Amateur Radio on Human Spaceflight Missions—30 Years

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Abstract

As I prepared for the enormous challenge of describing the entire 30 year history of Human Spaceflight Amateur Radio Operations in one paper, I was reminded of some sage advice I received 20 years ago from one of the founders and visionaries of this very unique and exciting endeavor. In 1993, as I prepared a forum presentation for the upcoming Dayton Amateur Radio Convention, I was lamenting to Roy Neal, K6DUE, about the challenges of stuffing all of our Shuttle Amateur Radio Experiment (SAREX) efforts into a 30 minute presentation. Roy, a former NBC science correspondent and newscaster, retorted "Frank, if I can communicate all the world's news in 30 seconds, then I am sure you will be able to present SAREX in 30 minutes." With that unique perspective from a mentor I feel privileged to have known, I will do my best to live up to Roy's expectations and provide a concise view of the highlights of ham radio development and operations on the Shuttle, Mir and ISS over the past 30 years. Throughout this paper, references will be cited to enable you to further delve into the comprehensive history of ham radio on human spaceflight. Please avail yourself to this more detailed information to learn more than I can convey in a few pages.

Evolution of Amateur Radio on Human Spaceflight

Starting with the U.S. operations on the Space Shuttle and culminating with sustained international ham radio cooperation on the International Space Station (ISS), amateur radio on human spaceflight missions has evolved through 3 developmental and operational phases. As NASA, its international partners, and commercial space have shifted their human spaceflight objectives and priorities, the amateur radio human spaceflight team has worked diligently to stay in lock-step with the plans and visions of the space agencies and commercial human spaceflight. We are now an integral part of the International Space Station program, having continuous presence as crew flight equipment and a payload since Expedition 1. And we continue to work and evolve our systems to be relevant to the space agencies, to the amateur radio community and to the world's youth.

This paper will walk the reader through all three phases of crew members using amateur radio in space: Phase I, the early experimental phase, Phase II, the frequent flyer operational phase on the Shuttle and Phase III sustained, long term operations on Mir and the ISS. This paper will also outline the early international opportunities on Shuttle and Mir which were pivotal in forming the current Amateur Radio on the International Space Station (ARISS) international team.

Phase I

The first phase, the pure experimental phase, introduced new amateur radio hardware and techniques to the Space Shuttle program and accomplished several firsts in human spaceflight history. These include the first communications between astronauts and people on the ground outside of the "official" channels (usually reserved for presidents and heads of state). This occurred on STS-9. Other firsts included the first uplink and downlink of pictures on STS- 51F, the first packet computer-to-computer radio link on STS-35 and the first video uplink on STS-37. Highlights of Phase I are described in the following paragraphs.

The Beginning—Owen Garriott, W5LFL

Owen Garriott, W5LFL, pioneered amateur radio communication from space on his historic STS-9 flight on the Space Shuttle Columbia. Launched on November 28, 1983, Owen was part of a six man crew that performed 24-hour-a-day international science investigations on the STS-9 Spacelab-1 mission. Garriott carried on board an amateur radio station consisting of a battery powered Motorola MX-300 series 2-meter FM handheld radio connected to a signal adapter module that allowed a standard Shuttle headset and a micro-cassette recorder to be used for communication and contact archival purposes. A specially built loop antenna was employed that could be temporarily installed in a Shuttle aft flight deck window. This radio station, developed and certified for spaceflight by Lou McFadin, W5DID from NASA Johnson Space Center and a Motorola Amateur Radio Club team, led by Kai Siwiak, KE4PT, enabled Owen to communicate with hams on the ground by FM voice and CW.

STS-9 Motorola Radio

The international ham radio community waited with much anticipation and excitement as W5LFL's mission approached. With the mission underway, many hams could hear Owen's voice on 145.55 MHz FM booming into their living rooms. But no one had yet to have a two-way communication with Owen, due to the many thousands that were simultaneously attempting to make that "ultimate DX" QSO with W5LFL. All Owen could hear was static and partial voices due to the FM capture effect and significant number of ham radio RF signals coming his way. On December 1, the third day of his mission, Owen donned his headset and made history by communicating with Lance Collister, WA1JXN, in Frenchtown, Montana. In his own words, this is how W5LFL's part of the contact went that fateful day:

Owen Garriott, W5LFL with Motorola MX-300 Series Radio

"...U.S. west coast and calling CQ. Calling CQ North America. This is W5LFL in Columbia. In another 30 seconds I'll be standing by. Our spacecraft is in a rotation at the moment and we're just now getting the antenna pointed down somewhat more toward the earth. So I should be able to pick up your signals a little bit better in the next few minutes. So W5LFL in Columbia is calling CQ and standing by. Go ahead.

Hello W1JXN, WA1 Juliet X-ray November, this is W5LFL. I picked up your signals fairly weakly. I think our attitude is not really the best as yet, but you're our first contact from orbit. WA1 Juliet X-ray November, how do you read? Over"[1]

This contact was groundbreaking for many reasons. First, it represented the first ham radio contact from a human in space to someone on Earth. Second, it allowed the general public to directly listen and communicate with the Shuttle crew. Prior to this, only NASA mission control personnel or heads of State (U.S. Presidents, etc) could talk to astronauts from space. Owen's flight opened human spaceflight to all on Earth. Through W5LFL, the ham community could witness, first-hand, the science and engineering happening during STS-9 by listening in their ham shacks. Third, the mission also showed that a group of volunteers could successfully build a ham radio station for the Shuttle, get it formally approved by NASA, fly it as an official payload on a human spaceflight vehicle, and ensure that it met NASA's stringent safety and RF compatibility

STS-9 QSL Card

requirements. The confluence of this contact, Owen Garriott's enthusiasm in ham radio and the STS-9 mission opened a new door in human spaceflight where crew members can share their experiences in space by directly communicating with anyone on Earth via ham radio.

During Owen's 10 day mission, he talked to over 250 hams around the world, including contacts with Jordan's King Hussein, JY1, US Senator Barry Goldwater, K7UGA/3 and his two sons, including Richard Garriott, at the JSC Radio Club, W5RRR.

Getting permission to fly the first ham radio station on the STS-9 Shuttle mission was extremely challenging and it wasn't the first time that this was attempted.[2,3] In fact, W5LFL attempted to get a ham radio station flown on his Skylab 3 mission in 1973. AMSAT's Harry Helfrich, W3ZM, developed a proposal called the SKYLARC (Skylab Amateur Radio Communications) project and submitted it to NASA for Owen's flight on Skylab 3. NASA turned down the proposal, citing the fact that there were no hardware penetrations on Skylab to support an external antenna and the short time from proposal submittal to the mission. Despite this setback, Owen's interest in radio propagation and ham radio was infectious, and ten years later, a second attempt was made to fly ham radio, this time on Owen's next flight, STS-9. AMSAT's Bill Tynan, W3XO led the proposal development, with guidance, support and encouragement from NASA Johnson Space Center Amateur Radio Club members Dick Fenner, W5AVI and Chuck Biggs, KC5RG, NASA JSC Chief of Public Affairs, who was instrumental in getting NASA support within the Johnson Space Center. Roy Neal, K6DUE, carried the torch to NASA Headquarters where he convinced General James Abrahamson, NASA's Associate Administrator for the Space Shuttle Program, that amateur radio on Garriott's flight was worth doing. The proposal was jointly submitted to NASA by AMSAT and the ARRL and was approved in April 1983.

