Current instrument status of the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)

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ABSTRACT

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) has been upgraded a number of times since its debut in 1987. This paper describes these improvements and is meant to serve as a reference for scientists working with AVIRIS data.

1. INTRODUCTION

AVIRIS is an airborne imaging spectrometer that utilizes a whiskbroom-type scanner coupled via optical fibers to four dispersive spectrometers.[1] These spectrometers provide complete spectral coverage over the visible and near-infrared wavelength regions from 0.4 to 2.45 micrometers. At any moment during flight, AVIRIS views a patch of the Earth's surface approximately 20 meters in diameter. At the same moment, the spectrometers and their line-array detectors capture the upwelling radiance spectrum of the materials in that patch of surface. This spectrum is digitized at 10-bit resolution and recorded on 1-inch high-density tape at a rate of 17 megabits/second. Each spectrum represents one pixel in an AVIRIS image, and the images are built up pixel by pixel, 614 pixels per scan line, 12 scan lines per second, as the ER-2 aircraft flies along at an altitude of 20 kilometers. Thus, AVIRIS acquires 7,368 spectra per second, a huge data volume by imaging instrument standards. Decommutation of the images from tape, calibration, distribution, and archiving of the imagery are performed at a dedicated data-processing facility at the Jet Propulsion Laboratory (JPL). AVIRIS has been operating since 1987, with continuous enhancements in data quality being made over the years, in the form of improved radiometric calibration and in-flight stability, a higher signal-to-noise ratio, improved scanner performance for geometric image fidelity, and enhanced instrument reliability (see Table 1).

Each flight season, AVIRIS has increased the annual number of square kilometers imaged: 7,400 in 1989, 90,000 in 1990, and 100,000 projected for 1991. AVIRIS has flown extensively over the United States, as well as sites in Canada and Central America, and most recently a wide variety of sites in Europe. AVIRIS data are finding wide utility in the areas of forest/vegetation ecosystem research, mineralogical surveying, oceanographic bioactivity, mountain snowpack analysis, and atmospheric water transport studies.[2] As the instrument's performance continues to improve, researchers in these fields will find additional value within the AVIRIS data, which we hope will lead to improved monitoring and understanding of geophysical and biological processes.

The following sections describe specific AVIRIS subsystems and changes made to them since 1987.

2. FOREOPTICS, FIBER OPTICS, AND IN-FLIGHT REFERENCE SOURCE

The AVIRIS scanner is a modified Kennedy scanner fitted with a custom scan mirror and aft optics. The aft optics image light onto the ends of four 200-micrometer-diameter fibers. From the 1987 to 1990 flight seasons, the optical components were exposed to the ambient atmosphere through the scan mirror aperture, thus allowing condensation to form on the surfaces once AVIRIS had landed after cold, high-altitude flights. Many of the front-surface mirrors had extensive degradation of their silver coatings by the end of four years of field operations. Before the 1991 flight season, all of the foreoptic mirrors were replaced, the scan mirror was resurfaced using replication technology* and a window with a special anti-reflection coating optimized for the short- and long-wavelength portions of the AVIRIS spectral range was placed over the entrance pupil. Also, the foreoptics housing was sealed and desiccant beds were placed inside the housing, as well as in the repressurization pathway for the air entering the housing upon aircraft descent. This ensures a benign environment for the front-surface silver-coated mirrors.

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* From Ventura Optical Industries, Ventura, California.

Table 1. General Performance of AVIRIS

Parameter	Performance
Spectral coverage	0.40 to 2.45 micrometers
Spectral sampling interval	9.6 to 9.9 nanometers
Spectral channel width	9.8 to 12.5 nanometers FWHM
Number of spectral channels	224
Number of pixels per scan line	614
Number of scans per second	12
Instantaneous field-of-view (IFOV)	1.0 milliradians
Radiometric calibration accuracy	6%
In-flight stability	1%
Spectral calibration accuracy	±2 nanometers worst case

After this rework, the alignment and operation of the automatic focusing mechanism were tested and adjusted to the original design specifications. This mechanism keeps the fiber ends at the focal point of the system by responding to foreoptics housing temperature changes. The onboard computer monitors the temperature and alters the position of the mechanism's stepper motor based upon an empirically determined look-up table.

During 1990, the fiber optic harness was redesigned. This redesign accomplished two goals: first, it increased the ease of replacement in case of fiber damage, and second, it improved the utility of the In-Flight Reference Source (IFRS). The first feature resulted from the use of current fiber-optic connector technology. The original approach had used steel capillary tubes in a ball-joint mount[3], which allowed angular adjustment of the light cone coming out of the fiber onto the spherical mirror in the spectrometer, but which was very awkward to install and difficult to align. Angular adjustment of the fiber end was deemed to be an unnecessary requirement that had complicated the original design (measurement of actual fiber angles used ranged from 1° to 5°). The adoption of a modified biconic-type fiber connector** allowed easy removal and adjustment of a fiber in a spectrometer, thereby reducing the number of weeks required between instrument reassembly and completion of pre-season calibration.

The second feature of the redesigned fiber harness was a separate, anhydrous silica glass fiber bundle to channel light from the IFRS up to the foreoptics, as shown in Figure 1. These output fibers are arranged around the four input data fibers connected to the spectrometers. This arrangement allows the IFRS light to shine onto the backside of the shutter (sandblasted aluminum) and provide the spectrometers with a stable radiance source. In the previous implementation, the IFRS light was channeled to the spectrometers via separate fibers, thus bypassing the data fibers. This configuration allowed changes in the data fibers to go unnoticed and precluded any subsequent attempt to apply a correction to the radiometric calibration of the flight data based upon the IFRS signal acquired before each run.

