Instrument verification tests on the
Multi-angle Imaging SpectroRadiometer (MISR)

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ABSTRACT

The Multi-angle Imaging SpectroRadiometer (MISR) cameras completed detailed calibration and characterization testing a year ago, as reported in earlier literature. Since that time the cameras have been assembled onto a common flight optical bench, along with photodiode detector standards and diffuse calibration targets. The orderly multiplexing of high-rate data streams from nine camera, twenty-four calibration photodiode channels, and engineering measurements of temperatures and voltages into packets has been verified. Camera fields-of-view clearances have been established, and a verification of camera and photodiode relative response established. These verification tests of the instrument have been followed by shipment of the instrument to the spacecraft integrator facility, where testing continues. Even for the simplest of experiments, the insight learned into the functionality of the instrument has been invaluable. This paper reviews a sampling of these tests and lessons learned, from the simplest verification experiments, to the complex camera boresight determinations.

Keywords: MISR, verification testing, geometric calibration

1. INTRODUCTION

The MISR instrument has been designed and built by the Jet Propulsion Laboratory (JPL), to be launched in 1998 as one of five instruments on the first Earth Observing System platform (EOS-AM1)[1]. Its nine refractive cameras point nadir, forward, and aftward with respect to the spacecraft motion, and view at slant paths of 1.0, 1.1, 1.4, 2., and 3., as expressed by the inverse cosine of the view angles (i.e., O.O°, 26.10, 45.6°, 60.0°, and 70.50). Global data sets will be obtained for each of these views at four discrete spectral bands within the visible and near-infrared.

The MISR cameras have been calibrated and characterized to unprecedented accuracy and detail[2]. As each of the nine cameras is self-contained and provide photon detection through signal digitization, it was reasonable to test them before they were assembled onto the MISR optical bench, and before complex data packetization procedures were introduced, This allowed testing to occur early in the development cycle, and to make use of small, specialized test stations. Detector standards have been utilized, in conjunction with a 1.65 m (65”) integrating sphere, to enable radiometric calibrations to 3% (1σ) absolute accuracy at the upper end of the sensor dynamic range (i.e., at an equivalent reflectance of 1.). Multiple lamp level combinations allowed the radiometric transfer curve to be determined throughout the dynamic range of the sensor. The spectral response has been determined for both the in- and out-of-band spectral regions. Although the integrated out-of-band response is small (worst case of 2.5% for the Band 1/ Blue channels), the measured response data are of sufficient quality to subtract this contribution from the reported radiance product[3]. Further, in measuring the channel response to pinhole images of light, the out-of-field response, modulation transfer efficiency, and point-spread-function response have been determined. These latter data are also available for usage in Level 1 standard product generation (radiance retrieval), to correct for focal-plane scattering that would otherwise contribute a 10% radiometric error over high-contrast scenes. These calibration data are compiled in a data file termed the Ancillary Radiometric Product (ARP)[4] and will be available electronically [o the scientific community.

[n recent months, MISR personnel have completed assembly of the instrument and thermal-vacuum testing. Verification testing included packet integrity checking, camera fields-of-view clearances, and radiance consistency across sensors of a fixed spectral response. Camera-pointing determination was conducted prior to, and following, all major ins[runwn[-level tests. This was done to 1) provide the geocalibration team with needed pointing information, 2) determine pointing stability through vibration testing (and thus verify stability through launch), and 3) verify instrument functionality following the stresses of thermal testing, shipping. and hardware and software reconfigurations. Following these tests, the instrument was delivered, on 27 May 1997, to Lockheed-Martin, at Valley Forge, Pennsylvania. Testing of [he interfaces with the spacecraft continue. The following sections summarize some of the test results, performed to insure complete functionality of the instrument throughout the final assembly steps.

2. INSTRUMENT PERFORMANCE VERIFICATION

2.1 Image construction verification

Deemed a significant qualitative test, MISR acquired an image of a single target, using all nine of its cameras simultaneously, on March 29, 1997. As MISR is a pushbroom imager, the target was required to sweep past the instrument, which was pointed in its build orientation (i.e., cameras viewing towards the ceiling). Positioned at a height of 4.5 m (15 ft) above the instrument, the target was secured to a crane which was capable of traversing the length of the 24 m (80. ft) high-bay. Using a crane speed of 0.3 m/ sec (I ft/ see), the data acquisition was accomplished in all channels. The instrument was operated in its baseline mode ("Global Mode"), and thus there was no data averaging for the nadir camera. The target was that of our instrument engineer, clad with a multi-colored shirt, and holding a color pallet in each hand. The MISR logo appears in the upper region, and various resolution targets can be seen, each providing multiple cascades of a discrete frequency bar pattern. Because the primary target was that of a MISR engineer, the test became known as the MISRMAN test.

