Mars Exploration Rover (MER) Project

Pancam Calibration Plan

Approved:

Steve Squyres
Athena PI

Joy Crisp
MER Project Scientist

Jim Bell
Pancam Payload Element Lead

John Callas
MER Science Manager

Mark Schwochert
MER Camera PEM

Art Thompson
MER ATLO Systems Lead

Justin Maki
Remote Sensing Technical Lead

October 28, 2001

JPL

Jet Propulsion Laboratory
California Institute of Technology

CHANGE LOG

DATE	SECTIONS CHANGED	REASON FOR CHANGE	REVISION
10/28/01	All	Initial Release	Initial Release

TABLE OF CONTENTS

1. Introduction 5
  1.1. Purpose 6
  1.2. Requirements 6
  1.3. Scope 6
  1.4. Applicable Documents 7
  1.5. Calibration Plan 7
    1.5.1. Objectives 7
    1.5.2. Performance Verification 7
2. Component Level Testing and Calibration 9
  2.1. Standalone CCD Test and Calibration 10
  2.2. Pancam Calibration Target Absolute Reflectance and Bidirectional Reflectance Distribution Function (BRDF) 11
  2.3. Pancam Filter Blocking and Transmission 14
  2.4. Pancam Optics Barrel Transmission 15
  2.5. Pancam Dust Cover Spectral Transmission 16
3. Pancam Standalone Camera Level Testing and Calibration 17
  3.1. Overview and Requirements 17
  3.2. Tests and Procedures 18
  3.3. Detailed Test Descriptions 20
    3.3.1. Light Transfer Curve Test 20
    3.3.2. Absolute and Relative Radiometric Calibration, Non-Solar Filters 22
    3.3.3. Absolute and Relative Radiometric Calibration, Solar Filters 23
    3.3.4. System Spectral Throughput 24
    3.3.5. Grid Target Imaging 25
    3.3.6. Bar Target Imaging 26
    3.3.7. Observations of Calibration, Rock, Magnetic, and Other Targets 27
    3.3.8. Scattered and Stray Light Tests 29
    3.3.9. CCD Temperature Sensor Functional Test 30
    3.3.10. CCD Blooming 31
    3.3.11. CCD Electronic Shutter ("Readout Smear") Effect 32
4. Pancam and PMA System Level (ATLO) Calibration and Testing 33
  4.1. Overview and Requirements 33
  4.2. Tests and Procedures 34
  4.3. Detailed Test Descriptions 35
    4.3.1. Geometric Target Imaging 35
    4.3.2. Physical Characterization of Cameras 37
    4.3.3. Pointing and Co-Alignment with Mini-TES 38
    4.3.4. Fiducial and Focus Marks 40
    4.3.5. Determination of Hard Stop Position and Reference Frame 41
    4.3.6. Target Imaging 42
    4.3.7. Scattered Light on Pancam Cal Target 43
    4.3.8. Coherent Noise 44
    4.3.9. Reflectivity of Rover Surfaces 45
    4.3.10. PMA Actuation Timing 46

5. Pancam Flight Software End-to-End System Testing 47
5.1. Outline 47
5.2. Facilities 47
5.3. Tests and Procedures 47
5.3.1. ICER Compression Performance 47
5.3.2. Auto Exposure Performance 47
5.3.3. Bias Levels and Dark Modeling Subtraction Capabilities 48
5.3.4. Bad Pixel Correction 48
5.3.5. Readout Smear (Electronic Shutter) Correction 48
5.3.6. PMA Pointing and Deployment 48
5.3.7. Subframing 48
5.3.8. Binning 48
5.3.9. Flat Fielding Correction 48
5.3.10. Pixel Summing Capability 48
5.3.11. Command Execution Time 48
5.4. Responsibilities 48
6. In-Flight Pancam Calibration Activities 49
6.1. Darks 49
6.2. Calibration Target Imaging 49
6.3. Sky Flats 49
6.4. Stellar/Satellite Imaging 49
7. Calibration Data Format and Archiving 50
8. Calibration and Test Schedule and Staffing 51

1. Introduction

The Panoramic Camera (Pancam) is one of the Athena Payload instruments on the Mars Exploration Rover (MER) mission. The Pancam system consists of two major components, the Pancam cameras themselves which acquire digital images, and the Pancam Mast Assembly (PMA) which provides the azimuth and elevation actuation of the cameras. Pancam is a multispectral, stereoscopic, panoramic imager, with a field of regard that extends from zenith to nadir and 360° in azimuth, providing a complete view of the scene around the rover. The PMA when deployed, extends approximately 1.5 meters above the Martian surface, acting as a periscope for the Mini-TES, and providing azimuthal positioning for both the Pancam and Mini-TES. Pancam and the PMA represent a complex system that will be pushed hard to deliver cutting-edge scientific measurements from the surface of Mars during a nominal 90-sol mission and beyond for each MER rover.

Pancam utilizes two 1024×2048 Mitel frame transfer CCD detector arrays. Each array is combined with optics and a small filter wheel to become one "eye" of a multispectral, stereoscopic imaging system. The optics for both cameras consist of identical 3-element symmetrical lenses with an effective focal length of 42 mm and a focal ratio of f/20, yielding an IFOV of 0.27 mrad/pixel or a rectangular FOV of 16°× 16° per eye. The two eyes are separated by 30 cm horizontally and have a 1° toe-in to provide adequate parallax for stereo imaging. The optical design is optimized for best focus at 3 meters range, and allows Pancam to maintain acceptable focus from infinity to within 1.5 meters of the rover, with a graceful degradation (defocus) at closer ranges. Each eye also contains a small 8-position filter wheel to allow multispectral sky imaging, direct Sun imaging, and surface mineralogic studies in the 400-1100 nm wavelength region. The expected characteristics of the Pancam filters are shown in Table 1.1. Modeling of expected signal levels based on the predicted Pancam CCD and optics performance and on Mars Pathfinder and telescopic experience indicates that typical bright soils illuminated directly by the Sun under low opacity conditions are predicted to provide a ~50% full well response with integration times of ~500 msec at 670 nm (near the peak of the solar reflectance curve), increasing to ~2 to 3 sec at 990 nm and ~5 to 6 sec at 440 nm (where the CCD QE and solar radiance are both quite low). Low albedo or shadowed regions will typically require integration times of at least 1 sec to produce a response of 20% to 50% full well.

This Pancam Calibration and Test plan is divided into 8 main parts: (1) This introductory and explanatory section describing the purpose and scope of Pancam calibration and its relationship to MER Project Requirements; (2) A review of component-level CCD testing and calibration (component level CCD screening and selection tests are addressed in a separate document: MER 420-1-485, D-20247); (3) A description of stand-alone camera testing and calibration; (4) A description of Pancam and PMA system level (ATLO) tests and calibrations;(5) A description of plans for Pancam flight software testing and verification; (6) A description of planned in-flight Pancam calibration activities; (7) An overview of calibration data format and archiving issues; and (8) A description of the schedule and staffing plans for Pancam calibration and testing.

Table 1.1. MER/Pancam Filter Characteristics	
Left Camera	Right Camera
1. EMPTY ("CLEAR")	1. 430 (SP)
2. 750 (20)	2. 750 (20)
3. 670 (20)	3. 800 (20)
4. 600 (20)	4. 860 (25)
5. 530 (20)	5. 900 (25)
6. 480 (25)	6. 930 (30)
7. 430 (SP)	7. 980 (LP)
8. 440 Solar ND	8. 880 Solar ND
Band centers and (FWHM) in nm *SP = Short Pass filter; LP = Long Pass filter ND = Neutral Density 5 coating for solar imaging	

1.1. Purpose

The intent of this Plan is to define a consistent method to test and calibrate the Pancam instrument and to define or reference the methods and types of tests used to validate the radiometric, geometric, thermal, optical, and mechanical performance against the functional requirements outlined in the MER Project Requirements Documents described below. This Plan will also establish a prioritized test sequence, so that verification of requirements takes place in a systematic and timely fashion and that the preflight (and inflight) calibration results in the delivery of a fully tested instrument that meets or exceeds expectations. The tests described in this plan will provide the data needed to clearly understand the accuracy, precision, and limitations of Pancam calibration.

1.2. Requirements

The primary goal of calibration and testing of Pancam is to verify that the instrument will meet or exceed all of the MER Project requirements relevant to multispectral stereoscopic imaging on Mars. The relevant requirements are compiled in the MER Project System Level 2 Requirements Document (JPL D-19650; MER 420-2-120), MER Flight System Level 3 Requirements Document (JPL D-19692; MER 420-2-401), MER Science Requirements Document (JPL D-19638; MER 420-2-128), and the MER Cameras Functional Requirements Document (JPL D-19702; MER 420-2-409). The relevant requirements extracted from these documents are summarized in Tables 3.1.1 and 4.1.1. Additional relevant documents are listed in Section 1.4.

1.3. Scope

This plan covers all Pancam "Deliverables" as described in the MER Project Implementation Plan (JPL D-19620; MER 420-1-101).

1.4. Applicable Documents

- MER Project Level 1 Requirements Document (MER 420-2-005)
- MER Science Requirements Document (JPL D-19638; MER 420-2-128)
- MER Project System Level 2 Requirements Document (JPL D-19650; MER 420-2-120)
- MER Flight System Level 3 Requirements Document (JPL D-19692; MER 420-2-401)
- MER Camera Functional Requirements Document PD 420-2-409 (JPL D-19702)
- MER Mission Assurance Plan PD 7924-013
- MER Configuration Management Plan PD 7924-012
- Science and Engineering Cameras IICD JPL D-20257, MER 420-3-480.i
- Pancam Filter Wheels (PFW) IICD JPL D-20265, MER 420-3-480.q
- MER Environmental Requirements Document (JPL D-19272)
- MER Planetary Protection Plan (JPL D-19534)
- MER CCD Test Plan (MER 420-1-485, JPL D-20247)
- MER Camera CCD Specification Document (MER 420-7-495, JPL D-20365)
- MER Archive Generation, Validation, & Transfer Plan (MER 420-1-200; JPL D-19658).
- MER Project Implementation Plan (JPL D-19620; MER 420-1-101)

1.5. Calibration Plan

1.5.1. Objectives

- To validate the design and implementation of the Pancam instrument;
- To maintain the Pancam Planetary Protection Control Plan's specified standards of cleanliness in all test phases and activities, including the preparation and maintenance of support facilities and equipment;
- To collect baseline data sets of engineering data in the various instrument states (these data sets shall be used during the I,T&C Program phases at JPL and elsewhere to assure correct instrument operation. These data sets shall also be used for trend analysis to detect any long-term change or degradation in instrument performance
- To monitor and document hours of use and/or cycles of limited life items, such as mechanisms and electronics;
- To implement procedures developed by the Optics and Calibration teams to perform thorough calibration and performance verification.

