By Juan Rivera

Remotes from 45,000 feet

Sometimes it's not how far out you go, but how far up.

The Bottom Line:– *For video professionals, remotes are a double-edged sword. No matter how well-planned, Murphy's Law must always be considered. At the same time, a well-executed remote goes a long way to strengthen a facility's professional image. Simply put, the ability to do quality remotes increases the opportunities available to see and be seen by your viewers.*

NASA Ames Research Center in Mountain View, CA, is home to the Kuiper Airborne Observatory (KAO). The KAO is a highly modified C-141 4-engine jet and is the world's only airborne infrared astronomical research facility. Cruising at up to 45,000 feet, the KAO flies above 85% of the earth's atmosphere and more than 99% of the earth's water vapor. In this clear, dry environment, extremely weak infrared sources, such as star-forming regions at the center of the galaxy, can be studied in detail. This is done using a 6,000-pound, 36-inch-Cassegrain telescope floating on an air bearing, guided by an elaborate tracking system and looking through a large opening forward of the aircraft's left wing.

The KAO typically flies two to three 7½-hour missions a week. Last October, it served as the center piece in a series of historic live broadcasts designed to stimulate interest in science and technology among school children. (See Figure 1.) While we cruised in the stratosphere doing actual science, students throughout the country watched us on television, asked questions and interacted with the flight crew and astronomers. To make all this possible, a bidirectional data and TV link was built, installed and integrated into the aircraft's systems.

NASA/JPL ACTS satellite

Using existing commercial satellites for this project would have been impossible due to the extremely large antenna required on the aircraft, and since we flew across most of the United States at seven-tenths the speed of sound, a link directly to the ground was not feasible. Fortunately, a NASA geosynchronous satellite called Advanced Communication Technology Satellite (ACTS) was available. Built by the Jet Propulsion Laboratory to explore future commercial applications, it operates in the K/Ka microwave bands at 20GHz and 30GHz. The use of these extremely high frequencies allows extremely small antennas to be constructed, which can easily fit on an aircraft.

***Above photo**: The NASA Kuiper Airborne Observatory with the telescope aperture door open forward of the left wing. The ACTS antenna, not shown in this picture, was mounted above the rear crew door and forward of the tail. (Photo courtesy of NASA Ames Research Center.)*

Each antenna is a waveguide slot array fabricated from five layers of machined aluminum brazed into a single 0.66-inch thick sandwich.

Aircraft antenna

Successfully constructing the aircraft antenna was one of the project's first major challenges. And for that, engineers from the Jet Propulsion Laboratory turned to a company called Electromagnetic Sciences. The antenna system the company constructed is a thing of beauty. The transmit and receive antennas each measure a little more than 4"x8" in size. Each antenna is a waveguide slot array fabricated from five layers of machined aluminum brazed into a single 0.66-inch thick sandwich. Inside the sandwich, power is distributed to eight resonant cavities. From these cavities, RF passes to 54 additional resonant cavities