Shown in Figure 1 are the images acquired from the second test, conducted on April 16, 1997. Here all four spectral bands are displayed from the MISR nadir camera. An increase in the reflectance of the skin relative to the clothing in the red is apparent. The images have been contrast stretched for this display. The target had little contrast in the near-infrared, and thus the stretch has brought out pixel-to-pixel non-uniformities dramatically. Compensation for these non-uniformities will occur during radiometric processing of MISR imagery. The dark horizontal line through the middle of the images, most apparent in the near-IR, is a cast shadow of one of the cables used to stabilize the frame containing the photograph. A slight vertical displacement of the images in one band relative to another is apparent, and is due to the spatial separation of the line arrays for the four bands in the camera focal plane.

This test served multiple objectives. It provided a visual demonstration of the imaging capability of the system; it verified that data packets could be sorted into files unique to a given camera and band, and reconstructed again in software; and it validated the flight-software command sequences. One error identified as a result of the test was a packetization of the bands in reverse of their correct order. This error was rectified by a straightforward change to the instrument software.

2.2 Camera pointing determination

The Collimator Array Tool (CAT), Figure 2, consists of nine small collimators, each of which projects a target into a MISR camera at the nominal angles. The CAT registers to three tooling points on the MISR optical bench so as to provide precise repeatability and thermal isolation. 'fire nine collimator targets are illuminated using three quartz-tungsten sources and fiber optic cables. The CAT was constructed to operate at room temperature, provided thermal gradients are minimized. Each collimator target is adjusted to be within 20 arcsec of the nominal camera angles. A table of deviation permits further refinement. The target assembly was designed and manufactured at JPL. A small integrating sphere resides within (he dome cap on the target assembly. This configuration is used to provide uniform illumination of the target. The integrating sphere also captures the tip of the fiber optic cable. The bench is made up of three sections of aluminum that were stress relieved and precision bored to receive the collimators after they were bolted and pinned together. The flexure legs are made of titanium to provide thermal isolation and some give during temperature excursions. An optical cube is rigidly attached to one end of the CAT and provides a calibration datum for X,Y, Z coordinates. The instrument is capable of operation within thermal-vacuum conditions, however all data acquisitions have been taken in ambient conditions.

The target which is projected into each camera is shown in Figure 3. Each target consists of 21 illuminated lines. The lines are grouped into sets of five parallel lines in a chevron pattern, with one odd bar to identify left/ right orientation. In addition to the chevron pattern, the target contains three cross-hair fiducials. For the case of perfect alignment, the center fiducial coincides with the camera boresight (no translational offset) and the camera linear arrays are parallel with the horizontal segment of the fiducial cross-hairs (no angular offset) as shown in the figure. The translational and angular offsets are determined by a [wo-step process: (1) the determination of the location of the chevron/ detector array intersections in pixel units; and (2) determine the translational and angular offsets based on these