1.5.2. Performance Verification

This Calibration Plan shall comply with the test requirements outlined in the MER Environmental Verification Matrix. Instrument compliance to this matrix shall be the responsibility of the Integration, Test and Calibration Lead. Measuring and test equipment shall be used in a manner that ensures that the measurement uncertainty is known and is consistent with the required measurement capability.

Accuracy of the required measurements shall be known and appropriate equipment shall be selected to perform the measurements. All measuring and test equipment used for verification of products shall be calibrated using calibration standards traceable to the national standard. The calibration status of measuring equipment shall be identified with calibration stickers. The equipment shall be maintained and its placement and use shall be controlled.

2. Component Level Testing and Calibration

Component level testing and calibration relevant to Pancam includes tests and calibrations of the CCD detectors, the Pancam narrowband and neutral density interference filters, and the Pancam optics assembly barrel. Details of the design and operation of the Pancam CCDs can be found in the Mars Exploration Rover Camera CCD Specification Document (MER 420-7-495, JPL D-20365). An outline of the standalone test and calibration plans is shown in Table 2.1. These tests will be performed at JPL, at JPL vendor facilities, or at other appropriate calibration and test facilities identified by the Pancam Payload Element Lead (PEL).

Table 2.1. Pancam Component Level Calibration and Testing

Test	*Brief Description*
CCD Component Level Testing	
1. Operating voltage windows	See JPL D-20247
2. Photon transfer/linearity	Determine system linearity, read noise, full well, gain, bias, and dark current in both full resolution and summation modes
3. Dark current	See JPL D-20247
4. Flat field	See JPL D-20247
5. Pinholes	See JPL D-20247
6. Image	See JPL D-20247
7. Summation Image	See JPL D-20247
8. Summation photon transfer/linearity	See JPL D-20247
9. Temperature cycling	See JPL D-20247
10. Impedance	See JPL D-20247
11. Spectral quantum efficiency	See JPL D-20247
12. Full well map	See JPL D-20247
13. Charge transfer efficiency	See JPL D-20247
14. Radiation tolerance (qualification test)	See JPL D-20247
15. Life testing (qualification test)	See JPL D-20247
16. Transfer area mask transmission	See JPL D-20247
17. Residual bulk image	Possible additional test; only significant ≤ -70°C
Other Component Level Tests	
18. Cal Target BRDF	Measure cal target BRDF over range of viewing circumstances expected on Mars
19. Pancam Filter Blocking & Transmission	Determine throughput of each filter in the bandpass and each filter's integrated rejection band
20. Optics Barrel Throughput	Determine throughput of each flight and flight spare optics barrel from 400 to 1100 nm
21. Pancam dust cover spectral transmission	Determine throughput of dust cover (or material from same batch), if transparent cover option implemented

2.1. Standalone CCD Test and Calibration

Priority: High

Initial component-level CCD test and calibration plans for all MER camera systems are described in the MER CCD Test Plan document 420-1-485 (JPL D-20247). All of these CCD tests are High priority. Details on the design and operation of the Pancam CCDs can be found in the MER Camera CCD Specification Document (MER 420-7-495; JPL D-20365).

Before the cameras are assembled, the CCDs and optical assemblies must be tested and their performance verified to meet requirements. This testing will be conducted primarily by JPL, as described in JPL D-20247. The CCD component-level test plan has undergone updates and revisions based on feedback from the Athena Instruments Calibration Peer Review Board report (review held on May 22, 2001; board report issued on June 15, 2001). The original CCD Test Plan was revised to include CCD QE testing at additional temperatures in order to characterize possible nonlinear variations at certain wavelengths indicated in initial CCD testing, and additional low-temperature characterization of CCD residual bulk image effects, based on some Cassini CCD experience.

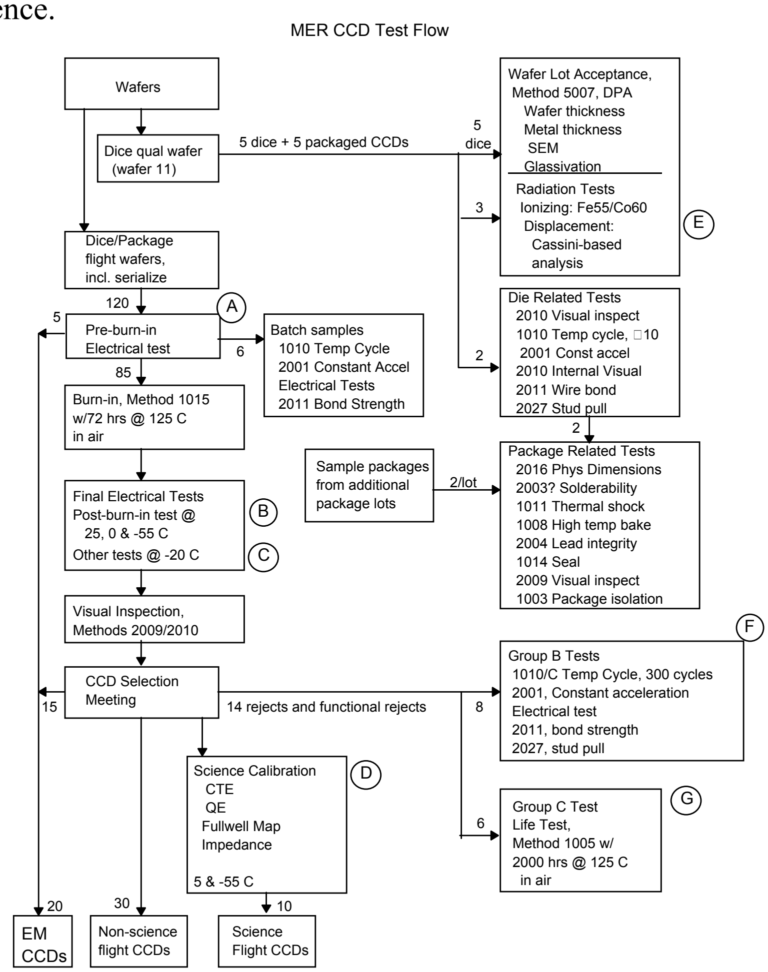
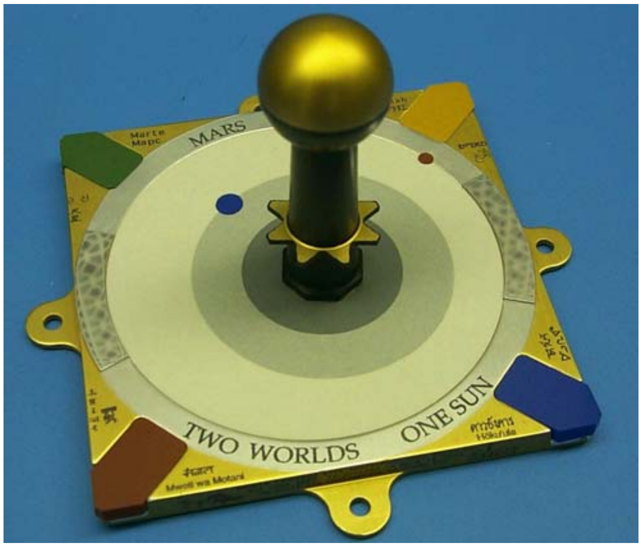


Figure 2.1.1. MER CCD component level test plan. From the MER CCD Test Plan, document MER 420-1-485 (JPL D-20247).

2.2. Pancam Calibration Target Absolute Reflectance and Bidirectional Reflectance Distribution Function (BRDF)

Priority: High

Purpose and Description
To determine the absolute reflectance and photometric properties (and their uncertainties) of the Pancam calibration target's three gray-level surfaces and four color target surfaces (Figure 2.2.1).



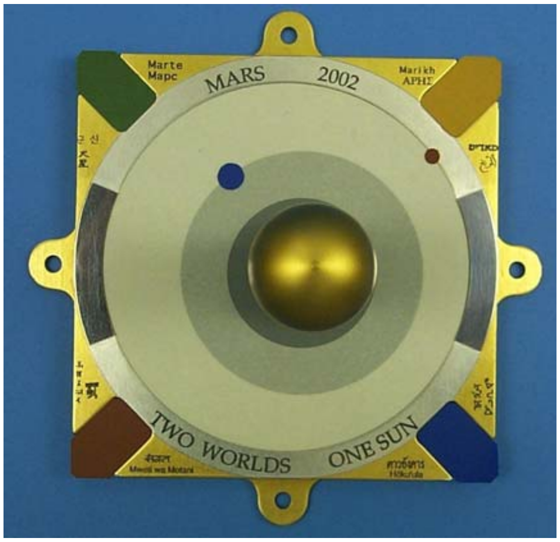


Figure 2.2.1. Pancam Calibration Target, imaged by the APEX/Pancam instrument during Mars Surveyor 2001 Lander APEX/Pancam standalone camera calibration in 1999. Left: Side view. Right: Top view. Target is 8 cm on a side, and the post is 6 cm high.

The BRDF of the black, gray, and white ring and color chip materials will be measured on representative samples of the Pancam calibration target materials, as well as on the Engineering Model calibration target. Measurements of the radiance factor will be obtained at a fixed emission angle and over a range of incidence angles within the principle plane from 0° to 75° in at least 15° steps. The same range of incidence angles will be measured in at least 6 other representative azimuth angles not in the principle plane. Measurements will be made using a standard set of lab filters having a spectral sampling of 20 nm or better over the 400 to 1100 nm wavelength region, as well as with a flight spare set of actual Pancam filters.

Parameters and Range
Fixed emission angles (~25°) for each eye of Pancam
Variable incidence angle (~0° to 75°, at least 15° steps)
Variable incidence azimuth (coarse sampling of range of possible scattering angles)
At least 36 points within upper scattering hemisphere should be sampled; Exact number of images or spectra will vary depending on implementation

Accuracy and Relationship to Requirements
Absolute reflectivities from 400 to 1100 nm to within ±2% accuracy
Determination of BRDF to within ±5% accuracy
These levels required to satisfy absolute and relative calibration requirements

Environment
Ambient

Supporting Instrumentation, Test, and Calibrations
Goniometer with NIST-calibrated light source, capable of out-of-plane measurements.