Some care was required to produce IFRS light with spectral properties close enough to terrestrial radiance to provide useful signal levels in all four spectrometers. The 2,900-Kelvin color temperature of the quartz-halogen bulb was modified by a 2-millimeter-thick Schott KG-4 heat-absorbing glass filter. This spectral shaping, combined with the attenuation properties of the 1-meter length of anhydrous silica fiber† in the IFRS bundle, yields a useful (100 to 800 DN) signal over most of the 0.4- to 2.45-micrometer range. A current-controlled power supply for the quartz-halogen bulb was also added, which provides a radiant stability of ±3% for the IFRS output.

** From Fiberguide Industries, Highlight Division, Caldwell, Idaho.
† Anhydroguide G fiber, from Fiberguide Industries, Stirling, New Jersey.

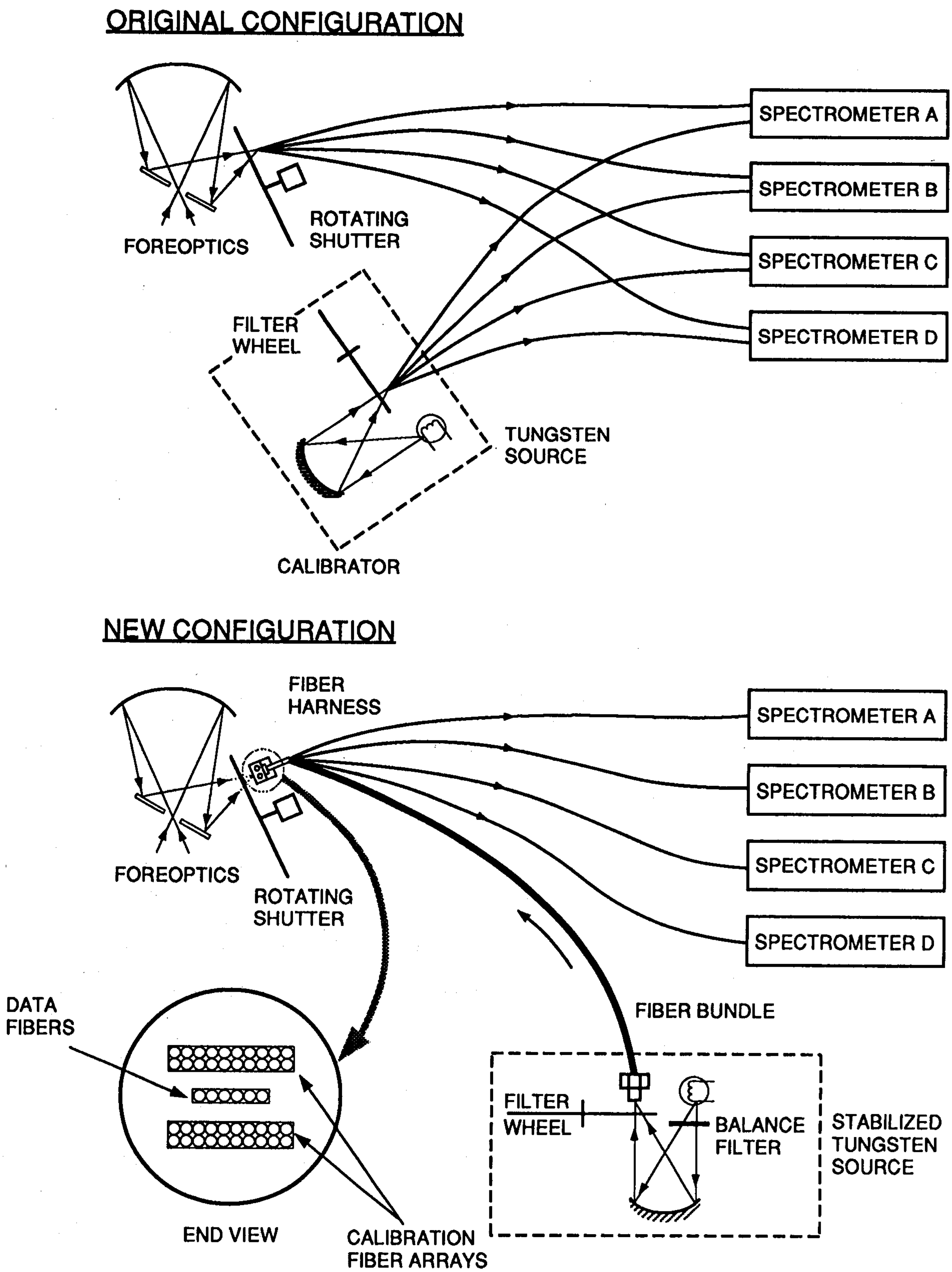

ORIGINAL CONFIGURATION
SPECTROMETER A
SPECTROMETER B
SPECTROMETER C
SPECTROMETER D
FOREOPTICS
ROTATING SHUTTER
FILTER WHEEL
TUNGSTEN SOURCE
CALIBRATOR
NEW CONFIGURATION
FIBER HARNESS
SPECTROMETER A
SPECTROMETER B
SPECTROMETER C
SPECTROMETER D
FOREOPTICS
ROTATING SHUTTER
DATA FIBERS
FIBER BUNDLE
FILTER WHEEL
BALANCE FILTER
STABILIZED TUNGSTEN SOURCE
END VIEW
CALIBRATION FIBER ARRAYS

Figure 1.