The barriers overcome to enable the STS-9 amateur radio communications to occur set the stage for a rich future of astronauts and cosmonauts conducting amateur radio operations in human spaceflight vehicles. The human spaceflight amateur radio team conducted a steady and ever increasing cadence of human spaceflight ham radio activities, including technological firsts through ham radio experimentation, "frequent flyer" payload status on the Space Shuttle, educational outreach opportunities in schools and museums, satellite deployments by the crew, and permanent, international ham radio presence on future human spaceflight vehicles, including Mir and the International Space Station. A firm foundation and amazing future was finally realized, with nearly 24/7 ham radio operations in multiple locations on ISS.

It is interesting to note that during the AMSAT Symposium which was held during Owen's flight, AMSAT President Tom Clark, W3IWI, in his address to the symposium audience, stated that one of the fundamental motivations of W5LFL's flight was "to encourage technical careers among youth".[4] What a prognostication that rings true with the SAREX and current ARISS initiative!

Phase I: SAREX—Shuttle Amateur Radio Experiment

Tony England, W0ORE

With Owen's success in-hand, a more ambitious activity was planned for the next ham in space opportunity, the STS-51F Spacelab-2 mission with Dr. Tony England, W0ORE on-board. The Space Shuttle Challenger mission, STS-51F, represented the first ham radio mission to be called SAREX, the Shuttle Amateur Radio Experiment. SAREX was a Space Shuttle payload sponsored by the Radio Amateur Satellite Corporation (AMSAT), the American Radio Relay League (ARRL) and the National Aeronautics and Space Administration (NASA). The primary goal of SAREX was to spark student's interest in the science, technology, and communications fields by allowing them to talk to Space Shuttle astronauts using amateur radio. In addition, SAREX increased public awareness of NASA's human spaceflight program by permitting radio amateurs worldwide to talk with the Shuttle astronauts.

Three STS-51F crew members were trained to use the radio system: Tony England, W0ORE, John-David Bartoe, W4NYZ, and Commander Gordon Fullerton, ex WN7RQR. For SAREX, the human spaceflight ham radio team wanted to realize the vision of inspiring youth to pursue science, technology, engineering and math (STEM) careers through amateur radio communications on the Space Shuttle. As such, ARRL and AMSAT encouraged local ham radio operators to invite youth groups to participate during SAREX passes. For pre-scheduled events, organizations were asked by the ARRL to submit a plan on how they would involve youth in the contact[5]. Students in the Young Astronaut Program, the Scouts and other programs, like Big Brother, Big Sister, were among the many groups and schools to hear and connect with W0ORE on-orbit.

Station hardware employed for this mission included the Motorola radio system and antenna used on W5LFL's flight for voice operations. Also on-board were cameras and monitors supplied by Panasonic and a Robot 1200C Slow Scan Television (SSTV) converter provided by Robot Research. These supported automated SSTV picture uplink and downlink. These automated capabilities allowed ham radio operations to continue despite the heavy crew workload that was anticipated for the STS-51F space science mission. Operations[6] included:

- Auto mode downlink SSTV, using the automated Robot 1200C capability, which was the predominant mode due to limited crew operations time
- Youth group ops; 2-way voice to prescheduled schools and organizations
- Open voice 2-way; to all hams on the ground
- Auto mode uplink SSTV; enabling hams to uplink pictures to the Shuttle Challenger crew

SSTV Image of Tony England, W0ORE

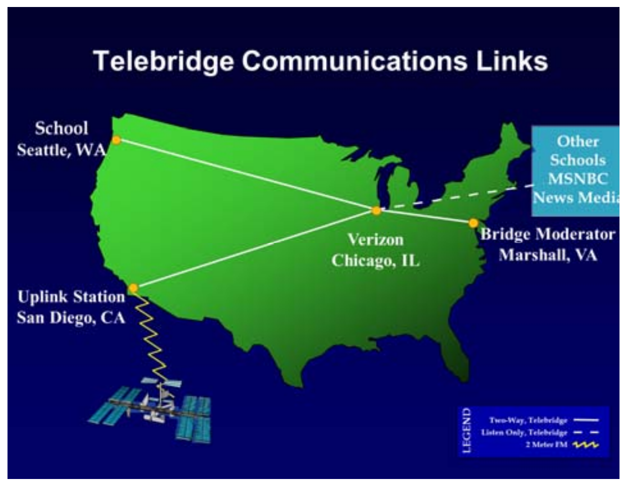
During the early Shuttle flights, when internet and computer tracking were either rare or non-existent, a tabular schedule, with radio opportunities, was developed and communicated to the media (e.g. ham magazines, bulletins) to facilitate communication of opportune times when the Shuttle crew might be available for ham contacts. These included Shuttle mission elapsed start and stop times and radio mode of operation for QSOs and informal events with schools. During the mission, NASA Amateur Radio Clubs at Goddard (WA3NAN), Johnson (W5RRR) and JPL (W6VIO) provided bulletins, pass times and updates to keep the ham radio community informed. WA3NAN provided simulcast information and shuttle mission audio retransmissions on up to 3 HF frequencies and VHF.

STS-51F was launched on 29 July 1985 and landed on 6 August 1985. By the conclusion of the mission, thousands of hams received and recorded the automated SSTV pictures sent down from Challenger, hundreds of hams around the world talked with Tony, W0ORE, and over 6000 of our nation's youth participated in the ham radio activities on Challenger through voice contacts and picture exchange. As a result, the January 1986 QST stated that SAREX on STS-51F "not only was deemed a tremendous success by NASA and will help obtain similar flights in the future, it also enabled countless young people around the world to enjoy an experience of a lifetime." This mission represented the first time that pictures were uplinked and downlinked to the shuttle.

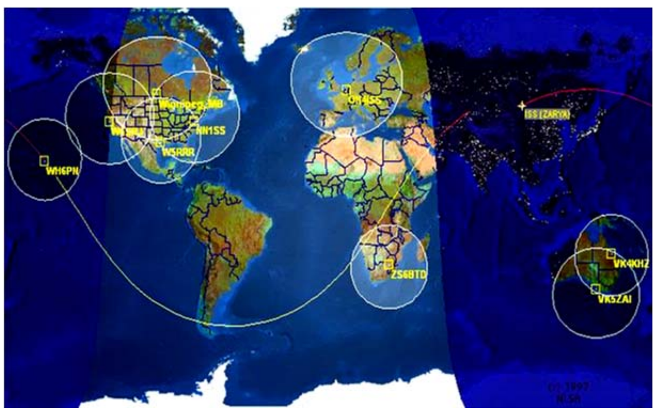
Ron Parise, WA4SIR

Ron Parise, WA4SIR, extended the reach of ham radio and SAREX through his 9 day "Ultimate DXpedition"[7] flight on the Space Shuttle Columbia. The prime objective of this mission, dubbed ASTRO-1, was to conduct 24/7 ultraviolet astronomy observations using a cluster of three telescopes that would be pointed to various locations in the sky. The Shuttle would be frequently reorienting during the mission to support different astronomical observations. As a result, the window mounted antenna designed for the aft flight deck used on W5LFL and W0ORE's flight would not be viable as this antenna would be pointed to space, not to the Earth. So AMSAT member, Lou McFadin, W5DID worked with the Motorola Amateur Radio Club in Schaumburg, Illinois, to design and fabricate a dual port annular slot 2 meter/70 cm antenna that could be mounted on the left and right-most cockpit windows near the Shuttle Pilot and Commander's seats[8]. Either of these windows provided Earth viewing during Ron's flight, depending upon vehicle orientation. This antenna was ultimately used for all future SAREX missions.