Data Processing and Products
Spectral catalog of the reflectance (with uncertainty) of each calibration target's reflectance surface and a model of each material's BRDF over the tested range of scattering angles.

Comments
Facilities do not exist at JPL to conduct these tests. Instead, a full suite of goniometric tests on representative samples of cal target reflectance material will be conducted at M. Shepard's lab (Bloomsburg Univ; Figure 2.2.2). As well, measurements of the engineering model cal target will be made over a wide range of viewing geometries using P. Pinet's wide-field (20 cm x 20 cm) goniometer facility at CNRS/Toulouse (Figure 2.2.3).

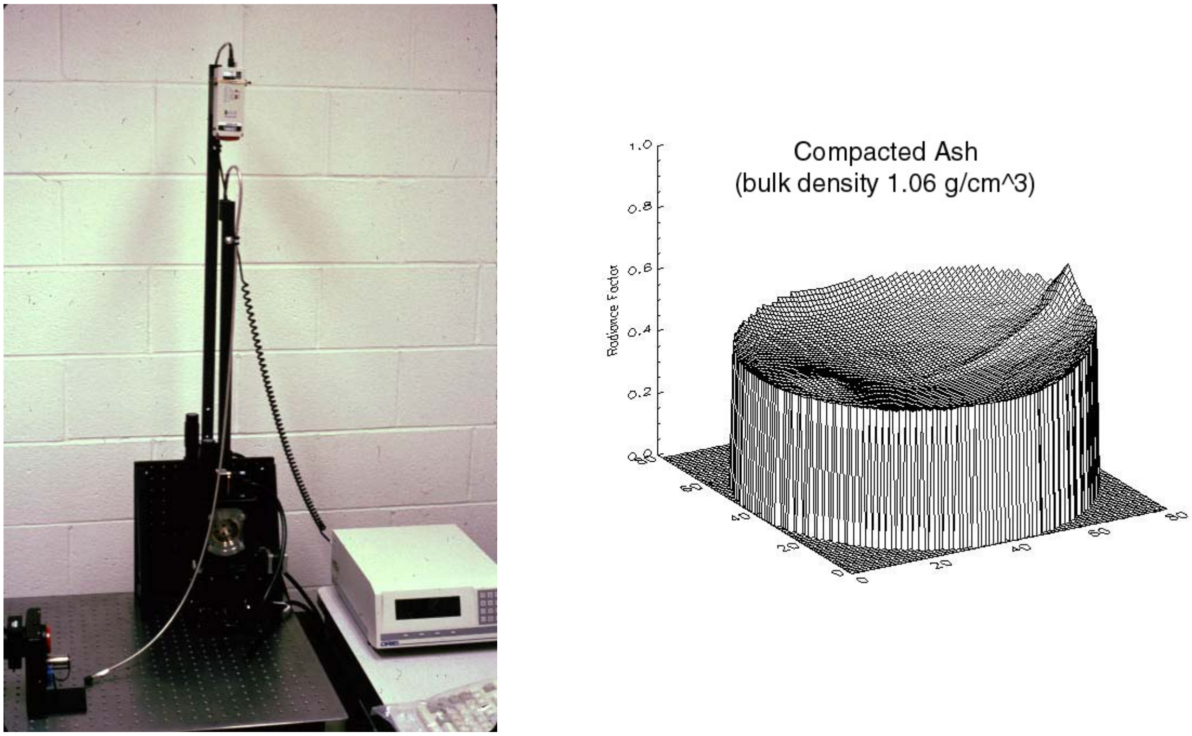


Figure 2.2.2. M. Shepard's Bloomsburg University Goniometer (BUG) Facility.

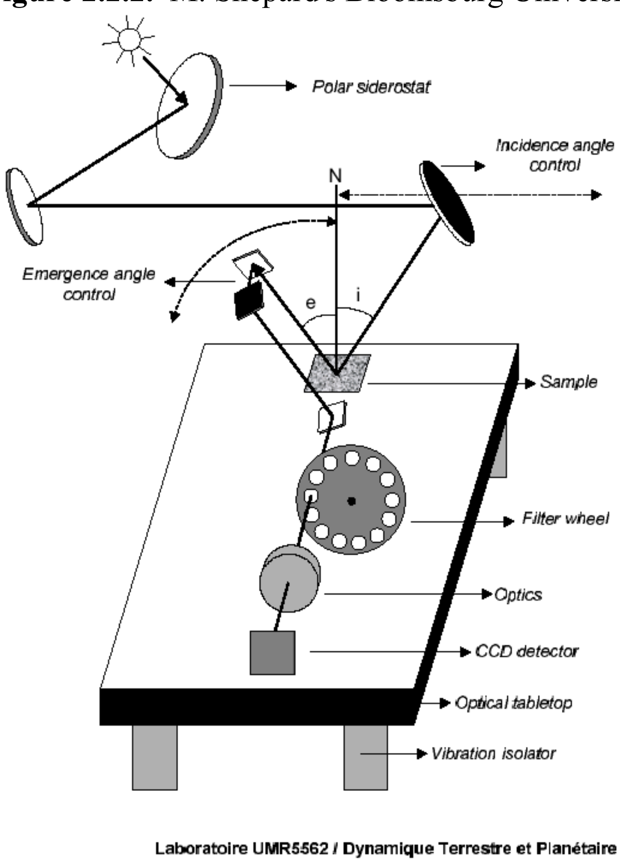


Figure 2.2.3. Schematic of P. Pinet's wide-field goniometer facility at CNRS/Toulouse.

2.3. Pancam Filter Blocking and Transmission

Priority: Low, assuming system-level throughput tests conducted (see 3.3.4)

Purpose and Description
Transmission of each Pancam filter over the entire spectral bandpass (400 to 1100 nm) must be measured before integration of the filters into the optical assembly. These data will be used to determine the absolute and spectral radiometric response of the camera in the event that the monochromator calibration (section 3.4.6) is unsuccessful. The results of this test will also serve as acceptance criteria for the Omega Optical Corp. filters.

Parameters and Range
Spectral transmittance of each filter assembly from 400 to 1100 nm in ≤ 5 nm steps within the nominal bandpass and ≤ 50 nm steps in the rejection band

Accuracy and Relationship to Requirements
Transmission accuracy of ±2% and 1 part in 10^4 blocking to meet Level 3 requirement #1205 (absolute radiometric calibration accuracy). Wavelength steps of ≤ 5 nm will ensure that Pancam spectral bandpasses are adequately sampled.

Environment
Ambient

Supporting Instrumentation, Test, and Calibrations
Calibrated spectrophotometer/monochrometer.

Data Processing and Products
Table of transmittance values at each wavelength.

Comments
Optics spectral transmission and CCD spectral quantum efficiency measurement uncertainties also contribute to overall radiometric calibration uncertainty. CCD spectral QE will not be measured to high level of accuracy.

Vendor data from Omega and data from 1999-2000 APEX/Pancam calibration process can be used to constrain the limits of the bandpass and the rejection band for each flight filter. The results from those data were presented in a report presented on 25 September 2001 by the Pancam PEL titled "Spectral Character of Pancam Filters."

2.4. Pancam Optics Barrel Transmission

Priority: Low. If system-level throughput tests conducted (see 3.3.4), optics barrel transmission measurements will not be needed.

Purpose and Description
Transmission of the Pancam optics barrel must be measured before integration of the optics into the camera. These data will be used to determine the spectral radiometric response of the camera in the event that the monochromator calibration (section 3.3.4.) is unsuccessful. The results of this test will also serve as acceptance criteria for the optical barrel assemblies.

Parameters and Range
Spectral transmittance of each optical barrel assembly from 400 to 1100 nm in ≤ 5 nm steps.

Accuracy and Relationship to Requirements
Transmittance accuracy of ±2% to meet Level 3 requirement #1205 (absolute radiometric calibration accuracy). Wavelength steps of ≤ 5 nm will ensure that Pancam spectral bandpass is adequately sampled. If absolute spectral calibration is not feasible, relative spectral transmittance is acceptable (absolute can be bootstrapped with JPL or vendor spot checks of absolute transmission).

Environment
Ambient

Supporting Instrumentation, Test, and Calibrations
Calibrated spectrophotometer or monochromator and photodiode.

Data Processing and Products
Table of transmittance values at each wavelength.

Comments
Filter spectral transmission and CCD spectral quantum efficiency measurement uncertainties also contribute to overall radiometric calibration uncertainty. CCD spectral QE will not be measured to high level of accuracy. Therefore, system spectral response calibration (section 3.3.4.) has higher priority than this test.

2.5. Pancam Dust Cover Spectral Transmission

Priority: Medium (assuming transparent dust cover design implemented)

Purpose and Description
Determine spectral transmission of flight dust covers or material from same batch using spectrophotometer.

Parameters and Range
Spectral transmittance of each dust cover assembly from 400 to 1100 nm in ≤ 5 nm steps.

Accuracy and Relationship to Requirements
Transmittance accuracy of ±2% to meet Level 3 requirement #1205 (absolute radiometric calibration accuracy). Wavelength steps of ≤ 5 nm will ensure that Pancam spectral bandpass is adequately sampled. If absolute spectral calibration is not feasible, relative spectral transmittance is acceptable (absolute can be bootstrapped with JPL or vendor spot checks of absolute transmission).

Environment
Ambient

Supporting Instrumentation, Test, and Calibrations
Calibrated spectrophotometer or monochromator and photodiode.

Data Processing and Products
Table of transmittance values at each wavelength.

Comments
These measurements will only be required if a transparent dust cover design is implemented for Pancam. They are medium priority as the results would only be relevant if the Pancam dust covers failed to deploy properly after landing; this is envisioned to be a low-probability failure/contingency scenario.

Filter spectral transmission and CCD spectral quantum efficiency measurement uncertainties also contribute to overall radiometric calibration uncertainty. CCD spectral QE will not be measured to high level of accuracy.

3. Pancam Standalone Camera Level Testing and Calibration

3.1. Overview and Requirements

Each Pancam camera consists of a 1024 × 2048 Mitel frame transfer CCD detector array. The array is combined with a 3-element optics barrel assembly, sapphire window, and an 8-position filter wheel to obtain high angular resolution multispectral images on Mars. The required operating temperature range for performance of the Pancam within specifications is -55°C to 5°C, and for survival is from -105°C to +50°C. Signal-to-noise ratio (SNR) is required to be ≥ 200 for nominal observing conditions (≥ 50% full well within operating temperature range). Dark current is expected to be significant at the high end of the operating temperature range, and therefore must be well characterized and calibrated, including any spatial nonuniformity. The spectral QE of the CCD is also expected to vary with temperature. Hence, temperature-dependent calibrations and tests will be performed in a thermal/vacuum chamber at temperatures spanning the required operating temperature range.