3. SPECTROMETERS AND DETECTOR DEWARS

After the 1987 flight season, deficiencies in the stability of AVIRIS's radiometric and spectral response were discovered and steps were taken to rectify them.[4,5] Radiometric and spectral response stability is dependent upon many factors, but chiefly the mechanical stability of the spectrometer optical components relative to the detector arrays. Early in the development of the AVIRIS spectrometers, thermal control was identified as an important issue, since the Q-bay of the ER-2 aircraft can experience temperatures from +40° C immediately after launch down to -5° C during long high-altitude flights. The alignment-critical spectrometers were initially isolated from this frigid environment with a simple heating system and modest thermal blanketing. During 1988, several changes were made to improve the spectrometers' mechanical stability: First, the main support for the detector dewars on the spectrometer bodies was changed from Delrin (which was initially used for electrical isolation of the dewars) to aluminum, which improved the rigidity of that attachment. Second, the mounts fastening the spectrometers to the instrument frame were changed from rigid aluminum mounts to vibration-isolation mounts to prevent warpage of the frame from causing distortions in the spectrometer bodies. Third, a more sophisticated thermal control and blanketing approach was implemented.[6] These changes improved in-flight stability by an order of magnitude, from ±50% to ±5%.

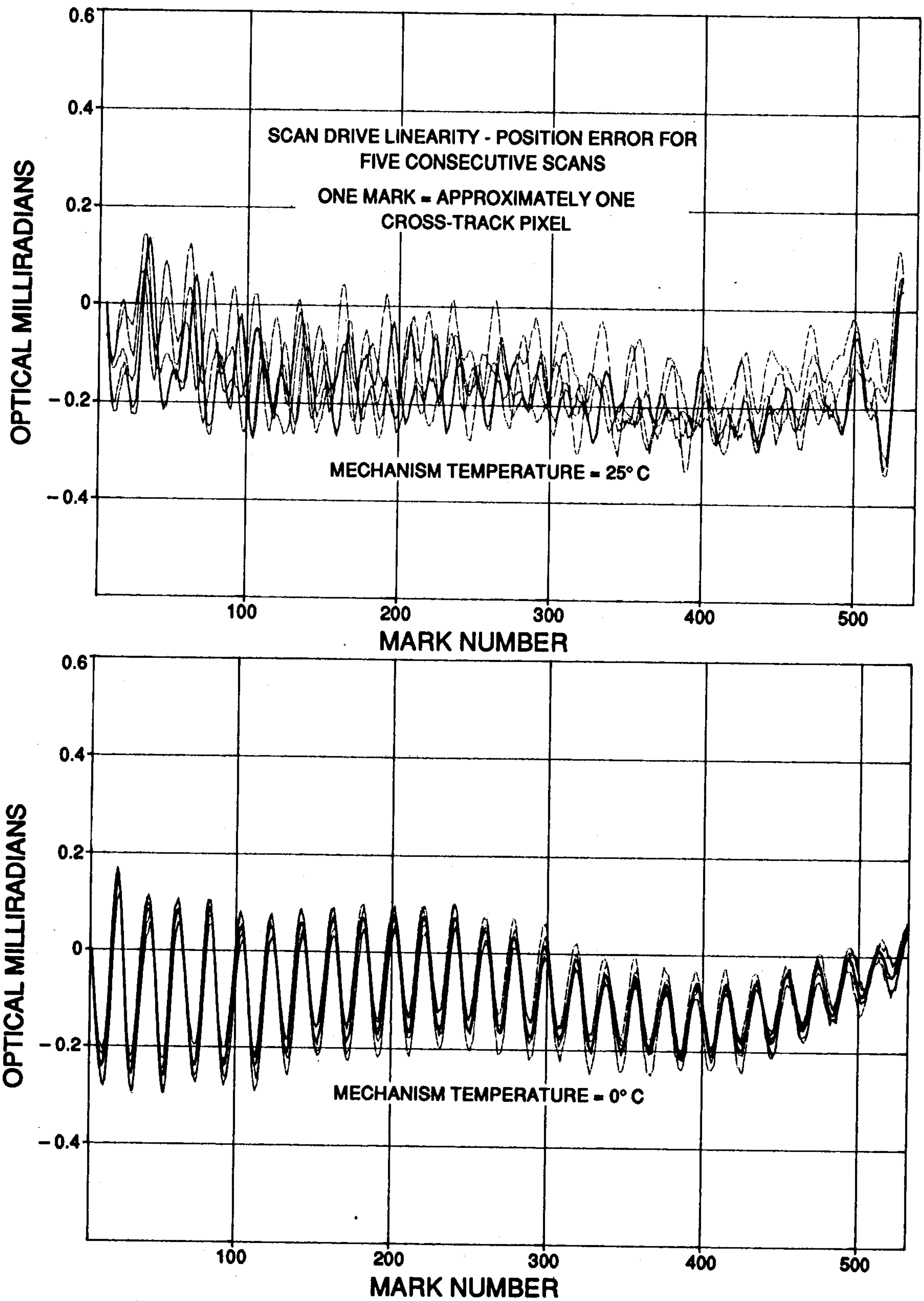
Several failures of AVIRIS in the field can be attributed to water damage from condensation collected on the cold dewar surfaces during liquid nitrogen filling. This condensation dripped down into the spectrometers along a path that included the exposed ends of the hygroscopic zirconium-fluoride optical fibers. Before the 1990 flight season, AVIRIS was outfitted with new dewars that have improved cryogen fill and vent plumbing, and neoprene rubber skirts that encircle the dewars and prevent water or debris from getting into the spectrometers or near the fiber ends. However, humidity may still be able to slowly degrade the fluoride fibers along their lengths, even though they are in sealed sheaths. To prevent such damage from occurring and to improve overall system reliability, AVIRIS is now heated in the Q-bay with warm, desiccated air after flight. This warm air is provided by a special dry-air unit described in detail in Section 9.

4. SCAN DRIVE MECHANISM

During the 1989 and 1990 flight seasons, some imagery data showed evidence of scan drive jitter. Scenes over Los Angeles and over Stapleton Airport in Denver had scan line misregistrations from 1 to 3 pixels in magnitude that were visible in high-contrast features running parallel to the flight direction. Other images did not exhibit this artifact. Earlier, during initial testing in 1986, poor scan drive performance had been observed for some settings of the desmodromic cam clearances. The observation of scan drive jitter in the imagery prompted an effort to refurbish the scan drive, which, by the end of 1989, had exceeded its design lifetime of 600 hours by a factor of five.