Ron's flight, originally designated STS-61E, was planned to fly in March 1986, right after the Shuttle Challenger, STS-51L mission. The loss of the Challenger mission and crew on STS-51L delayed ASTRO-1 until December 1990 on the re-designated STS-35 mission.



The 24/7 operational aspects of the ASTRO-1 mission, the low inclination orbit (28.5^o), coupled with Ron Parise's available times for operating posed multiple operations challenges. As a result, several new capabilities and techniques were demonstrated on STS-35 that would prove invaluable for future astronaut ham radio operations from space. These include the use of a telebridge—remote amateur radio ground stations bridged with the schools through a telephone connection to allow the school students to talk directly with WA4SIR—and the development and use of the packet radio robot, enabling hams, worldwide, to automatically connect with the on-orbit radio station while Dr. Parise was conducting science observations. These innovations proved invaluable. The telebridge allowed many students and schools in high latitude locations in the U.S. to communicate with WA4SIR. Without the telebridge, orbit dynamics and crew scheduling would have resulted in very limited school outreach. With these innovations employed, Parise was able to set up numerous (30+) educational opportunities. The telebridge enabled multiple schools to be connected together during a single 10 minute pass, opening SAREX to a much wider audience. The packet robot concept was devised by a team of AMSAT members from the DC area, led by Tom Clark, W3IWI with additional technical input from Bob Bruninga, WB4APR. Howard Goldstein, N2WX, developed the packet robot software. The packet robot was flown on STS-35 and, given its outstanding success on Parise's mission, all future SAREX shuttle flights.



SAREX & ARISS Telebridge Network

Prior to flight, over 860 educational proposals[9] were received by the ARRL for a pre-arranged school contact with WA4SIR. Of these, 38 were chosen for 2-way connections, 30 via telebridge and 8 direct. Also, 121 were chosen for listen-only connections.

While the schools and ham radio community were anxiously waiting, the STS-35 launch was plagued with a series of delays that resulted from a pesky hydrogen leak in the Shuttle Columbia's propulsion system. Columbia was rolled out for launch several times with an initial launch planned in May 1990.

After multiple attempts and a 6 month delay, on December 2, 1990, STS-35 lifted off on a picture perfect night launch from launch pad 39 of the Kennedy Space Center, starting the WA4SIR's 9 day mission. The ASTRO-1 mission experienced several failures early on that the operations crew worked around to ensure full science success. Despite these operational issues with the primary payload, SAREX, a secondary payload, was a phenomenal success. Ron made over 50 voice QSOs with hams on the ground and over 600 packet radio connections. Packet radio was on the air for 14 hours each day of the mission. Of the 30 telebridge educational events planned, 26 were successful and of the 8 direct educational contacts planned, 6 were successful. Contact failures were mainly attributed to unfavorable Shuttle attitude and/or vehicle blockage from the ground station line of sight. Window antenna gain pattern, particularly a null near station closest approach, was a contributing factor in contact failure. Dr. Parise suggested that in the future that SAREX should reduce the number of schools planned per pass to just 1-2, as compared to 3-4, to ensure all the schools realize a successful event. Lessons learned from STS-35 and some of the other early SAREX flights were factored in to maximize contact success in future human spaceflight school group contacts.

Ron Parise, WA4SIR with SAREX Station on STS-35

STS-37—The Whole Crew is Licensed!

The next SAREX flight and the last mission as part of Phase I, STS-37, bundled educational outreach with unique experimentation. Led by STS-37 pilot

Ken Cameron, KB5AWP, all 5 crew members on this mission were licensed amateurs[10]. See table 2. And all five enjoyed communicating with students, schools and ham radio operators throughout the world. Jay Apt, N5QWL, described his experiences by saying "The QSOs made the crew feel connected to people on Earth. It was great to think of the different cultures and what the people were like while we talked to them."

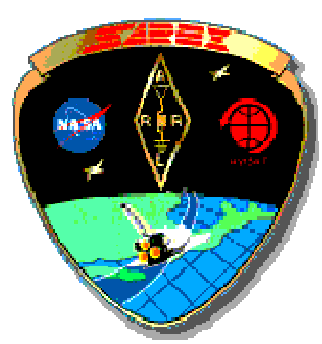
STS-37 continued the SAREX progress of firsts for human spaceflight. STS-37 was the first mission to receive television on-board a human spaceflight vehicle. Until STS-37/SAREX, no astronaut had received live video from space. Jim Steffen[11], KC6A, was the first to transmit live TV pictures to astronauts in space. Cameron was able to see video from several TV ground uplink stations, mainly black and white video. However, some stations were received in color, most notably color video from the Goddard Amateur Radio Club contact via the US Naval Academy dish antenna. Specifically, the following stations conducted successful TV uplinks as part of this experiment: N9AB, WA3NAN, WA4NZD and KC6A. In describing the video clips received, Cameron said, "it was really neat to see a rerun of our own launch transmitted to us while in space!" One of the video uplinks included a video clip scripted by Jay Leno with greetings to the Shuttle Atlantis crew.

Phase II: SAREX Frequent Flyer, Operational Phase

SAREX Phase II, which started in 1992, represented the operational frequent-flyer phase of amateur radio on human spaceflight missions. During this phase of SAREX, the paperwork, tools and operational techniques were honed to allow SAREX to fly up to 4-5 times a year on the Space Shuttle. The early amateur radio experiments required a significant amount of volunteer overhead. Completing the documentation required to fly SAREX on the Shuttle was, in some cases, a full time job. During the two year Shuttle flight stand-down after the Challenger accident,

Jay Leno SAREX Video for STS-37 TV Uplink

the SAREX team made a concerted effort to significantly improve this situation. Several specific SAREX hardware configurations were developed which allowed the generation of generic SAREX paperwork to meet Shuttle payload integration requirements. John Nickel, WD5EEV, was tapped to streamline the paperwork required for SAREX and to coordinate SAREX activities at the NASA Johnson Space Center. Members of the Johnson Space Center Radio Club initiated a successful amateur radio licensing program which has resulted in a large influx of astronauts obtaining their amateur radio licenses. The Crew Training Plan was formalized and made more efficient; generic lessons and educational material were developed by ARRL that could be used for every flight. In addition, a concerted effort was initiated to license NASA's astronauts. Almost half of the U.S. astronauts currently have ham radio licenses. To support long-term operations, AMSAT set up a network of volunteer mentors who prepared the schools for their SAREX contacts. These volunteers also provided real-time information bulletins to hams around the world. And for the Shuttle program, this volunteer team provided SAREX support in mission control, Houston for each SAREX Shuttle mission.