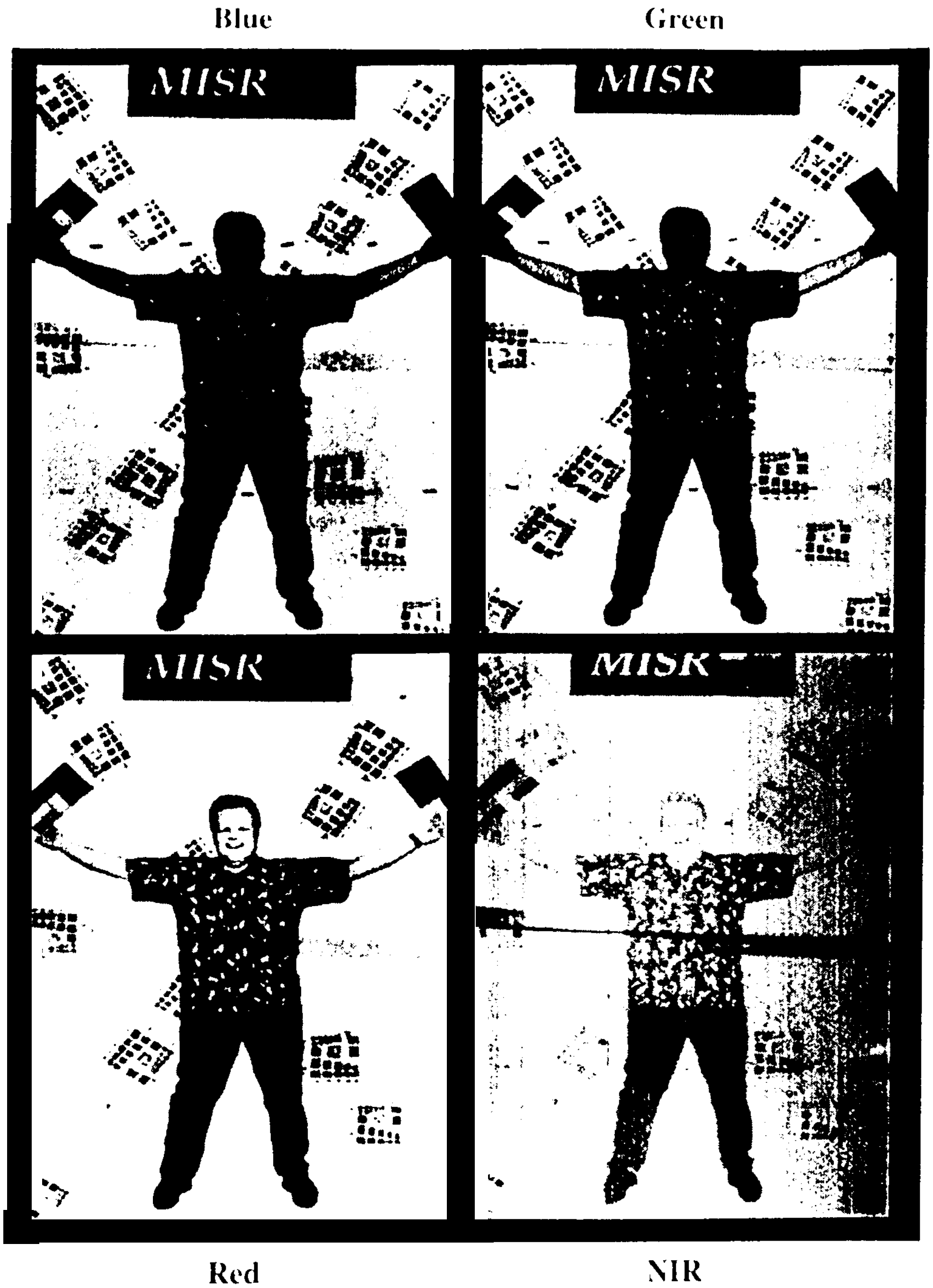

Figure 1. MISRMAN image, as acquired by the An camera on April 16, 1997

intersections. Results of CAT testing have indicated: 1) that the MISR cameras have been built to their design angles, to within their allowed tolerances; 2) that the cameras alignments are such as to provide the required minimal swath overlap of all 36 channels; and 3) that boresight shifts are insignificant following vibrational testing of the instrument. Further, testing provides the MISR geolocation/ registration team with a camera pointing model, to be used in the initiation of a camera geometric model. (This model will be verified and updated in orbit using ground control points.)