Standalone camera testing involves mounting each camera within a thermal vacuum chamber such that it has a clear view of sources that can be imaged through the chamber window. These sources include integrating spheres, monochrometers, and various geometric and geologic targets that are illuminated by calibrated external light sources. To save time, both Pancam cameras as well as the Microscopic Imager camera for each rover will all be mounted simultaneously inside the vacuum chamber, and will all be able to observe the same sources.

Full sets of calibration data will be acquired with the Pancams temperature-stabilized at the extremes of the operating temperature range (-50°C and +5°C). In addition, the Athena Instruments Calibration Peer Review Board report (June 15, 2001) strongly recommends that calibration data be obtained at at least one, if not more, additional intermediate temperatures between these extremes. The Pancam PEL strongly endorses this recommendation, and endorses the additional Calibration Peer Review Board recommendation that the highest-priority intermediate temperature should be the nominal average mid-day temperature expected during the MER mission, approximately –10°C. The Calibration Peer Review Board and PEL recommendations may ultimately be supported by component-level CCD QE and other tests results (see JPL D-20247) already planned at intermediate temperatures. Even if these recommendations are implemented, additional calibration data should also be acquired during dynamic vacuum chamber temperature transitions whenever possible.

These tests will provide the critical data that is required to verify that the MER mission requirements relevant to the Pancam CCDs have been met (Table 3.1.1) and to calibrate raw images via the Pancam downlink processing pipeline. Specifically, flatfield and radiometric calibrations are required in order to be able to obtain images that are free of detector and/or optical artifacts and that accurately depict the colorimetric and photometric properties of the Martian surface.

Table 3.1.1: MER Mission Requirements relevant to Pancam Component Level and Standalone Camera Calibration and Testing

Level	ID #	Requirement
2	922	The Project System shall ensure that the quality of the calibration of the science instruments be sufficient to satisfy the requirements and objectives in the Science Requirements Document and the Level 1 science requirements.
2	924	It shall be possible to produce radiometrically calibrated images from the Pancam and Mini-TES observations on Mars, using measurements of calibration targets on Mars.
3	1199	The Pancam Instantaneous Field of View (IFOV) shall be 0.28 ± 0.02 mrad/pixel on-axis.
3	1200	The Pancam shall be capable of imaging over the spectral range of 400 - 1100 nm.
3	1202	The Pancam shall have an effective depth of field of 1.5 meters to infinity.
3	1203	The Pancam shall have an MTF of ≥ 0.30 @ 30 lp/mm over spectral bandpass, (polychromatic)
3	1204	The Pancam optical design shall minimize the contributions of stray and scattered light onto the CCD.
3	1205	The radiometric calibration of the Pancam shall be performed with an absolute accuracy of ≤7%.
3	1206	The radiometric calibration of the Pancam shall be performed with a relative (pixel-to-pixel) accuracy of ≤1%.
3	1207	The Pancam Signal to Noise Ratio (SNR) shall be ≥ 200 for exposures of 50% full well over all spectral bandpasses and within the operating temperature range.
3	1208	Each Pancam shall have a temperature sensor, accurate to ± 2°C, on the CCD package that can be read-out and associated with the image data in telemetry.
3	1209	The Pancam shall be able to have the sun in its field of view (powered and unpowered) and not sustain permanent damage.
4	--	Pancam working f/# = f/20±1
4	--	Pancam operating temperature within calibrated specifications = -55±2°C to +5±2°C.

3.2. Tests and Procedures

Table 3.2.1 provides a prioritized overview of the Pancam stand-alone camera calibration and testing requirements. Each of these tests will be performed at JPL and is described in more detail in the subsections below.

Measurements of the full suite of rock target observations have medium priority because they do not directly affect Pancam calibration accuracy. However, based on the Athena Calibration Peer Review Board recommendations, performing these measurements on at least a representative subset of samples of the rock targets is a high priority.

The temperature sensor functional test has medium priority because it is not possible to accurately calibrate the CCD temperature sensor once it has been integrated into the camera.

Scattered and stray light can substantially affect calibration accuracy, but it will be difficult to apply laboratory test results to inflight observations of scattered/stray light from complex sources. Therefore, the scattered/stray light test has medium priority.

The CCD blooming and readout smear tests have low priority because the goal of the tests is to simply characterize the blooming behavior and “shutter effect” in support of flight software (autoexposure and shutter correction algorithm) development. These tests could be performed on the EM Pancam if the calibration schedule does not allow them to be performed on the flight units.

The other tests have high priority because they address significant sources of calibration uncertainty that must be properly evaluated to achieve the requirements listed above.

Table 3.2.1. Summary of Pancam Standalone Camera Calibration and Testing

Test	***Priority***	***Environmental Conditions***	***Brief Description***
1. Light Transfer Curve	High	T = -55°C, -10°C, and +5°C; $P \leq 10^{-6}$ torr	Determine system linearity, read noise, full well, gain, bias, and dark current
2. Absolute and relative radiometry, non-solar filters	High	T = -55°C, -10°C, and +5°C; $P \leq 10^{-6}$ torr	Determine conversion between DN and radiance for each filter; determine flatfield image for each filter; measure system NESR at each wavelength
3. Absolute and relative radiometry, solar filters	High	T = -55°C, -10°C, and +5°C; $P \leq 10^{-6}$ torr	Determine conversion between DN and radiance for each solar filter; determine flatfield image for each solar filter
4. System Spectral Throughput	High	T = -55°C, -10°C, and +5°C; $P \leq 10^{-6}$ torr	Determine relative throughput of system over each filter's bandpass
5. Grid Target Imaging	High	Ambient	Determine effective focal length, field of view, and geometric distortion in all non-solar Pancam filters
6. Bar Target Imaging	High	Ambient	Measure MTF and PSF by observing a target with dots and horizontal, vertical, and diagonal bars of varying thickness
7. Observations of calibration, rock, and magnetic targets	High / Medium	T = -10°C; $P \leq 10^{-6}$ torr	Validate calibration by obtaining measurements of known reflectance sources, including Pancam cal target
8. Scattered and Stray Light Test	Medium	Ambient	Estimate magnitude of light scattered into the FOV by bright sources outside the FOV
9. CCD Temperature Sensor Functional Test	Medium	T = -55°C and +5°C; $P \leq 10^{-6}$ torr	Verify accuracy of flight CCD temperature sensors under known environmental conditions
10. CCD Blooming	Low	Ambient	Determine number of images required to flush CCD charge from saturated images
11. CCD Image Readout Smear	Low	Ambient	Determine minimum exposure time where zero-exposure shutter image is required for calibration

3.3. Detailed Test Descriptions

3.3.1. Light Transfer Curve Test

Priority: High

Purpose and Description
Measure the system light transfer curve for each camera by illuminating the CCD with a series of broadband flat fields ranging from zero to above the average full-well (approx. 220,000 electrons); obtain at least 3 frames at each level, at at least 3 wavelengths per camera. These measurements will yield the linearity of the camera system response to an incident photon stimulus, the system gain and bias (offset), the system read noise, dark current and its spatial uniformity, and the average full-well value for 5 regions of the CCD (4 corners plus center of frame).

Parameters and Range
Obtain exposures at 11 well depths (0, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 0.9, 0.95, 1.0, and 1.1 times full well). Determine system linearity, gain, bias (offset), read noise, dark current, and average number of electrons in full-well for each region. Assess dark current nonuniformity using full-frame images.

Accuracy and Relationship to Requirements
Pixel response for each exposure to ±1%, to derive system linearity to ±1%, from 0.1 to 0.9 times full well. Measure read noise to ±2 electrons, system gain to ±2% (electrons/DN), bias to ± 5%, dark noise to ±0.1 electron RMS, full well to ±5%. These accuracies and the recommended number of images to be acquired are consistent with Level 3 requirement #1205 (absolute radiometric accuracy).

Environmental Conditions
Temperature = -55°C, -10°C, and +5°C required; Additional light transfer testing during chamber temperature transitions desired as possible. Pressure ≤ 10^{-6} torr.

Supporting Instrumentation, Tests, and Calibrations
1% uniform integrating sphere; red radiometer. Window transmission vs. wavelength; calibrate red radiometer and verify sphere uniformity to 1% level.

Data Processing and Products
6 wavelengths × 11 well depth levels × 3 frames per level × 2 to accommodate zero-exposure images = 396 images required per temperature. For linearity, analyze the response of 50 × 50 pixel regions, perform linear least squares fit to average signal between 0.1 and 0.9 times full well; determine nonlinear residuals and goodness of fit. Read noise is constant offset (at zero exposure) in plot of pixel signal variance vs. signal level. To find full well depth, track exposures into saturation on central (higher transmission) portion of CCD. Gain is inverse of slope from linear least squares fit of pixel signal variance vs. signal level. The bias is the mean of zero exposure dark frames. Dark current and dark noise are the mean and RMS deviation of bias-subtracted frames, respectively. Products include digital archive of photon transfer curve

(plot of noise vs. signal) and linearity graph (plot of average DN vs. exposure time) for five areas on the CCD frame, showing any departures from linearity; line trace showing full well of each pixel, column trace showing full well of each pixel in given region; images of fixed and random system noise; bad pixel map; assessment of any spectral variability of these parameters. Digital archive of each image.

Comments

These results will be critically compared to light transfer results derived during component level CCD testing, to verify stability of performance.

The three wavelengths at a minimum should be the 430SP, 600, and 750 filters in the left camera and the 430SP, 750, and 980LP filters in the right camera.

The GSE is expected to have a macro/script for performing light transfer measurements. Therefore it should be straightforward to make additional light transfer measurements during vacuum chamber temperature transitions.

3.3.2. Absolute and Relative Radiometric Calibration, Non-Solar Filters

Priority: High

Purpose and Description
To derive flatfield images as well as the coefficients to allow a conversion from reduced (bias, dark, and flatfield corrected) DN to absolute radiometric response (*e.g.,* $W/cm^2/nm$) for each of the 14 non-solar Pancam spectral filters in Table 1.1 above (including CLEAR), and to provide an estimate of the uncertainty in these coefficients and their temperature dependence.

Parameters and Range
Present absolutely-calibrated, uniform (± 1%) light source (large integrating sphere) to camera and acquire images over light transfer test range of source intensities. Obtain 3 identical images per light level, and 50 identical images only at the 50% full well level.