SAREX Patch

Prior to Phase II, significant constant lobbying efforts were required by high profile individuals like Roy Neal, K6DUE, to get NASA backing of the amateur radio experiment. Payload sponsorship from the NASA headquarters office of Education gave SAREX a significant boost as an educational payload, reducing the need for agreements on each flight.

The fruit of all these efforts rewarded the SAREX team with an envious frequent flyer status on the Shuttle with 3-5 missions per year from 1992-1996. See tables 2-4. In Phase II, the SAREX payload progressed from a pure experimental payload to an operational payload whose main goal was education.

SAREX Phase II Highlights & Program Details

The following paragraphs provide SAREX Phase II mission highlights and program details.

SAREX Working Group

The SAREX Working Group consists of a core group of "board of directors" that managed the day-to-day SAREX activities and provided strategic guidance and direction to the program. These individuals were instrumental in transforming human spaceflight amateur radio from a pure experimental activity into an operational payload. The SAREX Working Group included a human spaceflight lead from ARRL, AMSAT and the Johnson Space Center Amateur Radio Club with Roy Neal, K6DUE, as the working group lead. Rosalie White, WA1STO/K1STO, was the ARRL representative. Initially Bill Tynan, W3XO, and starting in 1991, Frank Bauer, KA3HDO was the AMSAT representative. And the Johnson Space Center Amateur Radio Club representative and SAREX principal investigator (PI) was initially Lou McFadin, W5DID. After Lou retired from NASA, Matt Bordelon, KC5BTL, was tapped as SAREX PI and SAREX Working Group member. As SAREX Phase II was primarily an educational outreach activity, the SAREX Working Group received NASA guidance from Pam (Bacon) Mountjoy, from the NASA Headquarters Division of Education.

Phase II Station Configurations[12]

SAREX was flown in one of five distinct configurations. Configuration selection for a Shuttle flight was determined by crew availability for attended operations, the number of ham astronauts on-board, Shuttle power constraints, Shuttle weight and balance considerations, and mid-deck locker availability.

Extremely power limited or weight critical missions flew configuration B: battery operated, 2 meter FM voice using the side window mounted antenna and the 2 meter FM Motorola MX-360 HT. STS-45 flew SAREX in this configuration. Flights with severe weight and balance constraints, mid-deck locker storage problems or crew members with little "free" time for attended operations flew configuration C: 2 meter voice via the Motorola HT and a robot packet radio capability using the Heathkit HK-21 TNC. Packet radio operations was performed interactively using the Shuttle Grid laptop computer or in an unattended robot mode. A 12 V DC power supply in the packet module interfaced with Shuttle power to provide battery-free operation. This configuration was flown during the STS-35 and STS-47 missions as examples. When power, Shuttle weight and balance, and mid-deck locker space are not severely constrained, configuration A, configuration D or configuration E were manifested. Configuration A allowed the Shuttle crew to operate SSTV, Voice and Packet. The TNC and 12V power supply are mounted in a special housing that includes the Robot 1200C SSTV scan converter. A Panasonic VCR/Monitor allowed the crew to view the SSTV video. Configuration D is virtually identical to Configuration A with the addition of 432 MHz FSTV uplink (receive only) capability. The ATV uplink module for this configuration was developed by Andy Bachler, N9AB. Configuration D flew on STS-37. For Configuration E, the Panasonic VCR/Monitor is replaced with a Shuttle provided Video Interface Unit (VIU). In this configuration, video from the FSTV or SSTV is viewed on color monitor in the orbiter. This modification results in a 50%

reduction in SAREX payload weight. Configuration E was flown on STS-50.

STS-50 Commander Dick Richards, KB5SIW, with Addison Elementary School SSTV Uplink

School Group Technical Mentoring

On the early SAREX missions, some of the school groups were ill prepared for the SAREX contact due to lack of technical information or guidance. This led to either missed or very weak contacts. In October 1992, an international operations team was formed by AMSAT-NA to significantly enhance the technical support to the school groups. Beginning with the first SAREX mission in 1993, each school group was assigned a technical mentor familiar with satellite communications. The primary responsibilities of this mentor were to provide guidance in the school technical setup, to be on-hand for any questions or problems, and to be a conduit for vital information before, during and after the contact. Weekly telecons are held with the operations team to ensure they have the latest information and were progressing with their schools. As a result of these efforts, the contact success rate was considerably improved. Since its inception, the success rate with the schools soared from 66-75% in 1992 to 95+% now. For ARISS, the technical mentor team was expanded internationally, due to the diverse, worldwide ARISS schools contact. Technical mentors continue to be key to school contact success. AMSAT would like to thank the mentors for their outstanding support and dedication in making these school contacts such a huge success. The author would particularly like to recognize Charlie Sufana, AJ9N, who has mentored schools since the technical mentoring project came into being. And for his longtime leadership in keeping the ARISS operations team informed and on top of their school contacts.

Mission Control Support

SAREX was an official shuttle mid-deck payload. As such, the SAREX team provided real-time support in the Mission Control Customer Support Room (CSR) for each of the 25 shuttle missions with SAREX on-board. Duties in the CSR included informing the mission control personnel of any problems with SAREX, scheduled contact successes (and failures), unscheduled contact highlights, and providing real time support to the Mission Control team. In addition, the SAREX team provided a summary of the day's events 2-3 times a day and generated SAREX-related teleprinter messages which were uplinked to the crew. The members of the JSC ARC and other selected SAREX team members from AMSAT-NA volunteered their time to maintain a 24 hour-a-day presence in the Customer Support Room from launch until landing.

SAREX Team Members in the Customer Support Room of NASA's Mission Control

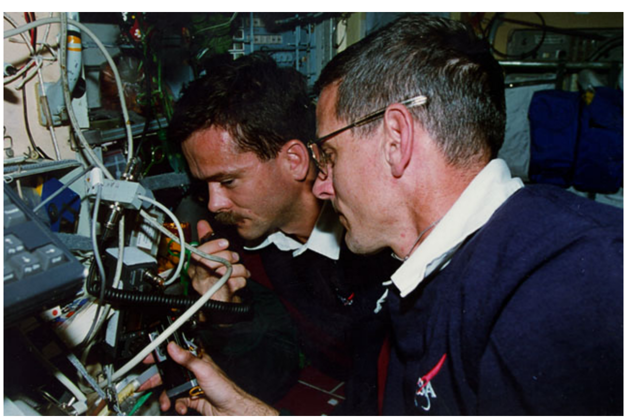
Mission Highlights

STS-45 represented one of the "high water marks" for crew on-orbit operations. The crew was enthusiastic about inspiring youth into STEM careers and saw SAREX as an excellent opportunity to make that happen. Many of the crew members became rabid operators during the mission. Nearly 1000 voice contacts were conducted during the eight-day mission[13]. Astronaut Kathy Sullivan stated after her flight, "Every time we picked up the radio while flying over the US and Europe, people were waiting and we worked a station every 15 seconds." STS-45 Commander, Charlie Bolden, KE4IQB, has an infectious interest in inspiring students. He picked up the radio and communicated with several schools and family on STS-45 and again on STS-60. (Charlie Bolden is now the current NASA Administrator.)