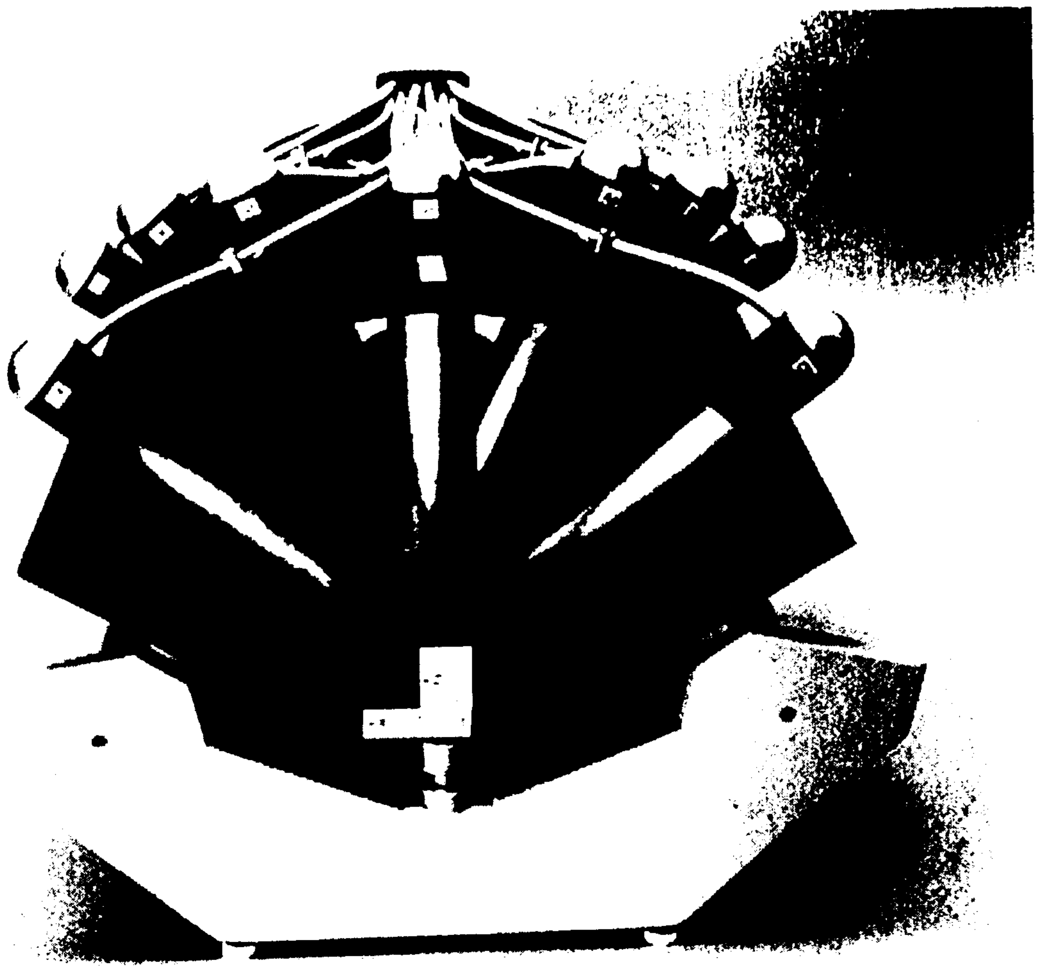

Figure 2. Collimator Alignment Tool (CAT).

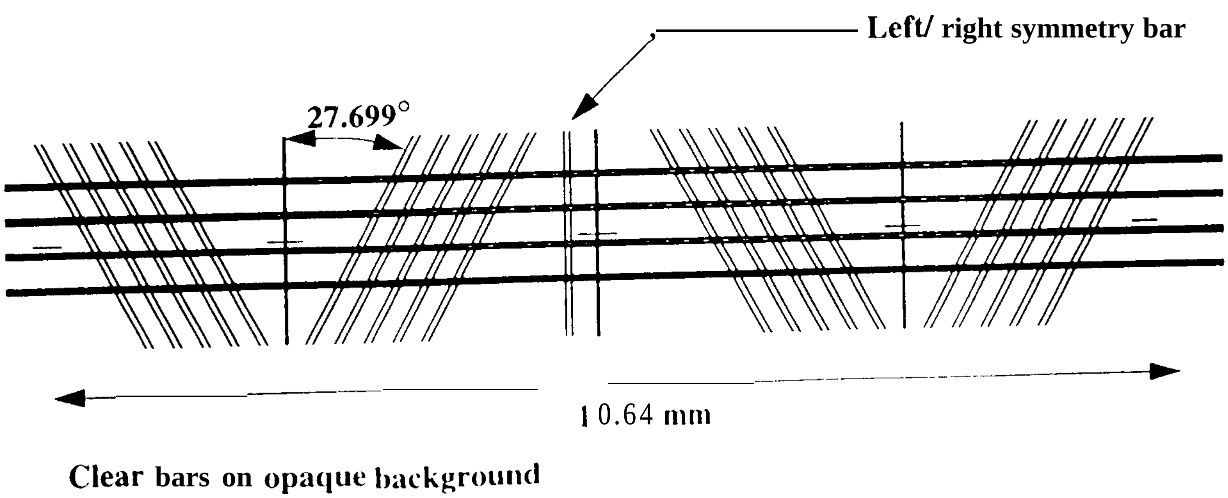

Figure 3 CAT target

2.3 System-level radiometric verification

By illuminating the instrument's deployed calibration targets, and running the on-orbit calibration sequences, the MISR radiometric calibration team have been provided a data set with which to test the processing algorithms. Additionally, a verification of the preflight camera and photodiode response calibrations has been made, by intercomparing the radiances measured by the various sensors.