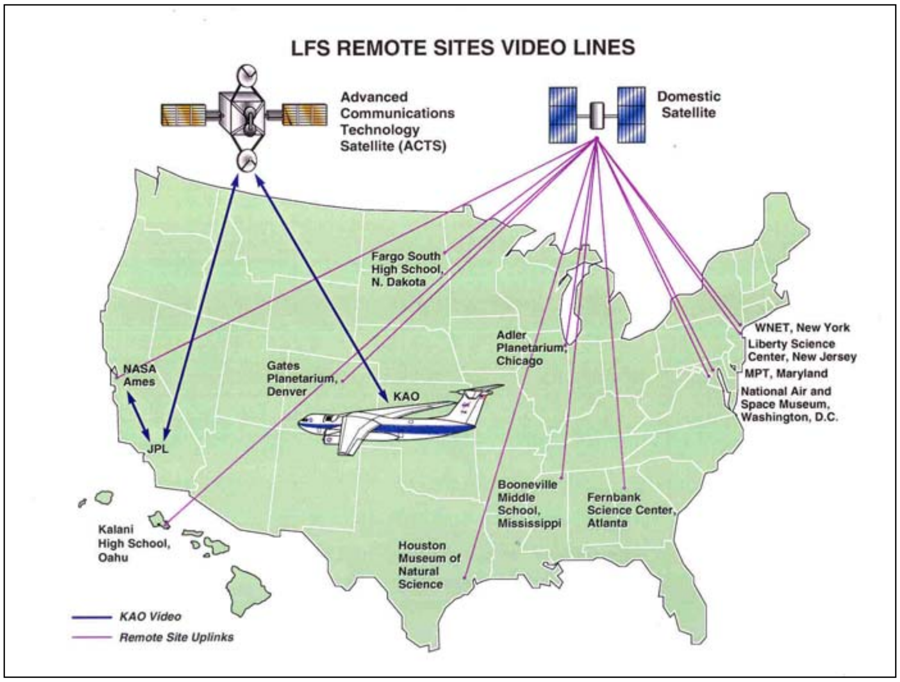

Figure 1. *Hundreds of students at ground sites throughout the country were linked sequentially via C-band satellite to Maryland Public Television for the first broadcast, and to WNET for the second one.*

in the next layer then to 366 shunt slot elements and finally through a polarizer, which converts the linear polarization to right circular — all of this in an antenna that you can hold in one hand. The two antennas were mounted on an az/el positioner and protected by a custom 5-layer radome consisting of alternating layers of special epoxies and foam. The thickness and electrical properties of each layer were carefully controlled to appear transparent at both 20GHz and 30GHz. Even the paint was special, and due to a tight development schedule, the entire array was designed and fabricated without the usual prototyping step. Our antenna was serial number 1A.

ACTS broadband aeronautical terminal

JPL designed and built the aircraft's broadband aeronautical terminal (BAT). The system permits simultaneous bidirectional high-bandwidth video, voice and data communications. (See Figure 2.) As with the antenna, most of this extremely complex equipment is custom one-of-a-kind technology. The BAT components were assembled into a 4-foot high, dual 19-inch rack and mounted in the rear of the aircraft directly below the antenna.

The various analog signals are compressed, digitized and multiplexed with additional digital data by a codec, which was also a critical element in the chain. There were several requirements, which are not normally of concern on the ground. Due to expected higher-than-normal bit error rates, it was essential that the codec degrade gracefully and recover quickly. Some codecs have a tendency to lock up, requiring the power to be cycled. It was also important that the video quality remain high at our intended rates of 128kb/s to 384kb/s. Image motion handling and resolution were also concerns. After a detailed, exhaustive survey and laboratory testing of many commercially available units, a codec from NEC was selected.

A sophisticated modem was designed by JPL to counteract the peculiarities of the K/Ka aeronautical channel. It used BPSK modulation combined with coherent demodulation and robust error-correction coding.

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It has the ability to deal with Doppler shift of up to 30kHz and recover within one second from signal outages. Commquest Technologies Inc. modified a commercial satellite modem to meet these requirements.

Aircraft antenna pointing and tracking

The KAO antenna's azimuth 3dB transmit beam width was only 2.6°. To keep the satellite in the middle of the main lobe, the antenna had to be kept pointed within a tolerance of less than six-tenths of a degree.

The mission director console occupies the middle of the cabin area. Researchers occupy the area toward the front (left of picture), and the ACTS/BAT and audio/video equipment and personnel were stationed aft.

Errors that had to be contended with included gear backlash, positioner lag, vibration, misalignment between the receive and transmit arrays, and radome beam shift. And it all had to work over a temperature range of -60°F to +120°F To do this in an aircraft bouncing down the runway during takeoff is an extremely difficult requirement.

A 3-loop system controlled the antenna pointing and required custom control software. The first loop took its input from a miniature 3-axis inertial rate-sensing package, which is visible at the bottom of the antenna. The output voltages from this loop were proportional to the angular velocity of the aircraft in pitch, roll and yaw. The tracking computer then integrated those rates to generate azimuth and elevation commands to the antenna's positioner.