Current NASA Administrator Charlie Bolden Talking to Students via SAREX on STS-45

Coordinating the STS-45 contact at the Belgian Space Camp was Gaston, Bertels, ON4WF. Gaston is the current Chair of ARISS Europe and was the ARISS International Chair for several years.

Other mission highlights of note included STS-50 where over 600 SAREX contacts were conducted and many SSTV images were shared with hams on the ground, STS-59, where 1674 packet radio connections and dozens of voice QSOs were made[14] and STS-74 where Ken Cameron, Bill McArthur and Chris Hadfield made about 100 general contacts per day during their mission.



Bill McArthur, KC5ACR, and Chris Hadfield KC5RNJ, on the Mir Space Station radio during STS-74

Inspiring school students to pursue STEM careers represented the prime objective of the SAREX program. Over the 25 shuttle missions with SAREX on-board, the astronauts conducted over 260 school contacts, enabling thousands of students to talk directly with a crew member, allowing tens of thousands of students to hear their school's contact and engaging millions from the general public in this one-in-a lifetime opportunity. The schools were encouraged to pursue pre-contact and post-contact activities to engage and educate the students in space science and engineering. Many took this seriously, developing their own simulated Shuttles and conducting science investigations that emulated their Shuttle/SAREX mission. Others had geography contests that combined amateur radio and Earth observations from space. And still others taught their students fundamental orbit mechanics and had them helping run the SAREX satellite station. While it is not possible to trace the success of our SAREX students we have learned of some notable positive outcomes: one STS-60 female student is now a key science advisor for the Office of Science Technology and

Policy (White House Science Advisor), a young man is an Aerospace Engineer at Northrop Grumman and a young lady graduated with her Aerospace Engineering degree with aspirations of becoming an astronaut.

A Presidential Commendation

SAREX and amateur radio, in general, received a big boost when President Clinton had a telephone conference with the STS-57 crew. During his address to the astronauts, President Clinton commended the astronauts, the SAREX team and the amateur radio community for their outstanding support to students around the world. Clinton said "I understand that later in the mission Janice (Voss) and Brian (Duffy) are going to be talking with school children around the world." He continued "But I want to tell you how much I appreciate the fact that you're making an international education project out of this mission. That's very important to me." Pilot Brian Duffy responded "Mr. President, we find that using amateur radio is an excellent way of communicating with children all around the world, and we're also able to excite them by using space and science. And letting them see space and science in action, we're able to excite them and hope they'll study harder." The President finished, "You have no idea -- you may be on this mission creating thousands of scientists for the future just by the power of your example and by this direct communication. I think sometimes we underestimate the impact that human contact in an enormously impressive setting like this can have on children all across the world--not only those with whom you'll talk, but millions of others who will just see it and know that it happened"

SAREX Transition

As more and more flights traversed to the Mir space station and ultimately to the ISS, it became more and more challenging to reserve astronaut time and shuttle cargo space and mass for SAREX. As a result, SAREX opportunities on the Shuttle dropped precipitously in 1997 and ended in 1999. However, the SAREX team transitioned with the astronauts, onto Mir and ultimately ISS.

Dick Richards and Ellen Baker Show off their Callsigns, and their "Tang" on STS-50

Phase III—International, Permanently Tended Operations

In Phase III, ham radio on human spaceflight transitioned from short duration, intense, Space Shuttle flights to long duration U.S. presence on the Russian Space Station MIR and finally permanently tended human operations on the International Space Station (ISS). As was required when SAREX transitioned from Phase I to SAREX Phase II, the team, hardware, documentation, and operations all evolved to better serve the new needs—in this case, sustained, long duration activities in space during the Phase III era. Since both MIR and ISS represent international facilities, the Amateur Radio on the International Space Station (ARISS) team was formed in 1996 to support international development and operations on these vehicles. The intent of ARISS is to develop and operate the station systems on ISS as a single coordinated entity. In this way, a single focus and entry point is created for all amateur radio activities on the ISS. The ARISS international team works with and leverages the capabilities and priorities of the international space agencies. They also are working with commercial companies (e.g. Space Adventures) to ensure commercial spaceflight participants gain access to the amateur radio capabilities on the ISS during their on-orbit stay. With the development of ARISS, the foundational development and ops processes honed in SAREX Phase II have evolved into international development and operations capabilities that leverage the strengths and resources of the international team. As a result, a bright, sustained future lies ahead for ham radio in space and more comprehensive, evolving educational activities abound.

International Operations Pre-Mir

Just a few months after Tony England's SAREX flight on STS-51F, two German astronauts and a Dutch astronaut carried a 2-meter, 70 cm amateur radio station on board the STS-61A Spacelab D1 mission. Dr. Ernst Messerschmid, DG2KM, Dr. Reinhard Furrer, DD6CF, and Dr. Wubbo Ockels, PE1LFO operated amateur radio equipment built by the Robert Bosch company using the callsign DP0SL[15]. The radio system was a 2-meter up/70 cm down FM cross band repeater that included an automated uplink recording mode. The Spacelab D1 module included an antenna feedthrough and externally mounted antenna, making communications with the Space Shuttle much easier than with the SAREX window antenna. Spacelab D1 was launched on the final successful fight of the Space Shuttle Challenger on October 30, 1985. The author was one of many stations that successfully worked this mission. The German team flew DP0SL again on the second German Spacelab mission, Spacelab D2 on STS-55. As part of this mission, an antenna test was performed between the SAREX window antenna and the German externally mounted antenna. Students were encouraged to participate and provide their observations as part of the educational aspects of this SAREX flight.

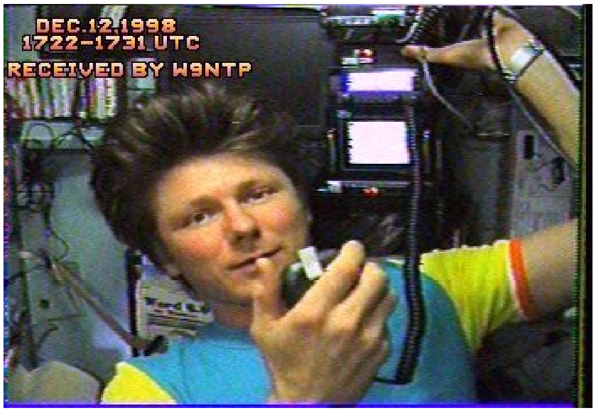
International Operations—Mir

A series of events occurred in 1988 which culminated in amateur radio operations on Mir on November 8, 1988[16] between Leonid Labutin, UA3CR and Musa Manarov, U2MIR. In March 1988, Musa Manarov asked for copies of the Russian Magazine "Radio" to be sent up to Mir. This resulted in an earnest effort by the Radio magazine staff to help the on-orbit crew get their amateur radio licenses and to send up amateur radio equipment. All three cosmonauts on board, obtained their licenses: Commander Vladimir Titov, U1MIR, Musa Manarov, U2MIR and Valery Polyakov, U3MIR. The first amateur station on-board Mir was

Musa Manarov, U2MIR

donated by Valery (Larry) Agabekov, UA6HZ. (Note that Larry is currently one of the ARISS Russia delegates). The station, a Yaesu FT290 was delivered to Mir using the Progress-37 cargo vehicle. A commercial antenna was up-massed to Mir on the subsequent cargo flight (Progress-38). During a regularly scheduled EVA on October 20, 1988, U1MIR transferred the antenna to U2MIR who mounted the antenna on a handrail. After the first contact on November 8, Leo made another QSO with U2MIR, this one on November 12 in the US, using Byron Lindley's station as W4BIW/M while at the 1988 AMSAT Space Symposium in Atlanta.