Accuracy and Relationship to Requirements
±7% absolute, ±1% relative to meet Level 3 requirements #1205 and #1206 (absolute and relative calibration accuracy).

Environmental Conditions
Temperature = -55°C, -10°C, and +5°C; Pressure ≤ 10^{-6} torr.

Supporting Instrumentation, Tests, and Calibrations
Sphere TBD. Vacuum chamber window transmission vs. wavelength; need to calibrate red radiometer and verify sphere uniformity to 1% level.

Data Processing and Products
[(14 wavelengths × 10 well depth levels × 3 frames per level) + (14 wavelengths × 1 well depth level × 50 frames per level)] × 2 to accommodate zero-exposure images = 2240 images required per temperature × 3 temperatures = 6720 images total. Dark and noise subtract. Relate DN to source absolute radiance. Derive absolute conversion between DN and radiance; derive flat field images; derive noise-equivalent spectral radiance (NESR).

Comments
PEL estimates that this will require setup time plus approximately 10 minutes per filter to obtain the required images at each temperature (total = roughly 3 hours per temperature).

PEL will be advocating conducting these measurements at additional intermediate transition temperatures for a selected subset of the Pancam filters, based on the strongly-worded recommendations of the Athena Instruments Calibration Peer Review Board report. The details will depend on the results of the MER CCD Test Plan.

3.3.3. Absolute and Relative Radiometric Calibration, Solar Filters

Priority: High

Purpose and Description
To derive flatfield images as well as the coefficients to allow a conversion from reduced (bias, dark, and flatfield corrected) DN to absolute radiometric response (*e.g.,* $W/cm^2/nm$) for the two Pancam solar ND filters in Table 1.1 above, and to provide an estimate of the uncertainty in these coefficients and their temperature dependence.

Expose 880ND and 440ND filters to a 250 W calibrated lamp. Image lamp filament in center and corners of CCD with a signal level at least 50% full well. Attempt to generate flatfield images with signal level ≥ 25% full well using a forward-scattering (or other) diffuser between the lamp and the camera.

Parameters and Range
Present absolutely-calibrated (± 2%) and intense light source to camera and acquire images near half full well.

Accuracy and Relationship to Requirements
Goal is ± 7% absolute, ± 1% relative to meet Level 3 requirements #1205 and #1206 (absolute and relative calibration accuracy).

Environmental Conditions
Temperature = -55°C, -10°C, and +5°C; Pressure ≤ 10^{-6} torr.

Supporting Instrumentation, Tests, and Calibrations
250W calibrated light source TBD. Vacuum chamber window transmission vs. wavelength; diffuser to attempt flatfielding. Lamp mounting hardware. Baffles to minimize stray/scattered light from elsewhere in lab.

Data Processing and Products
224 images required per temperature (50 images of centered, calibrated lamp filament per solar filter, 3 additional filament images in each corner of the CCD per solar filter, 50 additional images per filter of the diffused lamp image, to build up flatfield image statistics).
Dark and noise subtract. Relate DN to source absolute radiance.
Derive absolute conversion between DN and radiance; derive flat field images.

Comments
50% full well levels should be easily achievable for 880ND filter based on spreadsheet prediction; will be much more difficult for 440ND filter (need to coadd images?). The imaged filament of the irradiance-calibrated source may have substantial intensity variations across it, producing errors in the analysis of the result.

3.3.4. System Spectral Throughput

Priority: High

Purpose and Description
Planned CCD spectral quantum efficiency measurements may not provide sufficient data to allow the spectral response (effective wavelength and passband) of each Pancam filter to be accurately determined. Therefore, this test has higher priority than the component-level spectral transmission tests.

Present absolutely-calibrated monochromatic (≤ 1 nm passband) flux bundle to Pancam, with wavelengths traversing each filter's passband (1% points) in ≤ 5 nm increments. Increments can be coarser across each filter's rejection band. Obtain 3 images at each wavelength, at approximately 20 wavelength steps per filter.

Parameters and Range
Monochromator wavelength stepped by ≤ 5 nm within each filter's bandpass, and stepped by ≤ 50 nm in each filter's rejection band. Measure integral camera response at each wavelength.

Accuracy and Relationship to Requirements
Monochrometer wavelength accuracy, ± 0.2 nm. Flux accuracy, ±7%. Test will verify compliance with Level 2 requirement #922 (calibration quality) and Pancam Level 4 requirements on the spectral bandpass of each filter.

Environmental Conditions
Temperature = -55°C, -10°C, and +5°C; pressure ≤ 10^{-6} torr.

Supporting Instrumentation, Tests, and Calibrations
Computer-controlled monochromator; stable light source; reference photodiode; TBD alignment tools. Monochromator calibration; photodiode calibration; lamp stability test; chamber window throughput calibration.

Data Processing and Products
Approximately (14 × 20 × 3) = 840 total images required per temperature. Dark subtract. Sum all photoelectrons from monochrometer filament/slit image on chip, compare with photodiode output. Digital archive of each image. Plots of system spectral throughput profile.

Comments
Interception of monochromator flux by camera must be independent of wavelength. This test has higher priority than the component-level spectral transmission tests. Measurements at –10°C are required only for a subset of the filters, to be based on the results of the MER CCD Test Plan.

Vendor data from Omega and data from 1999-2000 APEX/Pancam calibration process can be used to constrain the limits of the bandpass and the rejection band for each flight filter. The results from those data were presented in a report presented on 25 September 2001 by the Pancam PEL titled "Spectral Character of Pancam Filters."

3.3.5. Grid Target Imaging

Priority: High

Purpose and Description
Image a well-characterized grid target at best focus. Characterize the geometric distortion introduced by the Pancam into its images. Measure the effective focal length and field of view by measuring dimensions of target image. Multiple images needed to reduce errors in image location precision. Image to 50% full well through all non-solar filters. Obtain 3 images per filter.

Parameters and Range
Effective focal length, field of view, and geometric distortion. The distortion may exhibit a wavelength dependence, so an attempt to measure the effect over all wavelengths is required. Intersections are to be spaced 50 pixels apart both horizontally and vertically and are to cover the entire field of view. Images are to be obtained through all non-solar filters, with 2 different target rotational orientations and 2 different target translational locations.

Accuracy and Relationship to Requirements
Accuracy of effective focal length to ±2%, field of view accurate to ± 0.2°, geometric distortion accurate to ± 0.3%. Such accuracies are consistent with verification of Level 3 requirement #1199 (IFOV).

Environmental Conditions
Ambient

Supporting Instrumentation, Tests, and Calibrations
Well-characterized grid target, light source, TBD alignment tools. The target grid pattern should be characterized to a precision of ≤ 0.2 mm (0.27 mrad/pixel × 0.2 pixel × 3 m).

Data Processing and Products
(14 wavelengths × 3 images per wavelength × 2 images to accommodate zero exposure image) × 2 rotational positions × 2 translational positions = 336 images required. Measure locations of intersections of a grid target in images to ±0.2 pixel using centroiding algorithm; compare image locations with their locations in object space. Produce file of geometric distortion vs. field position and wavelength, value of effective focal length on axis, value of field of view. Document residual errors between the image-space and object-space grid intersection locations after a best-fit matching of the 2 data sets by adjustments in scale, translation, rotation, skew, and/or aspect ratio. Table of maximum and RMS values of the residuals for each grid target image. Digital archive files for use in geometric distortion correction software. Digital image showing (for all intersections) the magnitude and directions of distortions.

Comments
Several targets that could meet the requirements may already be available (APEX/Pancam geometric target; CAHVOR target).

3.3.6. Bar Target Imaging

Priority: High

Purpose and Description
Determine depth of field (defocus blur) and camera modulation transfer function (MTF) by imaging bar target and knife edge or point source at various distances from camera, including best focus.

Observe TBD bar target (chart containing horizontal, vertical, and diagonal lines and bars of varying thicknesses as well as circular dots of various sub- and super-pixel sizes) at 5 positions on CCD at best focus (3.0 m) through each non-solar filter at 0.5 full well signal level. Obtain 3 images per position per non-solar filter. Repeat at predicted focus position of Pancam cal target (~0.8 m) and at largest possible distance within test lab (~9 m if lab in Bldg. 168).

Parameters and Range
Observe bar target and knife edge or point source at 3 distances from camera: 80 cm (approx. Pancam cal target distance), 3 m (best focus), and ≥ 9m (as far away as possible within calibration facility).

Accuracy and Relationship to Requirements
Distance from camera measured to accuracy of ±5 mm; MTF measured to ±10% at 30 lp/mm and Nyquist frequency. Level 3 requirement #1203 (optics MTF) will be verified by testing the optics at the component level.

Environmental Conditions
Ambient

Supporting Instrumentation, Tests, and Calibrations
Knife edge, point source, bar target, light source, TBD alignment tools. Dimensions of point source and bar targets known to accuracy of TBD.

Data Processing and Products
(14 wavelengths × 5 positions per wavelength × 3 images per wavelength) × 3 distances = 630 images required. Archive each image; compute MTF and point spread function vs. position within field of view and depth of field.

Comments
System knowledge; can be performed during camera assembly and focus if desired; TBD number of spatial frequencies.

3.3.7. Observations of Calibration, Rock, Magnetic, and Other Targets

Priority: Subset: High; Full Suite: Medium

Purpose and Description
Take images of rock standards targets designed by Athena Co-I R.V. Morris (Figure 3.3.7.1), the Pancam cal target (Figure 2.2.1), the Athena Pancam and RAT magnets, and rover deck solar panel materials in good focus to provide data for software testing and calibration pipeline verification.

Image targets through all non-solar filters at best focus and 50% full well signal level. 3 images per wavelength.

Parameters and Range
3 images through each filter of well-illuminated targets. Illumination level should be adjusted to mimic Mars solar radiances, so that integration times are similar to those expected during flight.

Accuracy and Relationship to Requirements
Flux accuracy, ±7%. Test will verify compliance with Level 2 requirement #922 (calibration quality) as well as recommendations of Athena Calibration Peer Review Board.

Environmental Conditions
Temperature = -10°C; Pressure $\leq 10^{-6}$ torr.

Supporting Instrumentation, Tests, and Calibrations
Rock target, calibration target, magnets, calibrated light source, TBD alignment tools, measurements of distance between camera and target.

Data Processing and Products
(14 wavelengths $\times$ 3 images per wavelength $\times$ 2 images to accommodate zero-exposure images) = 84 images required per target. Run images through PANCAL calibration pipeline for verification of calibration.