2.4 Field-of-view clearance verification

For space sensors, it is desirable to prevent optical surfaces from being directly illuminated by sunlight. The optical surfaces brown due to polymerization of the contaminants, if any, and the presence of energetic Lyman Alpha solar radiation. As a first measure of defense, the MISR optical surfaces are kept clean. During the build phase, stringent cleaning procedures, as well as vacuum baking, are imposed at the component, subsystem, and instrument level. The instrument is stored in an enclosure, with positive pressure nitrogen flowing from the optical surfaces, then to the remainder of the system. In addition, MISR makes use of a cover, which is opened on-orbit only after a 30 day outgassing period. Finally, the design of the instrument and operations plan are such as to prevent the cameras from having exposure to sunlight.

Before the addition of sun-blockers to the instrument, it was noted that sunlight was expected to fall onto the front optical elements of the C and D cameras (the instrument has two of each of these designs, to provide for the forward- and aftward-view directions). This was a consequence of the large view angles of these cameras (60.0° and 70.5° respectively), and occurred even considering that there existed baffle apertures, located 8 cm (3") from the front elements. Thus, four of the nine cameras would be illuminated near the terminator, even for the case of nominal spacecraft pointing. An additional concern was that if the spacecraft lost proper orientation, it might take as long as 30 seconds for the MISR cover to close after receipt of a safe command. This translates into an additional angular extent for which solar blocking is desired. It was deter-mined that a reasonable design compromise would be to design against solar illumination of the optical elements during the nominal pointing scenario, where the spacecraft maintains its 150 arcsec stability requirement. The solution was to place sun-blockers on the outer enclosure of the calibration panels. These are designed and positioned so as to stay out-of-the camera fields-of-view, yet provide solar shading for the C and D cameras.

On June 12th of this year, a test was conducted to verify that the four sun blockers did not obscure the fields-of-view of the respective cameras they were designed to protect. This test was difficult to design, in that it required a stable, uniform source of illumination across the camera fields-of-view. (For other tests uniform illumination was obtained by deploying the calibration panels. For this study, however, the panels needed to remain stowed in their science data acquisition configuration). Panels of white foam board were held in place above the instrument. Illumination was provided by four 300 W quartz-halogen work lights. Results did indicate that the sun blockers were obscuring a small portion of the D camera fields-of-view. It was quickly determined that the blockers were installed incorrectly, and the problem has been corrected.

3. ACKNOWLEDGMENTS

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4. REFERENCES

1. Diner, D.J, C.J. Bruegge, J.V. Martonchik, T.P. Ackerman, R. Davies, S.A.W. Gerstl, H.R. Gordon, P.J. Sellers, and J. Clark, J.A. Daniels, E.D. Danielson, V.G. Duval, K.P. Klassen, G.W. Lilienthal, D.I. Nakamoto, R. Pagano, T.H. Reilly (1989). MISR: A Mul[i-angle Imaging SpectroRadiometer for geophysical and climatological research from EOS. IEEE Trans. Geoscience and Remote Sens., Vol. 27. No. 2, March, p. 200-214.

2. Bruegge, Carol J., Nadine L. Chrien, Barbara J. Gaitley, and Robert P. Korechoff, Preflight pert'(mnancc testing 01' the Multi-angle Imaging SpectroRadiometer cameras. In *Satellite Remote Sensing III*, Proc. SPIE 2957, Taormina, Italy, 23-26 September 1996.

3. Chrien, N. L., C.J. Bruegge (1996). Out-of-band spectral correction algorithm for the Multi-angle Imaging SpectroRadiometer. In *Earth Observing System*, Proc. SPIE, Vol. 2.820, Denver, Co, 5-9 August.

4. Woodhouse, Robert M., Carol J. Bruegge, Barbara J. Gaitley, Ghobad Saghri, and Nadine L. Chrien. Multi-angle SpectroRadiometer (MISR) Ancillary Radiometric Product. In Earth Observing System II,SPIE3117, San Diego, CA, 28-29 July 1997.