Over the years, several upgrades were made to the Mir radio station by international partners in Russia, Germany, the U.S. and Austria. These include a 10 watt 2 meter transceiver that was carried up with the crew that replaced U1MIR & U2MIR on Mir, an ICOM-228A, PacComm Handi Packet and laptop for packet radio operations in 1991, and a digital voice memory module in 1992 by German astronaut DP1MIR. In 1995, a Kenwood TM-733, dual band (2 M/70 cm) antenna and PacComm 9600 bps packet modem was installed. This radio system, an SSTV capability and the German SAFEX-II 70 cm repeater, mounted in the Priroda module remained the mainstay capability for Mir until the end of mission. Note that all the U.S. crew



SSTV Image Received by Don Miller, W9NTP of Russian Commander Gennady Padalka

members that resided on Mir utilized this equipment for school contacts, family contacts

Mir Space Station

and general QSOs. Also note that the SAFEX-II repeater project leader was Thomas Kieselbach, DL2MDE, one of the charter members of ARISS and an ARISS-Europe delegate until his passing.

U.S. Operations on Mir

Continuous US presence on Mir started with the transfer of Shannon Lucid from STS-76 to Mir on March 22, 1996. Then continuous SAREX amateur radio operations on Mir started when Shannon was replaced by John Blaha, KC5TZQ during the STS-79 flight in September 1996 through to Andy Thomas's expedition which ended in June 1998. Table 1 depicts the continuous string of 5 astronaut hams that resided on the Mir space station for nearly 2 years. U.S. astronauts learned valuable lessons on Mir during their 4-6 month stays. During this time, the US crew members on Mir performed numerous SAREX school group contacts, sent packet radio mailbox messages and talked with ham radio operators on the ground. Ham radio became an important communication resource during the Progress collision on June 24, 1997. Mike Foale sent down many messages using the packet mailbox, as shown in the following figure. Lessons learned on Mir, coupled with the substantial international coordination with Russian colleague Sergey Samburov, RV3DR and team members from the US Mirex team and

Andy Thomas, KD5CHF/VK5MIR at the Mir Ham Radio Station

German SAFEX team, set the stage for international amateur radio coordination on ISS as the ARISS program begins.

Posted : 06/28/97 17:58
To : ALL
From : R0MIR
Subject: Mir Status

We have now got the base block, the module Kvant 2 back on line, leaving 2 more modules. Working very hard, lights in our mouths, in the dark, moving batteries about, to enable better charging, with solar arrays. O2 electrolysis soon, in old Kvant. Much interest from control center to do internal eva to reconnect power to lost Spkektr module, to receive its substantial electrical power from its large arrays.
Thanks for all your good wishes. Mike.

CMD(B/H/J/K/KM/L/M/R/S/SR/V/?)>

Astronaut	Expedition	# Schools	Notes
John Blaha, KC5TZQ	Sept 1996-Jan 1997	8	
Jerry Linenger, KC5HBR	Jan-May 1997	9	Mir Fire
Mike Foale, KB5UAC	May-Oct 1997	0	Progress Collision with Spektr Module on June 24, 1997
David Wolf, KC5VPF	Oct 1997-Jan 1998	7	
Andy Thomas, KD5CHF/VK5MIR	Jan-June 1998	8	End of US presence on Mir

U.S. Licensed Amateur Radio Operators on Mir
Table 1

ARISS[17]

Amateur Radio on the International Space Station (ARISS) represents the first educational outreach program to fly on the International Space Station (ISS). The astronauts and cosmonauts work hard on the International Space Station, but they plan to take some time off for educational activities with schools. The National Aeronautics and Space Administration's (NASA's) Education Division is a major supporter and sponsor of this student outreach activity on the ISS. This meets NASA's educational mission objective: "To inspire the next generation of explorers…as only NASA can." The amateur radio community is helping to enrich the experience of those visiting and living on the station as well as the students on Earth. Through ARISS sponsored hardware and activities, students on Earth experience, first-hand what it is like to live and work in space. Through ARISS, today's youth are inspired to pursue STEM careers.

In 1996, as the International Space Station neared initial hardware delivery, Pam Mountjoy from NASA HQ Education, asked the SAREX working group to spearhead an effort to bring together an international delegation to discuss the future of ham radio on ISS. The reason: to consolidate the many ham radio voices around the world into one voice—a team that would coordinate the development and operations of ham radio on ISS. Invited were representatives from national amateur radio organizations (e.g. the ARRL in the US), AMSAT, and other ham radio groups that possessed expertise in ham radio on the U.S. Shuttle and Russian Mir space station. In November 1996, the first ISS ham radio meeting was held at the Johnson Space Center in Houston, Texas. In attendance were members from eight national amateur radio organizations, including Russia, Germany, Italy, Japan, Canada, France, Great Britain, and the USA. This meeting served to initiate the dialog on the development and operations of a permanent amateur radio station on ISS. Those humble beginnings really impressed NASA. Actually, NASA was skeptical that an international amateur radio meeting of this magnitude could be accomplished, especially as quickly as was requested. But the team succeeded and the rest is history---the international working group called ARISS--Amateur Radio on the International Space Station—was formed. Today, hundreds of team members from around the world are supporting the development and operation of the amateur radio systems on ISS. And most importantly, they are inspiring and educating our youth, enabling them to acquire a firm foundation to pursue technical careers.

Hotel Sign at Conclusion of 1996 Meeting

The primary goals of the ARISS program are: 1) <u>Educational outreach</u>—Through school contacts, ten or more students at each school ask the orbiting ISS crews questions and hundreds of students and family members participate. The nature of these contacts embodies the primary goal of the ARISS program -- to inspire students' interest in science, engineering, mathematics, technology and amateur radio. 2) <u>Crew psychological factors</u>—Contacts can be scheduled with the astronauts' friends and families. Random contacts with the amateur radio public provide a unique opportunity for casual conversations with non-project related individuals. These boost the crew's morale by reducing the sense of isolation. 3) <u>ISS-based Communications Experimentation</u>—ISS provides a testbed for development of new communications techniques which can be used to develop new educational projects. 4) <u>International Good Will</u>—Astronaut contacts to schools and the amateur community fosters international good will. Joint hardware development provides a forum to enable international technical partnerships. 5) <u>Emergency Communications Backup—</u> Serves as an emergency communications backup, in case the US or Russian communication links go down.