The scan drive mechanism was first separated from the foreoptics, then disassembled. Next, the drive's components were closely inspected and new bearings installed. Finally, the drive was reassembled, with a redesigned coupling mechanism. This new coupling consisted of a flexible bellows structure secured to the drive and mirror shafts via cone-shaped locking rings. This design made reassembly and alignment easier and will make decoupling the scan drive from the foreoptics easier in the future. Though the coupling is expected to have adequate holding power, a preventive measure has been implemented to shut down the scan drive should the coupling ever slip. Such slippage could cause the drive mechanism to pound the scan mirror into the housing structure, causing potentially catastrophic damage. Hence, limit switches have been installed at the extremes of scan mirror travel to shut the drive down if contacted, and a software change in the data-processing facility allows monitoring of the scan drive linearity housekeeping data to detect any gradual coupling slippage.

The drive mechanism was tested at various operating temperatures and the overall drive linearity was found to be excellent, equal to or exceeding original performance levels. The pointing error was less than 0.5 milliradian (0.5 pixel) over the +30 to -30° C temperature range. Figure 2 shows a typical mirror pointing error for five consecutive scans at 25° C and 0° C. At room temperature, the residual oscillations in the pointing error profile appeared randomly variable and out of phase, but at lower temperatures, the oscillations grew increasingly consistent from scan to scan. The lower temperature performance may actually be better from an image fidelity standpoint: the change in pointing error from scan to scan for a given cross-track pixel would be less at a low temperature than it would be at room temperature. This would effectively bring the instrument's IFOV closer to the design goal and minimize the type of jitter seen in the Los Angeles and Stapleton Airport imagery. However, pointing misregistrations up to 0.4 pixel over a longer period of scans would still be possible; gyro roll correction can modify the mirror angle at which data acquisition actually begins.


0.6
0.4
0.2
0
-0.2
-0.4
OPTICAL MILLIRADIANS
SCAN DRIVE LINEARITY - POSITION ERROR FOR
FIVE CONSECUTIVE SCANS
ONE MARK = APPROXIMATELY ONE
CROSS-TRACK PIXEL
MECHANISM TEMPERATURE = 25° C
100
200
300
400
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MARK NUMBER
0.6
0.4
0.2
0
-0.2
-0.4
OPTICAL MILLIRADIANS
MECHANISM TEMPERATURE = 0° C
100
200
300
400
500
MARK NUMBER

Figure 2.

Table 2. Required and Achieved Performance of the AVIRIS Scan Drive

Parameter	Required	Achieved
Cumulative mirror pointing error over 1 scan line	0.5 pixel	< 0.45 pixel
Maximum scan-to-scan mirror pointing error for a given pixel:		
at 25° C	Not specified	0.3 pixel
at 10° C	Not specified	0.15 pixel
at 0° C	Not specified	0.08 pixel
Maximum pixel-to-pixel error within 1 scan line	0.1 pixel	0.08 pixel
Uncompensated motion of foreoptics housing due to vibration	0.1 pixel	0.05 pixel

Although the scan linearity appeared excellent (see Table 2), a residual scan-to-scan cross-track misregistration was detected after the scanner was integrated with the instrument. The IFOV of the foreoptics was measured at 1.0 milliradian with the scanner off and at 1.4 milliradians (RMS) with the scanner running. Figure 3 shows the IFOV response measured with the scan drive both on and off. Multiple peaks can be observed in the cross-track IFOV data taken with the scanner running. If the source of this IFOV broadening were the residual scan-to-scan pointing error discussed above, the profile would appear more Gaussian in shape.

Several potential sources of this broadening were investigated and absolved of blame: peak-to-peak vibration of the fore-optics housing was measured and found to be 0.048 milliradians in the cross-track direction (1/20th of a pixel); stability of the optical shaft encoder signals, which generate the start-of-scan signal, was confirmed; and cleanliness of the gyro roll correction signal was confirmed. A remaining candidate source of this image "jitter" is the position of the start-of-scan index pulse within the scan. Currently, the index pulse occurs very near the actual mirror turnaround; hence, any variation from scan to scan in the smoothness of the mirror turnaround can translate into a time variation for the beginning of a scan. This effect has been artificially demonstrated with data from the scan drive environmental testing. Unfortunately, simply moving the index pulse away from the scan turnaround position degrades the cross-track vignetting profile, although the jitter effect might be minimized with a very small adjustment. Greater adjustment may be possible by modifying a timing delay in the gyro roll correction loop.

5. SIGNAL CHAIN

Originally, AVIRIS was flown on a U-2 aircraft, and the weight limit this aircraft imposed on AVIRIS forced the design team to make a number of compromises in packaging the instrument electronics. When the U-2 was retired from the NASA fleet, AVIRIS was transferred to the ER-2 aircraft. The ER-2's heavier payload capability has allowed the sensitive detector timing generation electronics to be physically separated and opto-isolated from other digital electronics. This has resulted in a tremendous reduction in the noise, from between 4 to 6 DN over all four spectrometers in 1988 down to 1.5 to 2 DN in 1989 (see Table 3).

Before the 1990 summer flight season, detector preamp circuits were modified to accommodate new operational amplifiers with lower equivalent input noise and a higher slew rate. During noise-reduction efforts at the time of system integration, it was determined that timing jitter on the clock driver signal lines generated significant amounts of noise at the detector output.