Navigational data was supplied to the second loop from the aircraft inertial navigation system and a GPS receiver. The tracking computer used these inputs for blind pointing during initial satellite acquisition and long-term drift correction.

And finally, the antenna constantly dithered. The small cyclic changes in signal strength provided the third loop's input. If, for example, the signal was stronger while the dither cycle was to the right, then the center of the dither was too far to the left of the satellite, so a correction was made. The result was an antenna that stayed pointed at the ACTS satellite during two takeoffs and landings and eight hours of flying without a single loss of signal.

The ACTS satellite uses a steerable antenna with a 3dB contour that is only 280 miles wide at ground level, requiring the satellite to track the KAO. This was accomplished by multiplexing KAO geographic coordinates along with the audio and video programming and Internet data. At JPL, the KAO positioning data was demultiplexed and passed to the ACTS ground control site for processing and satellite control.

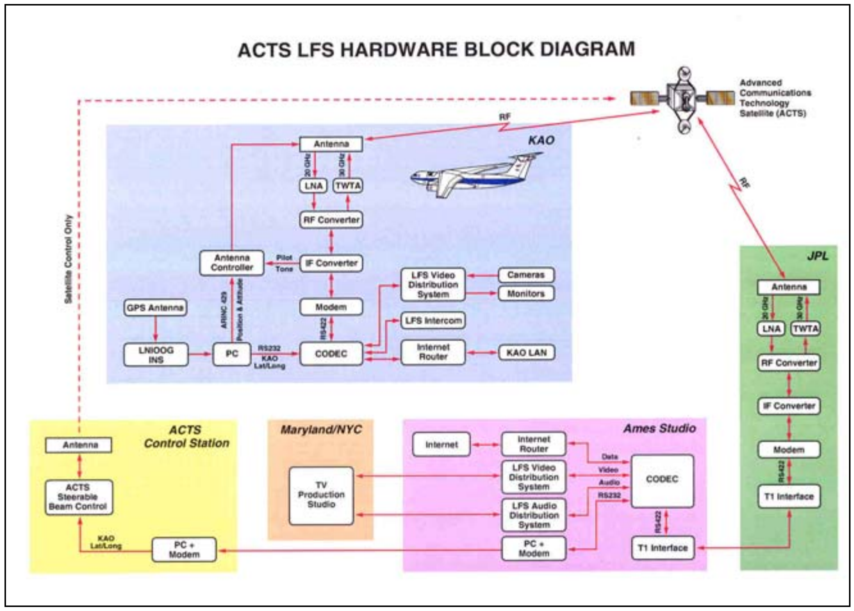

Figure 2. Basic block diagram of the equipment used. Nearly all of this is experimental one-of-a-kind cutting-edge technology.

Signal sources

The video sources consisted of three double image-intensified extreme low-light monochrome cameras boresighted up the axis of the telescope. (These cameras are about 10,000 times as sensitive as a normal broadcast camera.) They're used by the telescope systems for acquisition and tracking.