1996 ARISS Inaugural Meeting Attendees

In the opinion of the author, the two biggest ARISS accomplishments have been: 1) the team's enthusiasm to learn from each other's culture to become a high performing international team and 2) the team's ability to demonstrate to the space agencies and the amateur community that the ARISS team can produce results and meet the stringent safety requirements for ISS. These two accomplishments were a requirement for success on ISS. But it was not easy. It took a lot of discussion, arguments, and compromise to make it work. Over the first couple of tumultuous years, ARISS started to gel as a team. Now they are a high performer.

Some specific ARISS accomplishments include:

- the first human spaceflight frequency plan for 2 meters and 70 cm
- Installation of the Ericsson 2 meter radio system and pico-packet for voice and packet in the FGB. This occurred less than two weeks after the first crew arrived (making ARISS the first payload on ISS)
- The development of 4 multi-functional antenna systems that were mounted by 3 EVAs on the periphery of the Russian service module; these support 2 meters, 70 cm, L band, S Band, HF operations and GPS reception
- The installation of a UHF/VHF Kenwood D-700E & D-710 in the Service Module, near the dinner table and window, marking the second station location on ISS
- The installation of L/S band antennas and 2M/70cm antennas on the Columbus Module
- The installation of the Ericsson 2 meter radio system to support voice and packet in the Columbus Module, marking the third ham station location to date. ARISS now has the ability to operate in 3 different modules—Zarya (FBG), Zvezda (Service Module) and Columbus
- The installation of two different SSTV capabilities, the Kenwood VC-H1, delivered by spaceflight participant Richard Garriott in 2008 and the computer controlled Spacecam SSTV system
- The development of a Ham TV system, led by ARISS Europe, enabling the crew to downlink TV pictures to schools and ham radio operators worldwide
- The successful completion of over 856 international schools to date—kudos to the operations team, education team and volunteer mentors on a job well done!
- 37 ISS expedition crews using our radio system to conduct thousands of QSOs with hams on the ground
- An ARISS contact as a segment of the IMAX Space Station 3D movie

Bill McArthur, KC5ACR operates Kenwood D700

- Over 15,000 students touched each year
- Millions, worldwide have heard an ARISS connection
- Witnessing students, worldwide, become scientists and engineers as a direct result of the ARISS connection
- The first Spacesuit satellite—SuitSat-1/Radioskaf deployed from ISS.
- The first satellite deployed from ISS with a student payload--ARISSat-1

And many, many other accomplishments too numerous to capture in this paper.

Frank Culbertson at the ARISS Station

Astronaut Peggy Whitson with one of the ARISS Antennas Prior to Installation

Spaceflight Participants

The ARISS team has had the unique opportunity of supporting 7 of the 8 spaceflight participants that have flown to the ISS. Our volunteer network has aided them in license training, license testing, equipment training and on-orbit operations support. We have supported their efforts to connect to friends, family, schools and ham radio operators on the ground through the ARISS amateur radio system. The table below depicts the spaceflight participants that have utilized the ARISS ham radio system. Our relationship with the spaceflight participants has been a win-win for the participant and ARISS. ARISS has provided a vital link to the spaceflight participant's friends and family. And the spaceflight participant has supported numerous ARISS school contacts, they have conducted contacts with thousands of hams radio operators, they were responsible for delivering ARISS hardware systems to the ISS, (e.g. Kenwood VC-H1 SSTV communicator) and have helped ARISS checkout key systems, including the SSTV capabilities.

Spaceflight Participant	Dates
Dennis Tito	April 28-May 6, 2001
Mark Shuttleworth	April 25-May 5, 2002
Greg Olsen	October 1-11, 2005
Anousheh Ansari	Sept 18-29, 2006
Charles Simonyi	April 7-21, 2007
Richard Garriott	October 12-23, 2008
Charles Simonyi	Mar 26-Apr 8, 2009

American Dennis Tito was the first person from the general public to pay for a ride to ISS. When Dennis requested the use of our equipment during his stay on ISS, we worked with NASA, Energia and Mr. Tito's team to ensure that ARISS fulfilled the ISS international agreements and served Mr. Tito. Given that Dennis was the first citizen to fly to ISS, the paperwork and approval process was challenging. And ARISS, being an member of the ISS team, experienced these challenges first-hand. But shortly before he was scheduled to fly, the green light was given to proceed. Dennis was quite pleased to use the ARISS equipment to talk to his family once per day during his stay on ISS. You could hear the sheer excitement in his voice as he talked to his family about his journey into space.

Mark Shuttleworth and all follow-on spaceflight participants performed pre-scheduled school contacts and communicated with ham radio operators on the ground.

2 Ham Radio Generations in Space
Owen, W5LFL (L) & Richard Garriott, W5KWQ (R)

Richard Garriott's flight to ISS stands out in many ways. Richard was the first second generation American to fly in space. Richard's dad, Owen Garriott, W5LFL, pioneered amateur radio in space on STS-9 in 1983. When first licensed, Richard requested the callsign W5KWQ as it was his grandfather's, making Richard a third generation ham and resulting in all three generations of Garriott's having a space connection. Richard had successful contacts with 7 several Challenger Learning Centers in the U.S., the Austin Liberal Arts and Sciences Academy in Austin, Texas, the Pinehurst School in Ashland, Oregon, the Budbrooke School in the U.K., and the National Space Challenge in Kuala Lumpur, Malaysia. Garriott also conducted random chats with scouts world-wide as part of the amateur radio "Jamboree on the Air".

Budbrooke School Contact

Richard generously flew a Kenwood VC-H1 SSTV communicator on his Soyuz flight and delivered it to ISS for ARISS operations. He also personally set up and checked out the VC-H1 for his use and for future ARISS use. He supported SSTV operations using the Kenwood VC-H1 and the Spacecam & MMSSTV software that are installed on the ISS laptop. At the conclusion of Richard's mission, he made over over 500 random voice QSOs and over 1000 SSTV images sent during his mission. He was well prepared! And, in the footsteps of his father, he made a phenomenal impression on the world-wide ham radio community. Our thanks to Richard and all the spaceflight participants for their outstanding ARISS support.

SSTV Picture of Richard Garriott, W5KWQ from the ISS

The Future

The thirty years since the first ham radio operations by a crew member in space, an international team of ham radio enthusiasts have accomplished some marvelous achievements for ham radio and school children around the world. We now have a permanent ham radio system in space. At this juncture, it is unclear what human spaceflight's next destination will be. Surely, it will be beyond low Earth Orbit. As the international space agencies work this out and develop a common vision, the ARISS international team is prepared to evolve again to ensure amateur radio is part of the crew's journey. To paraphrase Sergey Samburov's great-grandfather, Konstantin Tsiolkovsky, this ham radio team is looking at moving away from our "cradle"—Earth—to destinations beyond. We hope you will all work with us as a team as we make this happen!!