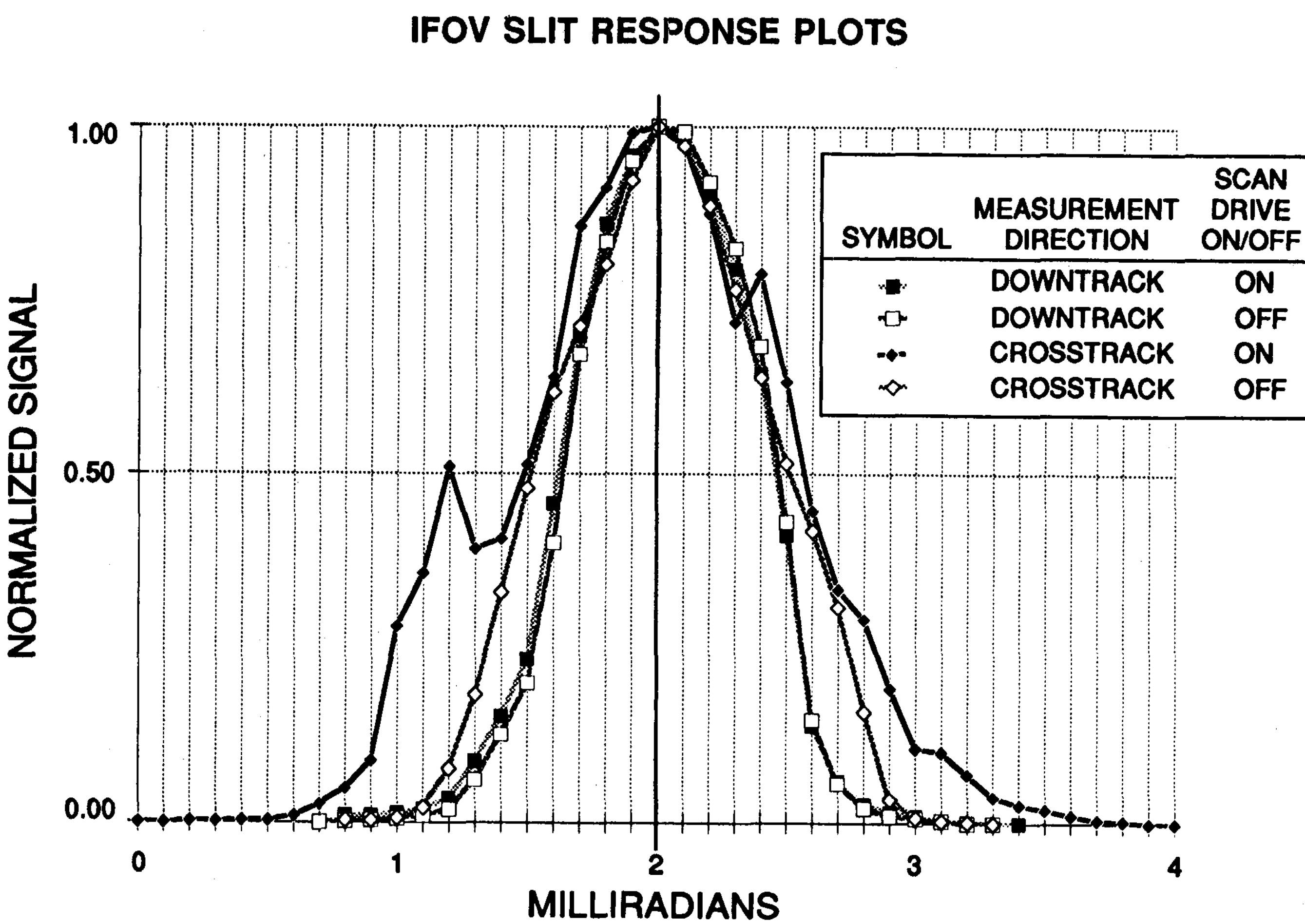

Figure 3.

One factor that aggravated this jitter was the opto-isolator used in the circuit. Device-to-device jitter performance variations were observed and a new opto-isolator type was selected. Also, the high-to-low transition at the opto-isolator output was observed to have markedly less jitter than the low-to-high transition. The high-to-low transition corresponds to the off-to-on transition of the LED, which has less uncertainty associated with its current vs. light output characteristic than the on-to-off transition does. The clock driver circuitry has been modified to use this cleaner signal edge.

Temperature sensor signal lines were also found to couple in noise from the instrument to the detector signals. These sensor lines were disconnected before the 1990 flight season. Self-induced noise was reduced further by improvements in cable shielding and component grounding. All these changes combined brought the overall noise level down to the 1.1- to 1.4-DN range in the lab, but the in-flight noise levels remain slightly higher. Future work will attempt to eliminate the noise coupling pathways that still remain in the system. In-flight noise levels should then approach those levels measured in the lab.

6. DIGITAL ELECTRONICS

At the beginning of the 1990 flight season, a problem developed in AVIRIS immediately after it arrived at the NASA/Ames Research Center in Mountain View, California. During the post-shipping checkout in the laboratory, the ground support equipment (GSE) computer would not display data from the instrument and indicated a "SYNC WORD NOT RECEIVED" error. The GSE processes instrument data major frame by major frame. It looks for the major frame sync word at the begin-

Table 3. Best In-Lab Noise Performance (RMS DN)[§]

Year	A	Spectrometer B	C	D
1987	4	3	7	10
1988	4.3	3.3	5.8	5.5
1989	1.6	1.9	1.9	1.5
1990	1.5	1.1	1.1	1.3
1991	1.35	1.05	1.1	1.2

[§] In-flight noise values are slightly higher.

ning of a major frame, and if that is incorrect, the GSE assumes that the entire major frame of data is bad. The GSE then issues only the error message.

The GSE instrument data simulator indicated that the GSE was operating properly. Troubleshooting then focused upon the embedded 8085-based multibus computer, which generates the sync word. The complexity of the instrument and the field environment mandated the assembly of a field tiger team. While troubleshooting progressed in the field, replacements for the three commercial boards in the computer were quickly procured. Science flights were suspended for a period of two weeks while operation of the instrument was restored and confidence reestablished. This episode clearly illustrated the need to stock field-replaceable parts for AVIRIS to minimize downtime during a busy flight season and maximize the chances to conclude a remote deployment successfully.

