]