Comments
Pancam cal targets are in bonded storage at JPL; Rock target will be brought to JPL by Athena Co-I R.V. Morris (JSC). Magnets to be provided by Athena Co-I M. Madsen (Denmark). Other targets (rover surface materials) acquired by TBD.

The priority of this entire test is Medium; however, based on strongly-supported feedback from the Athena Instrument Calibration Peer Review Board report, the priority of just measuring the rock chip target provided by R.V. Morris is High.

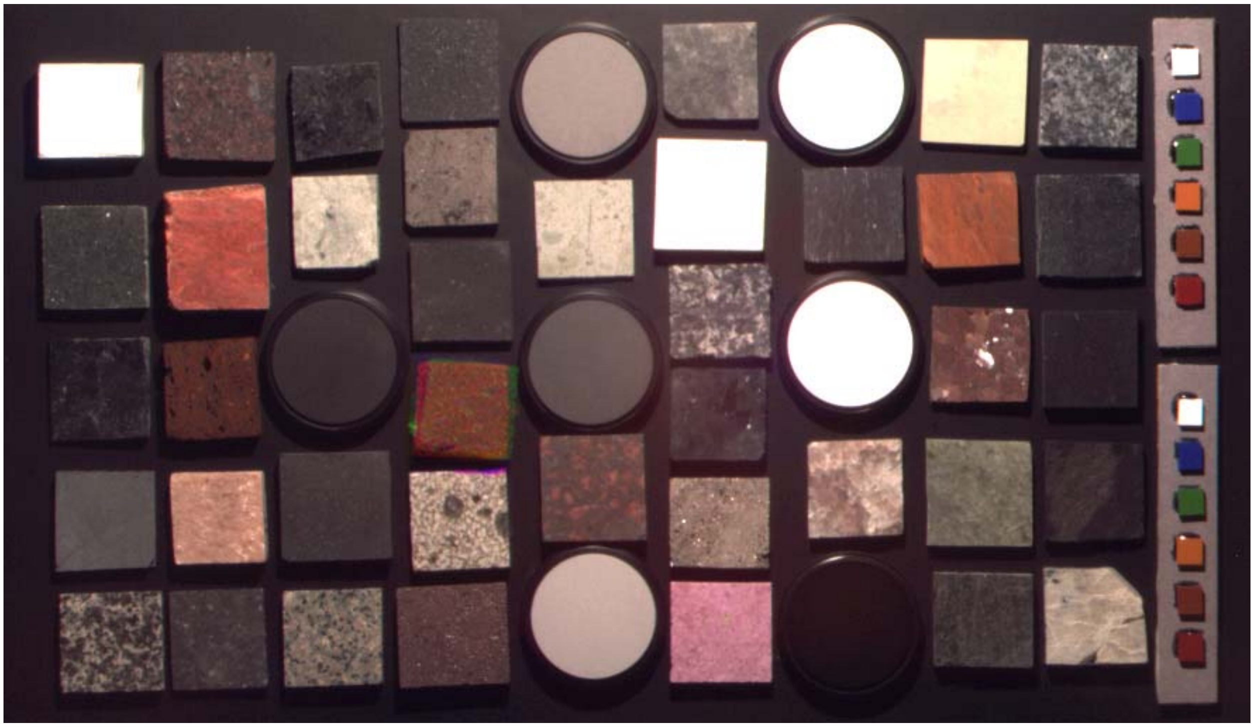


Figure 3.3.7.1.: Example of a rock and standards calibration target designed by Athena Co-I R.V. Morris, imaged by the APEX Pancam instrument during standalone camera calibration in 1999. Each tile is approximately 2.5 cm square.

3.3.8. Scattered and Stray Light Tests

Priority: Medium

Purpose and Description
To determine the intensity of light reaching the CCD from off-axis or internally-scattered sources (ghosts), as a function of source intensity and either distance off-axis or (for bright point-like sources) position on-axis. Direct a collimated beam towards camera entrance pupil at varying angles. The reference scattering is derived from an attenuated on-axis image of the point source. The minimum angle is between 2° to 5° outside the FOV. The maximum angle is that angle where the scattered light can be measured. Take illuminated and background frames at each location. Perform this along one axis through at least the 430 SP and 750 nm filters per camera. Obtain 3 frames each of source and background at each of approximately 5 positions off-axis in each direction.

Parameters and Range
Move the beam in 10° angular increments past the edge of field to a TBD deg final angle, taking illuminated and background frames at each location. Perform this along one axis.

Accuracy and Relationship to Requirements
Factor of 2 to 10 in scattered/stray light relative to source will verify that Level 3 requirement #1204 has been met.

Environmental Conditions
Ambient

Supporting Instrumentation, Tests, and Calibrations
Collimator, camera holding bracket, 1-axis angular motion, black shroud, target, 10" sphere light source. Perform light source stability test; measure reflectivity of black shroud material.

Data Processing and Products
Approximately 4 wavelengths × 2 to accommodate zero exposure images × 5 positions along axis × 3 images of each source = 120 images required. Background subtracted from illuminated frames, which are then compared to a background frame. Curves of scattered light intensity vs. field angle for off-axis sources. Magnitude and preferential orientation of any internal ghost images. Results graphed to show scattering vs off-axis angle for comparison with scattered light model.

Comments
Compare to theoretical ray-trace stray light analysis by E. Freneir and L. Scherr

3.3.9. CCD Temperature Sensor Functional Test

Priority: Medium

Purpose and Description
Verify proper function of temperature sensor by comparing with a reference sensor at high and low temperatures.

Parameters and Range
CCD temperature sensor output and reference sensor output at full range of temperatures reached in chamber.

Accuracy and Relationship to Requirements
Temperatures measured to ±2°C or better to meet Level 3 requirement #1208 (temperature sensor accuracy = ±2°C).

Environmental Conditions
Temperature = -55°C, -10°C, and +5°C; pressure ≤ 10^{-6} torr.

Supporting Instrumentation, Tests, and Calibrations
CCD temperature sensor calibration; reference temperature sensor calibration. Flight-like temperature sensor circuitry; precision calibrated temperature sensor on CCD housing.

Data Processing and Products
Convert reference temperature sensor output to °C based on supporting calibration, plot temperature vs. CCD sensor output.

Comments
Take and record data frequently during chamber temperature changes. Functional test and calibration of temperature sensor should be performed during system thermal/vacuum testing.

3.3.10. CCD Blooming

Priority: Low

Purpose and Description
Characterize CCD performance when signal exceeds the full well capacity. Take images at lower signal level (shorter integration or reduced illumination) immediately following bloomed image to evaluate residual effects, if any. Results will aid in design of autoexposure algorithm.

Parameters and Range
For each camera, measure the horizontal and vertical charge distribution of a CCD image illuminated at 5 times full-well level at five locations in the array (in the four corners and in the center), both for a point and extended area broadband source; 3 frames each. Also examine 3 immediately subsequent images taken at same exposure time with the source off.

Accuracy and Relationship to Requirements
Signal level in adjacent pixels to ±5%, in compliance with Level 3 requirement #1206 (relative radiometric accuracy). Also addresses Ability to image Sun without damage to CCDs (Level 3 requirement #1209).

Environmental Conditions
Ambient

Supporting Instrumentation, Tests, and Calibrations
Point sources; integrating sphere used for absolute radiometry testing

Data Processing and Products
5 positions on CCD × 3 images per position × 2 exposure levels × 2 cameras = 60 images required. CCD images, digital archive of horizontal and vertical and/or diagonal charge distribution, as appropriate for each location. Evaluate residual image, if any. Determine number of subsequent dark frames required to "clear" the CCD.

Comments
Initial assessment of this effect can be made based on CCD component-level testing, but this test must be repeated at the camera level and not component level because it requires flight electronics.

Repeat test at 2 times full well if time available.

3.3.11. CCD Electronic Shutter ("Readout Smear") Effect

Priority: Low

Purpose and Description
To determine the integration times at which frame transfer of the image of a bright spot from imaging to storage areas on the CCD will leave a “readout smear” or shutter effect. This should be done with the final flight electronics, which govern the frame transfer speed.

Parameters and Range
Images taken at 10 exposure times from 0.0 sec to beyond full well; 3 images at each exposure time; perform at 5 staggered positions on each CCD; 750 and 430SP filters; point and flat field sources. If assessment can be made in real time, the exposure time should be increased until the shutter effect can no longer be measured.

Accuracy and Relationship to Requirements
Pixel response for each exposure to ±1%, in compliance with Level 3 requirement #1206 (relative radiometric accuracy).

Environmental Conditions
Ambient

Supporting Instrumentation, Tests, and Calibrations
Flight electronics; targets, linear motion stage, and integrating sphere.

Data Processing and Products
Dark subtract. Compare long and short exposures to determine radiometric error; calculate minimum integration time for which radiometric error is less than 1%. Digital archive of each image.

Comments
Dark current at ambient temperature will limit accuracy of measurement of shutter effect.

Test could be done in parallel with rock and calibration target imaging.

4. Pancam and PMA System Level (ATLO) Calibration and Testing

4.1. Overview and Requirements

The Calibration and Test activities at the PMA-integrated level are primarily geometric in nature, designed to determine the physical layout of the cameras relative to the PMA as well as to assess the actual PMA pointing performance compared to Pancam requirements (Table 4.1.1.). All of the tests can be performed in room temperature and pressure (Ambient) conditions, but a subset of these tests should be performed during ATLO in thermal vacuum conditions to validate performance in the flight environment.