7. TAPE RECORDER

AVIRIS uses an Ampex AHBR-1700 high-density digital tape recorder with 5 gigabytes of storage. Up to 40 minutes of imaging data can be recorded onto a 14-by-1-inch reel of Ampex 799 certified tape. A brand-new, freshly degaussed reel is used for every flight. To satisfy tight weight and volume constraints, only half of the recording electronics are flown, leaving only the odd 14 tracks available for recording. For lower inter-track cross-talk and compatibility with the data facility playback unit (an Ampex HBR-3000), 28-track heads are used.

Over the more than three seasons that AVIRIS has been in service, the tape recorder has repeatedly been a source of difficulty in the field. The most critical problem has been the occasional inability of the data facility to read an AVIRIS tape. It has been recognized that the record-to-playback-speed ratio of 10.4 leaves no margin for misalignments between the instrument and the data facility machines. To prevent misalignments, preventive maintenance and alignment are performed on both tape units before the start of a season, then a test tape is run. This procedure has been in effect since the 1989 season and has resulted in good data transfer integrity; typical line dropout rates for the 1991 flight season are less than 1%.

In addition, tape path cleaning and tape threading—both labor-intensive activities—are performed during pre-flight preparation. To prevent tape misthreading, which would cause unreadable tapes, the buddy system is used: one person threads the tape and a different person checks the threading.

Two mechanical weak spots over the tape recorder's service life have been the tape tensioning brakes and the hub. These components have required unscheduled service several times and are expected to require attention again in the future. Improper tape tension compromises the quality of the recording and risks tape breakage in flight. The hub mechanism has been found to be intolerant to overtightening when a tape is being loaded, causing premature wear and greater difficulty in manual operation. A JPL-designed modification to the hub mechanism has made it more robust.

The AHBR-1700 model of tape recorder has been in existence for more than 15 years and is currently built to order only. The cost of stocking critical spare parts and procuring a backup tape recorder has become prohibitive. Experienced technical support has also become less available. Therefore, evaluation of a tape recorder update candidate is under way. The unit being evaluated is lighter, smaller in volume, and lower in cost, and it can record 80 minutes of AVIRIS data on a certified S-VHS cassette. Although not designed for a high-altitude airborne environment, this model is flown in low-altitude military airplanes and helicopters and endures other hostile environments. Acceptable operation will be demonstrated in simulated ER-2 mission environments before this unit is accepted as a replacement for the AHBR-1700.

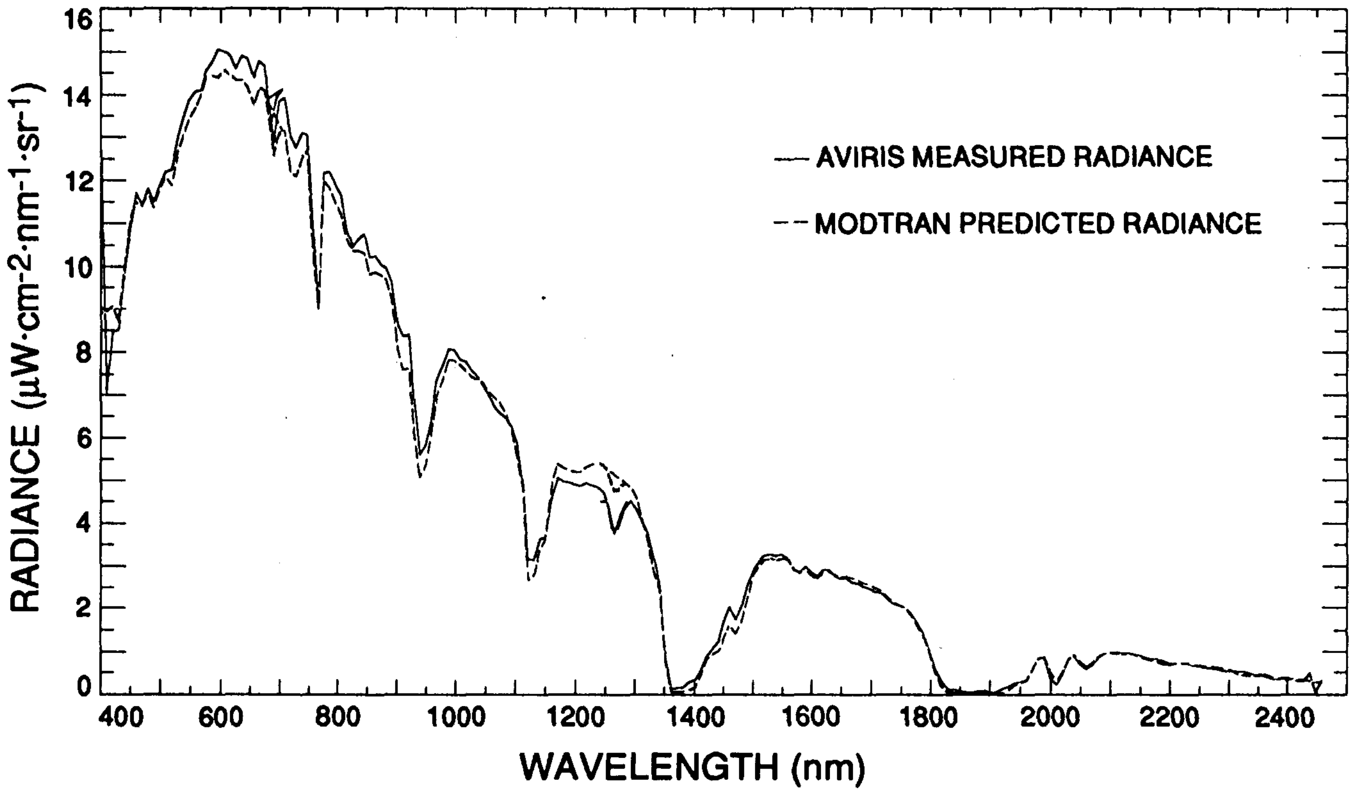

Figure 4.