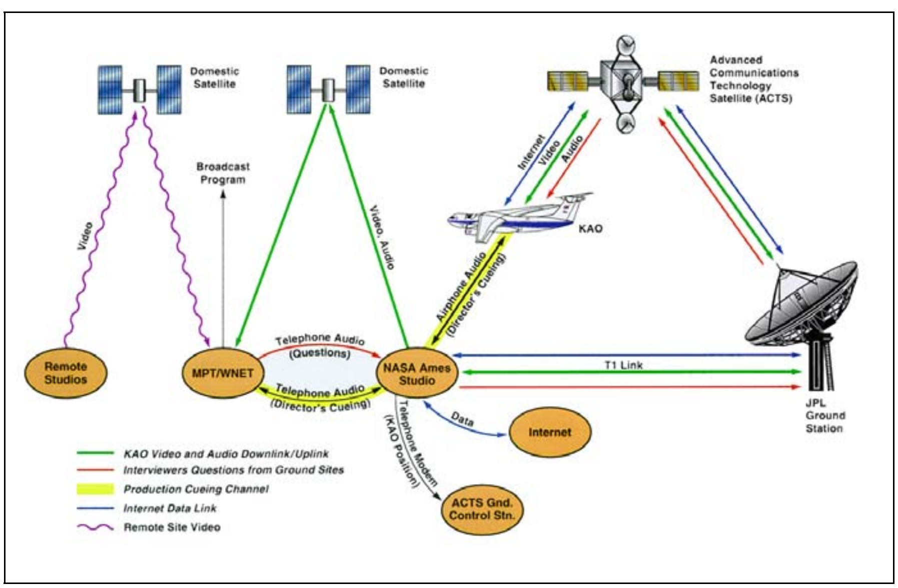

Figure 3. Communications and data links to and from the KAO *required not only the ACTS satellite, hut a flight phone as well. At any given time, at least four satellites were in use: ACTS between the KAO and Ames Research via a T-l line from JPL, C-band from Ames to* MPT/WNET*; at least one and sometimes two more from remote ground sites to* MPT/WNET, *and program distribution via C-band. In addition, NASA Select carried most of both shows on its transponder.*

Next came six color micro cameras that were fixed throughout the cabin and flight deck, and finally, there was one hand-held broadcast-quality mini cam. All sources were gen-locked and H-phased carefully to prevent time base errors from disturbing the codec. A 12-input vertical interval switcher selected the program source.

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Since the noise level during flight precludes unaided conversations (80dB to 100dB), everyone involved in the show was on a noise-canceling headset with a beltpack. We had three channels of audio in our ears: mix-minus from the ground, program audio and a cue channel. To add to the confusion, there was a completely separate aircraft interphone system with its own headsets. So while the program was on the air, we had to constantly change headsets depending on whether we were doing science or involved with the show. And finally, we installed a flight phone with three handset positions. It provided our cue channel, our technical hotline, and general all-around backup link to the ground. It was not uncommon to see

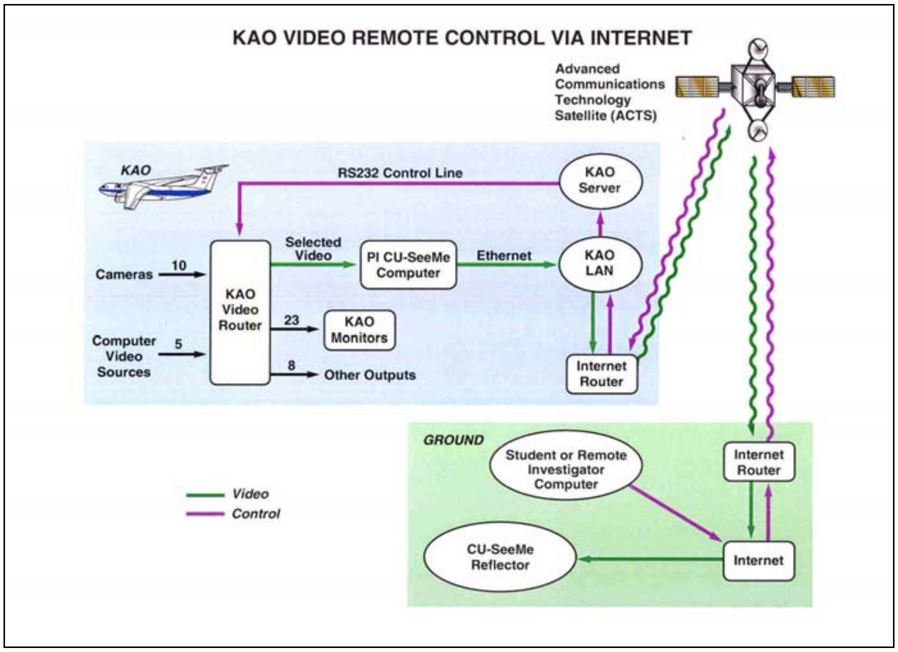

Figure 4. *Another first was the use of Internet connectivity during the flights to allow interactive teleconferencing via CU-Seeme. Students on the ground were able to remote control the KAO's 32x32 video router to select video sources for themselves. This Internet link also provided real-time system health monitoring and remote control of the aircraft's telescope from the ground.*

The left bay contains all the video equipment and the right side contains the ACTS antenna tracking computer and audio equipment.

someone with two headsets clamped around his neck, a finger jammed in one ear and the phone handset in the other, while madly shaking his leg trying to get it free of several tangled intercom cables.