Table 4.1.1. MER Requirements relevant to Pancam System Level and ATLO Calibration and Testing

Level	ID #	Requirement
2	922	The Project System shall ensure that the quality of the calibration of the science instruments be sufficient to satisfy the requirements and objectives in the Science Requirements Document and the Level 1 science requirements.
2	924	It shall be possible to produce radiometrically calibrated images from the Pancam and Mini-TES observations on Mars, using measurements of calibration targets on Mars.
3	293	The MS shall have the capability to coregister the Mini-TES, Pancam and Navcam data to an accuracy of 0.27 mrad (one Pancam pixel).
3	296	The rover shall have at least 4 fiducial marks that are visible to the Pancam and whose positions can be known to within 1.5 millimeters (0.2 mm desired) with respect to the PanCam mast base, and which are spaced over a wide range of azimuth and elevation
3	301	The [Pancam calibration target] placement shall minimize the amount of diffuse or reflected sunlight from rover structures that could provide "contamination" illumination of the target.
3	978	The horizontal boresight separation of the Pancam cameras shall be between 20 and 30 cm (± 0.5 cm)
3	1043	Flight system shall ensure Pancam shall be able to provide sun knowledge.
3	1115	The PMA shall provide Pancam azimuthal pointing placement to an accuracy of ± 2° relative to the actuator hardstop.
3	1116	The PMA shall provide Pancam elevation pointing placement to an accuracy of ± 2° relative to the actuator hardstop.
3	1117	The PMA shall provide Pancam azimuthal pointing knowledge to an accuracy of ± 0.1° relative to the actuator hardstop.
3	1118	The PMA shall provide Pancam elevation pointing knowledge to an accuracy of ± 0.1° relative to the actuator hardstop.
3	1125	The Pancam stereo pair shall have a toe-in of 1°± 0.25° half angle.
3	1126	The Pancam stereo pair CCDs shall have a rotational co-alignment (twist) about boresight relative to each other of ± 0.1 degrees.
3	1127	The PanCam stereo pair shall have a relative elevation alignment of < 28 mrad (1.60°).

4.2. Tests and Procedures

Table 4.2.1 provides a prioritized overview of the Pancam and PMA system-level calibration and testing requirements. Each of these tests is described in more detail below.

Table 4.2.1. Overview of Pancam and PMA System Level (ATLO) Calibration and Test Plans

Test	*Priority*	*Environmental Conditions*	*Brief Description*
1. Geometric Target Imaging	High	Ambient OK; STV validation and verification desired	Image a standard target of known geometric properties and characteristics from one or more fixed distances; use images to derive camera models for left and right Pancam eyes.
2. Physical Characterization	High	Ambient OK; STV validation and verification desired	Measure (a) left and right eye separation; (b) each camera's toe-in; (c) relative orientation of the boresights; (d) relative roll (plane of detector) between cameras; and (e) relative pitch (elevation) between cameras
3. Pointing and Co-alignment with Mini-TES	High	Ambient OK; STV validation and verification desired	Determine absolute accuracy and repeatability of Pancam elevation actuator and PMA azimuth actuator as well as accuracy of pointing knowledge
4. Fiducial and Focus Marks	High	Ambient OK; STV validation and verification desired	Define and measure the positions of fiducial marks on the rover deck or other structures, and image the fiducials and focus marks during ATLO
5. Hard Stop position and reference frame	High	Ambient	Determination of Hard Stop position (az/el when at commanded 0,0 position) within rover reference frame of Pancam elevation actuator, PMA azimuth actuator, and PMA Deployment Drive
6. Target Imaging	High	STV	Image well-characterized geologic targets to verify and validate Pancam performance
7. Scattered Light on Pancam Cal Target	Medium	Ambient	Assess the level of scattered light impinging on the Pancam calibration target from rover structures
8. Coherent Noise	Medium	Ambient OK; STV validation and verification desired	Search for any evidence of noise in Pancam images induced by other rover instruments or systems
9. Reflectivity of Rover Structures	Medium	Ambient	Measure reflectivity of solar panels, brackets, HGA, other RED surfaces
10. PMA Actuation Timing	Low	Ambient	Determine wall clock time for PMA actuation through entire range of motion

4.3. Detailed Test Descriptions

4.3.1. Geometric Target Imaging

Priority: High

Purpose and Description
Locating objects in Martian surface coordinates is one of the highest priorities of the Pancam investigation. The Pancam has a complex geometric relationship between the stereo camera eyes and the pointing motor axes. Precision stereo distance measurement (within a few millimeters) requires that the parallax be known to within a fraction of a pixel width and any distortion created by the optics is well understood. The image scale can be calculated by knowing the exact distance from the lens to the CCD and the size of a single pixel. It is difficult, however, to obtain an accurate measurement of the lens to CCD distance. An alternate method for determining scale is to image a target of precisely known dimensions at two distances (d1 and d2) The difference between these positions (d2-d1) must be known to a high degree of accuracy.

This test will also gather data to calculate camera parallax and geometric dissertation by taking images of a known (geometric) target at a variety of known distances, azimuth angles and elevation angles. The data will then be analyzed by the Robotic Vehicles Group and the Science Team to determine camera parallax as a function of angle, as well as other desired geometric parameters.

Parameters and Range
Pancam cameras and supporting hardware must provide the ability to position in both Azimuth and Elevation in a flight like fashion, with full command and telemetry capability.

Command the cameras in both azmuth and elevation into their respective hard stops, then to their zero positions. Using Theodolites/MANCAT, establish a coordinate system that encompasses the Pancam flight hardware and the Pancam Geometric Distortation Target at a distance of 5 meters from the Pancam hardware and approximately normal to the Pancam boresight.
Within this coordinate system measure the boresight of the Pancam.

Accuracy and Relationship to Requirements
Flight System Level 3 requirement #293 (Pancam, mini-TES co-alignment); Flight System Level 3 requirements #1115 to #1118 (pointing placement and pointing knowledge); Flight System Level 3 requirements #1125 to #1127 (camera relative alignment); Also, camera model required to construct quick-look mosaics and generate other operational products (*e.g.,* stereo range maps)

Environmental Conditions
Full characterization in ambient conditions. Strong desire to obtain limited subset of geometric validation measurements in flight-like environmental conditions, however.

Supporting Instrumentation, Tests, and Calibrations
Geometric calibration target, theodolites

Data Processing and Products
Pancam images will be inspected to ensure proper exposure (no saturated pixels on target, at least 2000 DN signal), pointing, and quality. CAHVOR camera models will be generated from the test images acquired.

All Pancam images and orientation data shall be fully recorded and archived.

Comments
Will involve substantial cooperation among science team and JPL/MIPL rover and ops staff to derive camera models.

4.3.2. Physical Characterization of Cameras

Priority: High

Purpose and Description
Determine physical dimensions of Pancam system. Measure (physically or through imaging): (a) left and right eye separation; (b) each camera's toe-in; (c) relative roll (plane of detector) between cameras; and (d) relative pitch (elevation) between cameras

Parameters and Range
Physically measure distances and angles using theodolites or via analysis of geometric calibration target images (section 4.3.1).

Accuracy and Relationship to Requirements
Horizontal boresight separation must be measured to ±0.5 cm per Level 3 requirement #978. Toe-in angle must be measured to ±0.25° per Level 3 requirement #1125. Rotational co-alignment (twist about boresight) must be measured to ±0.1° per Level 3 requirement #1126. Relative elevation alignment must be measured to 0.27 mrad per Level 3 requirement #1127.

Environmental Conditions
Full characterization in ambient conditions. Strong desire to obtain limited subset of geometric validation measurements in flight-like environmental conditions, however.

Supporting Instrumentation, Tests, and Calibrations
Theodolite, geometric targets

Data Processing and Products
Drawings and tables of relevant dimensions, orientations.

Comments
None.

4.3.3. Pointing and Co-Alignment with Mini-TES

Priority: High

Purpose and Description
Locating objects on Mars requires a great deal of knowledge about the characteristics of the Pancam Mast Assembly (PMA) motors used for pointing the camera. Pointing accuracy and repeatability are a function of several parameters including exact motor step size, consistency of stepping and motor backlash. In these tests the goal is to determine these parameters. When used in conjunction with camera model data (including parallax, toe-in, vertical alignment and scale), the pixel difference may be converted to an angle. Continuing this process for the entire range of motor travel, an angle versus motor count relationship may be determined.

Another check of accuracy and consistency may be performed by gathering large excursion data. Using this procedure for several different excursion sizes will help determine if accuracy and repeatability are a function of movement size.

The third important parameter is backlash. Depending upon how well the gear teeth mesh together in the motor gearbox, there can be varying amounts of travel within a motor step. A motor step can end in a slightly different position each time since the gears are free to turn in between the teeth gaps. By forcing the motor to one side and then the other of a tooth gap, the backlash may be measured. One way to do this is by applying a load to the camera head to pin it up against a gear tooth. A scenario closer to actual operations of the camera, however, is to approach an ending position from one direction or the other and compare the results. The difference is a measure of the relative operational backlash. By choosing a variety of starting and ending locations within the camera motor range of travel, backlash as a function of distance may also be determined.

This procedure will collect data to determine the pointing accuracy of the Pancam elevation, azimuth and Mini-TES elevation drives as well as their repeatability. All three motors will be tested separately at the sub-assembly level, and the procedure used on all three motors will be the same with the exception of mounting to a precision rotary stage. All three motors must then be re-tested at the PMA system level under ambient and STV conditions. Data will be reduced to determine accuracy and repeatability as a function of motor count. Backlash as a function of distance and location will also be determined.

Testing of Pancam and Mini-TES co-alignment during System Thermal Balance testing will be achieved by imaging of the "hot L" targets mounted at different positions on the chamber walls.

Parameters and Range
Drive assembly mounted to rotary table with full command and telemetry capability.
Optical reference and Sighting scope. The table below can be used to accurately estimate angular displacement verses encoder telemetry.

Mechanism	Ratio	Range in Motion	Encoder counts
Deployment	+17932.9:1	0° - 90°	71732
Azimuth	-3948.4:1	0° - 360°	63174
Mini-TES Elevation	-307.8:1	-180° - +30°	2873
Pancam Elevation	-1815.3:1	-90° - +120°	16943

Accuracy and Relationship to Requirements
Level 3 requirement #293: The MS shall have the capability to coregister the Mini-TES, Pancam and Navcam data to an accuracy of 0.27 mrad (one Pancam pixel);Level 3 requirements #1115 to #1118: The PMA shall provide Pancam azimuthal pointing placement to an accuracy of ± 2° relative to the actuator hardstop. The PMA shall provide Pancam elevation pointing placement to an accuracy of ± 2° relative to the actuator hardstop. The PMA shall provide Pancam azimuthal pointing knowledge to an accuracy of ± 0.1° relative to the actuator hardstop. The PMA shall provide Pancam elevation pointing knowledge to an accuracy of ± 0.1° relative to the actuator hardstop.

Environmental Conditions
Full characterization in ambient conditions. Strong desire to obtain limited subset of geometric validation measurements in flight-like environmental conditions, however.

Supporting Instrumentation, Tests, and Calibrations
TBD: Theodolites, rotation stages, geometric targets.

Data Processing and Products
Images processed to develop CAHVOR and other standard camera models.

Comments
All Rotary Table, Alignment Telescope or Theodolite, and GSE Encoder readings shall be fully recorded and archived at each stage.