8. CALIBRATION

Calibration allows quantitative analysis of AVIRIS-measured radiance as well as a comparison of data acquired from different regions and times. In addition, calibration is essential for analysis of AVIRIS data in conjunction with data measured by other surface, airborne, and spaceborne instruments. To provide confirmation of AVIRIS's in-flight characteristics, periodic validation/calibration experiments are performed.[7] During these experiments, measurements of the surface and atmosphere are acquired on the ground concurrently with AVIRIS's overflight. These *in situ* measurements are used to constrain the radiative transfer modeling algorithm and predict the upwelling radiance arriving at AVIRIS. Comparison of this predicted radiance with the AVIRIS reported radiance allows validation of the spectral and radiometric characteristics of AVIRIS in flight.

Figure 4 presents a comparison of the predicted and measured radiance for the AVIRIS in-flight validation/calibration experiment held at the Ivanpah Playa, California, on March 7, 1991. The agreement in spectral position of the atmospheric absorption features confirms AVIRIS's in-flight spectral characteristics. This agreement is assessed quantitatively through a nonlinear least squares routine developed at JPL.[8] The absolute radiometric agreement between these data is better than 6%, excluding the strong atmospheric water bands at 1400 and 1900 nanometers. Figure 5 compares the signal-to-noise determined in flight for this experiment with the signal-to-noise requirement for AVIRIS. This requirement is based on a 50% reflectance surface illuminated at the 21.5° solar zenith angle (summer solstice, noon, 45° north latitude, sea level) through an atmosphere with 23 kilometers' visibility. In virtually all portions of the spectral range, AVIRIS is shown to exceed this requirement. AVIRIS's geometric characteristics are assessed through examination of linear features of high-reflectance contrast contained within the imagery.

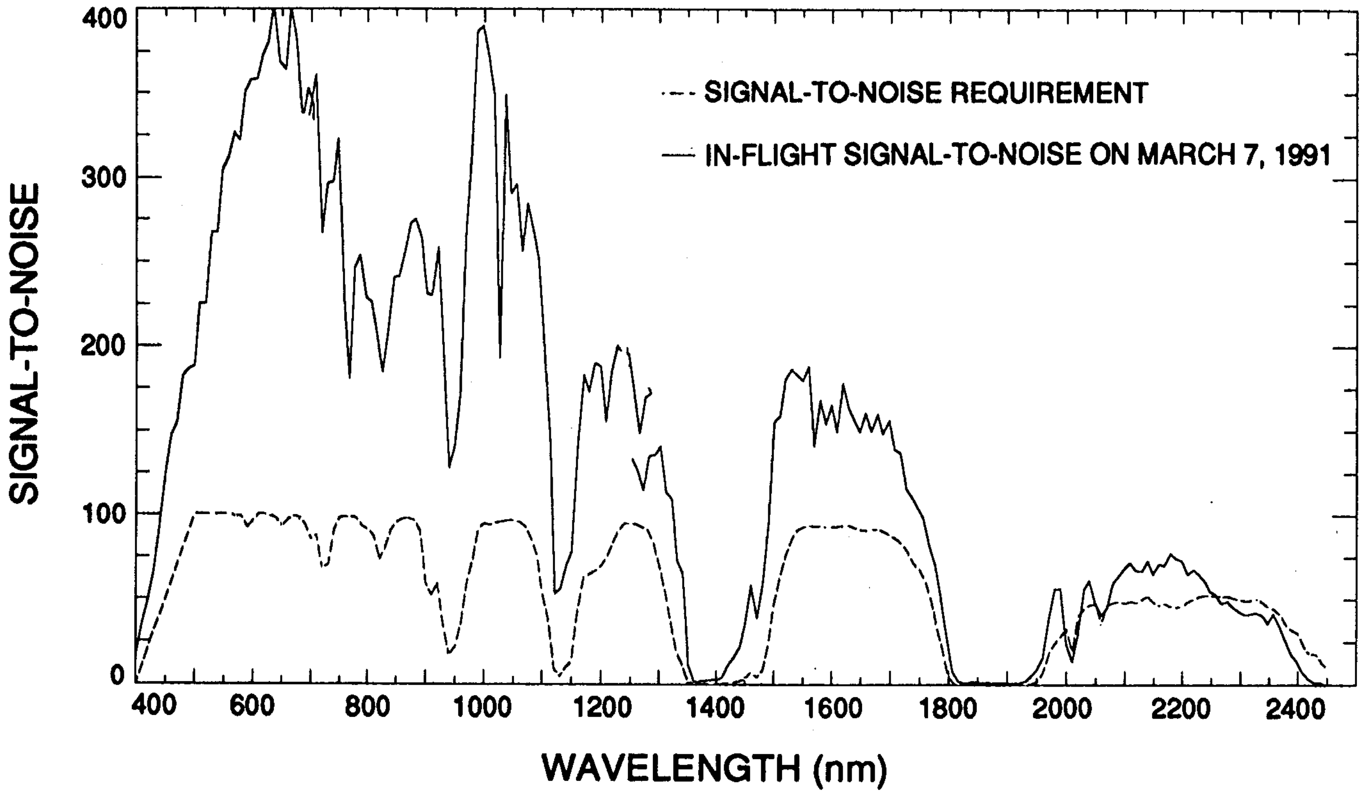

Figure 5.