Also onboard were five Sun workstations on an Ethernet that was connected to an onboard Internet router for real-time Internet connectivity.

Putting it all together

The compressed and digitized bitstream included bidirectional video and audio, KAO positional data, system health monitoring data, telescience remote control of instruments and Internet communications. This was passed through the ACTS satellite, which acted as a stovepipe relay between the aircraft and JPL in Pasadena. (The KAO's RF output was 120W at 30GHz.)

Data passed through JPL via a fractional TI line back to our home base at Ames Research Center in the San Francisco Bay Area. From there, it was fed to a remote truck that also originated programming from our hanger. From the truck, it passed via C-band satellite back to Maryland Public Television and WNET on the East Coast. Students' questions from remote sites on the ground were a reverse of this path, resulting in a 6-satellite round trip and some impressive delays. (See Figure 3.)

While the show was on the air, students were able to log on to the Internet and send up E-mail. Some sites were able to access our video router and select the camera they wanted to see using a low-resolution system called CU-Seeme. One group was allowed to actually control the telescope remotely while our onboard astronomers logged into an observatory on the ground and remote controlled it. (See Figure 4.)

The last broadcast was also the last research flight of the KAO. After 21 years of operation, the KAO has been shut down for good as a cost-saving measure. NASA hopes to replace the KAO with a 747 version called SOFIA. Hopefully, it will receive funding shortly after this article goes to print. If SOFIA is funded, it is scheduled to become operational about 2002. Who knows? Perhaps these weren't the last live remotes from the stratosphere. ■

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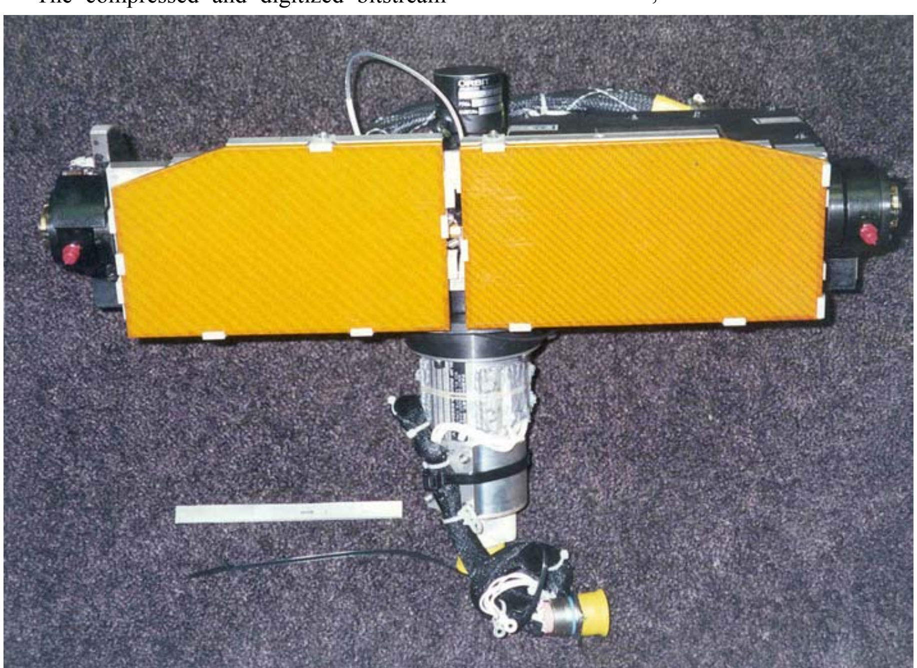

Bidirectional interactive television from a moving aircraft was made possible by this small experimental antenna system. A 6-inch rule is shown in the foreground for scale.