Personal Thanks

As the current ARISS International Chairman, I feel privileged to serve as the leader of this outstanding team. I look forward to the future, where many more astounding ARISS accomplishments are on the horizon, including Ham TV, the S-band beacon project and more in-depth educational outreach opportunities. I would like to personally thank all who have poured their hearts into this program to inspire school children and inspire our ham radio community through amateur radio.

Dedication

This paper is dedicated to four founding members of ARISS and an astronaut ham that provided unwavering support to ARISS but have since passed away. Specifically, we would like to dedicate this paper to Pam Mountjoy from NASA, Ken Pulfer, VE3PU from the ARISS Canada Team, Thomas Kieselbach, DL2MDE, from the ARISS Europe team and Roy Neal, K6DUE from the ARISS USA team and Astronaut Ron Parise, WA4SIR.

Pam was the vision behind making ARISS a one ham radio team focal point into the space agencies. As an educational outreach executive at

NASA, she was instrumental in getting NASA behind the ARISS and getting initial funding for SAREX and ARISS.

Ken was a leader, mentor and sage that will be sorely missed. ARISS favored greatly from Ken's vast knowledge and understanding of the workings of the international space agencies, especially the Canadian Space Agency where he was an executive. He was instrumental in guiding ARISS to solution on several amateur radio policy initiatives, including callsign & ITU decisions. He also was key in helping ARISS formulate our terms of reference.

Thomas' excitement for hardware development was infectious. His guidance in the early years was pivotal in the development of the antenna design. His idea and excitement for a digitalker on ISS was a primary reason why the student voices were on-board SuitSat-1. He gave us great ideas and pushed the team hard.

Roy was a key moderator and leader within the ARISS team. When things got rough or contentious, he would always remind us of our primary objective—to make ham radio a permanent fixture on human spaceflight vehicles.

Ron was a dear friend, passionate ham radio operator, creative thinker (especially when it came to ham radio projects), first class astronaut and a leader who recognized the significant impact that ham radio in space could have in inspiring youth to pursue STEM careers. The amateur radio community is deeply indebted to Ron for bringing his tremendous enthusiasm of ham radio into the astronaut office, into space and to hams on Earth.

My deepest thanks, thoughts and prayers are with each of you

Flight	Date	Ham Crew	# Schools	Modes
STS-9 Columbia	Nov-Dec 1983	Owen Garriott, W5LFL	0	Voice
STS-51F Challenger	July-Aug 1985	Tony England, W0ORE John-David Bartoe, W4NYZ	informal	Voice, SSTV
STS-35 Columbia	December 1990	Ron Parise, WA4SIR	38	Voice, Packet
STS-37 Atlantis	April 1991	Ken Cameron, KB5AWP Jay Apt, N5QWL Linda Godwin, N5RAX Steve Nagel, N5RAW Jerry Ross, N5SCW	10	Voice, Packet, SSTV, ATV Uplink
STS-45 Atlantis	March 1992	Dave Leestma, N5WQC Brian Duffy, N5WQW Dirk Frimout, ON1AFD Kathy Sullivan, N5YYV	17	Voice
STS-50 Columbia	June 1992	Dick Richards, KB5SIW Ellen Baker, KB5SIX	15	Voice, Packet SSTV, ATV Uplink
STS-47 Endeavour	September 1992	Jay Apt, N5QWL Mamoru Mohri, 7L2NJY	8	Voice, Packet
STS-56 Discovery	April 1993	Ken Cameron, KB5AWP Ken Cockrell, KB5UAH Mike Foale, KB5UAC Ellen Ochoa, KB5TZZ Steve Oswald, KB5YSR	18	Voice, Packet SSTV, ATV Uplink
STS-55 Columbia	April 1993	Steve Nagel, N5RAW Jerry Ross, N5SCW Charlie Precourt, KB5YSQ Hans Schlegel, DG1KIH Ulrich Walter, DG1KIM	14	Voice, Packet
STS-57 Endeavour	June 1993	Brian Duffy, N5WQW Janice Voss, KC5BTK	8	Voice, Packet
STS-58 Columbia	October 1993	Bill McArthur, KC5ACR Marty Fettman, KC5AXA Rick Searfoss, KC5CKM	16	Voice, Packet

SAREX Missions 1983-1993
Table 2

Flight	Date	Ham Crew	# Schools	Modes
STS-60 Discovery	February 1994	Charlie Bolden, KE4IQB Ron Sega, KC5ETH Sergei Krikalev, U5MIR	5	Voice, Packet
STS-59 Endeavour	April, 1994	Jay Apt, N5QWL Linda Godwin, N5RAX	9	Voice, Packet
STS-65 Columbia	July 1994	Don Thomas, KC5FVF Bob Cabana, KC5HBV	13	Voice, Packet
STS-64 Discovery	September 1994	Dick Richards, KB5SIW Blaine Hammond, KC5HBS Jerry Linenger, KC5HBR	10	Voice, Packet,
STS-67 Endeavour	March 1995	Steve Oswald, KB5YSR Bill Gregory, KC5MGA Wendy Lawrence, KC5KII Tammy Jernigan, KC5MGF Sam Durance, N3TQA Ron Parise, WA4SIR	26	Voice, Packet
STS-71 Atlantis	June-July 1995	Charlie Precourt, KB5YSQ Ellen Baker, KB5SIX	5	Voice
STS-70 Discovery	July 1995	Don Thomas, KC5FVF Nancy Curie, KC5OZX	10	Voice, Packet
STS-74 Atlantis	November 1995	Ken Cameron, KB5AWP Jim Halsell, KC5RNI Bill McArthur, KC5ACR Jerry Ross, N5SCW Chris Hadfield, KC5RNJ, VA3OOG	5	Voice
STS-76 Atlantis	March 1996	Richard Searfoss, KC5CKM, PLT Shannon Lucid, TBD, MS Linda Godwin, N5RAX, MS Ron Sega, KC5ETH, MS	5	Voice
STS-78/LMS Columbia	June-July 1996	Susan Helms, TBD, MS Charles Brady, N4BQW, MS Robert Thirsk, VA3CSA, MS Jean-Jacques Favier, TBD, MS	11	Voice Packet
STS-79 Atlantis	Sept 1996	Jay Apt, N5QWL, MS Jerry Linenger, KC5HBR, MS	3	Voice

SAREX Missions 1994-1996
Table 3

Flight	Date	Ham Crew	# Schools	Modes
STS-83 Columbia	April 1997	James Halsell, KC5RNI Janice Voss, KC5BTK Donald Thomas, KC5FVF	0[1]	Voice
STS-94 Columbia	July 1997	James Halsell, KC5RNI Janice Voss, KC5BTK Donald Thomas, KC5FVF	18	Voice
STS-93 Columbia	July 1999	Eileen Collins, KD4EDS Cady Coleman KC5ZTH Michel Tognini, KD5EJZ	0[2]	Voice

Notes: 1-Mission cut short, reflown as STS-94; 2-experimental

SAREX Missions 1997-1999
Table 4

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