During the 1990 flight season, the new foreoptics window generated a stray reflectance, which appeared as a 0.5% to 1% bump in the cross-track response near cross-track pixels 250 and 320 (the exact location depended upon the gyro roll correction at the time of data acquisition). This was found to be the result of reflected light off the fiber harness' polished end face traveling back through the foreoptics, reflecting off the window, and returning to the fibers. This minor artifact was removed before the 1991 flight season by applying an anti-reflection coating on the window and tilting the window so that any remaining return reflection missed the fiber ends.

9. GROUND SUPPORT EQUIPMENT

For the 1991 flight season, a second set of ground support equipment was assembled to ease logistical constraints and make more efficient use of the available prime flight season. When AVIRIS is deployed from the NASA/Ames Research Center (its normal base of operations) to a remote operations site, there is no longer instrument downtime while waiting for the GSE to arrive. With the GSE already in place, science flights can resume the day after the ferry flight arrives. This arrangement also makes overseas deployments feasible by eliminating the 6-week (or more) downtime required each way while the GSE is being shipped.

When AVIRIS began operating in the field in 1987, it was shipped on its transport cart inside a heavy two-piece wooden box whose lid was removable only by overhead hoisting (using a forklift or crane). A need to replace this huge shipping box with something easier to use and more suitable for long-term field operations quickly became apparent. Therefore, a lighter, yet more protective box has been built with a two-piece lid and an air-cushioned carrying frame inside. Three people can easily remove the cover. For strength and weatherability, the box has been constructed of fiberglass-covered plywood. The purpose of the carrying frame is to provide a significant improvement in shock and vibration isolation during shipping. In addition, a climate-controlled air-ride van is always used for surface-shipping AVIRIS. The complex nature of the instrument, along with the desire to maintain stable calibration over a flight season, demands this level of care.

For a variety of scientific and logistic reasons, AVIRIS is frequently deployed to operational sites where the weather and humidity are potential causes of instrument performance degradation. This problem became apparent during AVIRIS's first deployment in 1987 to NASA's Goddard Space Flight Center/Wallops Flight Facility in eastern Virginia. In the normally high relative humidity there, the unprotected instrument began to deteriorate rapidly. After AVIRIS had been operated in an ambient environment of around 0° C during flights, heavy condensation was usually observed on the scan mirror.

AVIRIS degraded to the point where it was no longer yielding usable data and it was returned to JPL. Disassembly revealed that widespread damage, of varying severity, had occurred. The zirconium-fluoride IR fibers of the C and D spectrometers were beyond repair and had to be replaced. The lower spherical mirrors in all four spectrometers had condensation deposits, which were cleaned off, but which left behind minor corrosion damage to the coatings. The scan mirror had visible corrosion damage over its entire surface. However, the optical fiber and spectrometer repairs already performed had restored instrument performance to 90% of its previous level. Therefore, repair of the scan mirror was postponed until the time of the major foreoptics/scanner refurbishment discussed in Section 2.

In the winter of 1990, AVIRIS was deployed briefly to Kelly AFB in San Antonio, Texas. There, high humidity caused the loss of the D spectrometer signal once again. Although Kelly AFB normally has a benign environment at that time of year, a weather fluke brought in greater than 85% humidity. This impacted the instrument in less than a day. After this episode, the various safeguards against humidity described in Section 3 were implemented.

This marginal track record and a planned deployment to Wallops later in 1990 made the pressing need for environmental control painfully obvious. Therefore, a dry air unit (DAU)[††] was procured that supplies 50 to 100 cubic feet per minute (cfm) of warm (32° to 38° C), dry (< 20% R.H.) air, and is used to purge the ER-2 equipment bay (the Q-bay) immediately following flights. The DAU is left on long enough to purge humid air out, as well as to warm the instrument to ambient levels. If the ambient humidity is high, the DAU purges the Q-bay between flights. When AVIRIS is out of the airplane, it is enclosed in the top portion of its shipping box, which is purged by the DAU. As an enhancement before the 1991 flight season, removable jack wheels have been installed on the top part of the box, to facilitate the opening and closing of the shipping box when AVIRIS is stored in the hanger. Two Wallops deployments that have occurred since the DAU's procurement have resulted in no instrument degradation attributable to humidity.

During AVIRIS's development and first flight season, the GSE used a desktop 8086/DOS computer for instrument checkout. This served the GSE's purpose, but the realities of pre-flight and the environment in the field, as well as the demands of laboratory calibration, required more timely performance and more thorough checkouts. An upgrade to a ruggedized industrial 286 with an EGA monitor made the GSE more user-friendly and durable.

During a shipping leg in the 1989 season, the laboratory rack containing the GSE computer was damaged, along with both the ground power supplies and the printer shipping box, due to improper securing inside the truck. To prevent such accidents from occurring in the future, the GSE computer, printer, and ground power supplies have been mounted in double-walled, foam-insulated, weatherproof, airline-rated transportable racks. No further equipment damage has resulted from shipping incidents.

When an anomaly occurs during instrument checkout, an instrument data simulator is used to effectively localize the problem between the instrument and the GSE. This has made troubleshooting expeditious in field operations as well as in the lab. Also, to facilitate troubleshooting and repair of the instrument in the field, a spare parts program is under way. Based on past experience and coordination of maintenance and upgrades, an inventory of field-replaceable components is accumulating.

[††] From Later Engineering in Los Angeles, California.

10. CONCLUSIONS

Since 1987, AVIRIS has come a long way in fulfilling its original design goals and exceeding performance expectations. AVIRIS data have become increasingly useful for a widening range of remote sensing applications, and future efforts to improve the instrument will focus upon areas where the research community perceives the greatest need. The AVIRIS team will pursue these improvements as funding allows. Hopefully, AVIRIS will remain on the cutting edge of imaging spectroscopy and will contribute to the development of spaceborne sensors to be deployed in the next century.

11. ACKNOWLEDGMENTS

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