4.3.4. Fiducial and Focus Marks

Priority: High

Purpose and Description
The use of reference (or fiducial) marks provides an absolute reference frame for verification of PMA and Pancam pointing on Mars. Determination of the preflight distances between these reference marks and the Pancam cameras will allow for highly accurate reconstruction of pointing knowledge after landing. Reference marks shall include fixed locations on the rover as well as external locations (*e.g.,* solar panels, points on floors and walls of test chamber). The center of the shadow post of the Pancam Calibration Target shall be one of the fiducial marks.

Focus marks are fiducials having a specific shape and/or geometric pattern that can be used to verify focus of the Pancam (and other) cameras on Mars. Focus marks will be located on the rover deck as well as on the lander structures.

Parameters and Range
Relative positions of fiducial marks determined using theodolites or other standard metrology techniques, once PMA and rover are in final flight configuration.

Pancam images of the fiducials and focus marks can be obtained during ATLO testing.

Accuracy and Relationship to Requirements
Level 3 #296: The rover shall have at least 4 fiducial marks that are visible to the Pancam and whose positions can be known to within 1.5 millimeters (0.2 mm desired) with respect to the Pancam mast base, and which are spaced over a wide range of azimuth and elevation

In addition, proper radiometric calibration of Pancam images requires knowledge of the distances between the CCD focal plane of each camera and this Calibration Target's fiducial mark, to an accuracy of ±0.5 cm.

Environmental Conditions
Full characterization in ambient conditions. Strong desire to obtain limited subset of geometric validation measurements in flight-like environmental conditions, however. For example, the latter could be achieved by obtaining a rover deck panorama during STV testing.

Supporting Instrumentation, Tests, and Calibrations
Theodolites and associated measurement equipment. Pancam images of fiducials.

Data Processing and Products
Drawings and tables of relevant measurements and fiducial locations. Mosaicking and processing of Pancam images.

Comments
Fiducials must be re-measured if PMA or other rover components with fiducial marks are removed or re-aligned.

4.3.5. Determination of Hard Stop Position and Reference Frame

Priority: High

Purpose and Description
To determine the rover-based azimuth and elevation values for each of the Pancams when the PMA is commanded to the low hardstop position (0,0 in instrument motor steps).

Parameters and Range
Hard stop absolute pointing position should be expressed in terms of the rover coordinate system.

Accuracy and Relationship to Requirements
Absolute and relative position of hard stop within rover reference frame required to be known to $\leq 0.1°$ in order to satisfy Level 3 pointing knowledge requirements #1117 and #1118.

Environmental Conditions
Ambient

Supporting Instrumentation, Tests, and Calibrations
Orientation of boresight vector for each camera with respect to PMA mounting screws.
Need geometric target orientation and position determined relative to PMA using theodolite.

Data Processing and Products
Absolute values (and uncertainties) of PMA-based azimuth and elevation for each camera eye corresponding to the PMA hardstop position.

Comments
Hard stop position must be re-measured if PMA is removed or re-aligned.

4.3.6. Target Imaging

Priority: High

Purpose and Description
Image well-characterized geologic targets to verify and validate Pancam resolution and calibration performance at the system level.

Parameters and Range
Target imaging at ambient and at least one cold temperature required to validate calibration pipeline over expected range of Mars temperatures.

Accuracy and Relationship to Requirements
Validate radiometric performance of Pancam; requires use of a solar-like light source (color temperature ~ 6000 K) and measurements of the target illumination and viewing geometries. There is a strong desire (but not a requirement) that the light source be calibrated to ≤ 5% absolute across the Pancam spectral response range.

Environmental Conditions
Initial measurements can be made at ambient conditions, but final set of target measurements should be made in flight-like environmental conditions. For example, at T = -10°C and $P \leq 10^{-6}$ torr.

Supporting Instrumentation, Tests, and Calibrations
Rock target (similar to Figure 3.3.7.1), solar-like light source, measurements of distance between camera and target.

Data Processing and Products
Pancam images processed through PANCAL pipeline; Derived reflectances compared to "known" values of geologic targets used.

Comments
This test strongly endorsed and recommended by Athena Instruments Calibration Peer Review Board report (June 15, 2001).

4.3.7. Scattered Light on Pancam Cal Target

Priority: Medium

Purpose and Description

The Pancam Cal Target may receive a certain amount of secondary illumination from other structures on/near the rover deck. Proper calibration of Pancam images requires accurate knowledge of all secondary illumination sources. We expect diffuse skylight to be the dominant source of secondary illumination, but additional rover sources may also contribute. This test is designed to assess the level of secondary illumination, especially from possible specular surfaces.

Move a calibrated lamp in a circular path around the rover at a fixed distance from the cal target. Obtain Pancam images of the target at each lamp position and search for any evidence of specular glint illuminations or other "contamination" light sources falling onto the cal target.

Parameters and Range

TBD depending on test setup. Desire is to obtain images with the lamp at at least 8 azimuth positions (45° increments) at an incidence angle of 30°, corresponding approximately to 10:00 a.m. or 2:00 p.m. local Martian solar time.

Accuracy and Relationship to Requirements

Test designed to validate Flight System Level 3 requirement #301: The [Pancam calibration target] placement shall minimize the amount of diffuse or reflected sunlight from rover structures that could provide "contamination" illumination of the target.

Environmental Conditions

Ambient

Supporting Instrumentation, Tests, and Calibrations

Stable light source (±5% over timescale of test) on a moveable stand. Lamp calibration certificate, if available.

Data Processing and Products

Pancam images processed through PANCAL pipeline; relative target illumination assessed as a function of illumination azimuth.

Comments

Light source need not be absolutely calibrated but should be demonstrably stable over duration of test. Source could be same as used for target tests in section 4.3.6.

4.3.8. Coherent Noise

Priority: Medium

Purpose and Description
Examine a suite of Pancam dark current images (using solar filter as a blocker) taken during system testing, especially those at low temperatures, for evidence of coherent noise. Noise sources on the integrated flight system should be recognized when subsystems are powered.

Parameters and Range
Acquire Pancam dark frames at a wide range of exposure times, temperatures, and operating conditions during STV, especially at low temperatures and especially while other potential noise sources are operating on the rover in a flight-like environment.

Accuracy and Relationship to Requirements
Measure amplitude of coherent noise to ±10 e^- to verify that Level 3 requirements #1206 (relative radiometric accuracy) and #1207 (SNR) are met.

Environmental Conditions
Full characterization in ambient conditions. Strong desire to obtain limited subset of rover structure spectral properties measurements in flight-like environmental conditions, however.

Supporting Instrumentation, Tests, and Calibrations
Dark frames at similar temperature and integration time taken during standalone camera calibration. Determine source(s) of coherent noise (if any) at subsystem (camera) level. If different noise patterns are detected during system tests, attempt to locate and evaluate noise sources.

Data Processing and Products
Contrast-enhance and analyze all images in near-real time to search for coherent noise patterns. Archive all image data and command sequences used to acquire them.

Comments
Potential noise sources must be operating during these tests.

4.3.9. Reflectivity of Rover Surfaces

Priority: Low

Purpose and Description

Even crude knowledge of the spectral reflectance properties of some of the rover structures and solar panels, likely to be in many Pancam images, would assist the science team with verification of the calibration, and perhaps monitoring of dust loading on rover structures.

For this test, samples of individual rover surface materials should be characterized (a) by obtaining Pancam panoramas of the rover deck and other visible surfaces under well-characterized illumination conditions, and (b) in the laboratory by science team members.

Parameters and Range

Samples of solar array panels and other rover deck structures should be characterized spectroscopically and/or directly with Pancam.

Accuracy and Relationship to Requirements

Low priority because not directly addressing specific requirement.

Environmental Conditions

Full characterization in ambient conditions. Strong desire to obtain limited subset of rover structure spectral properties measurements in flight-like environmental conditions, however. For example, the latter could be achieved by obtaining a rover deck panorama during STV testing.

Supporting Instrumentation, Tests, and Calibrations

Calibrated lamp to illuminate rover; distance measured to lamp.

Data Processing and Products

Pancam images will be inspected to ensure proper exposure (<1% saturated pixels, at least 2000 DN signal), pointing, and quality. All Pancam images shall be fully recorded and archived.

Comments

Test would have to be expanded and priority elevated if solar panel imaging were to be considered by the Project as a possible secondary dust monitoring activity.

4.3.10. PMA Actuation Timing

Priority: Low

Purpose and Description
To determine the amount of time required to position the PMA across a wide range of anticipated imaging scenarios. This information will be used to generate accurate Pancam imaging sequences during flight.

Parameters and Range
PMA actuation over full range of motion should be characterized.

Accuracy and Relationship to Requirements
Low priority because not directly addressing specific requirement.

Environmental Conditions
Ambient

Supporting Instrumentation, Tests, and Calibrations
Stopwatch, Flight-like PMA electronics

Data Processing and Products
Table of PMA motion rates and durations.

Comments
Can be performed in parallel with pointing tests.

5. Pancam Flight Software End-to-End System Testing

5.1. Outline.

Pancam flight software must be tested at the system level before launch to verify proper function. Much of the Pancam flight software (FSW) is similar to the FSW that will support operation of the other MER cameras, so some of the software tests discussed below are duplicated in the test plans for the other cameras. Table 5.1.1 provides a prioritized overview of the Pancam software calibration and testing requirements. Each of these tests is described in more detail below.

Table 5.1.1. Overview of Pancam Software Calibration and Test Plan

Test	*Priority*
1. Verification of ICER Compression Performance (including effects on radiometry)	High
2. Verification of Auto Exposure Performance	High
3. Verification of Bias levels and Dark Modeling Subtraction Capabilities	High
4. Verification of Bad Pixel Correction	High
5. Verification of Readout Smear (Electronic Shutter) Correction	High
6. Verification of PMA Pointing and Deployment	High
7. Verification of Subframing	Medium
8. Verification of Binning	Medium
9. Verification of Flat Fielding Correction	Medium
10. Verification of Pixel Summing Capability	Low
11. Determination of Wall Clock Time to Complete Every Commandable Feature	Low

5.2. Facilities

Flight system testbed, and/or GSE computer system used during camera level calibrations.

5.3. Tests and Procedures

5.3.1. ICER Compression Performance

At least one high-signal/noise Pancam image each of natural rock and soil surfaces (such as those described in section 3.3.7 above) should be compressed losslessly and using various levels of lossy compression. Compare the compressed images with the original 16-bit images and gather statistics of the differences. Deviations between the original and compressed images will be used to assess the effects of various levels of ICER compression, choice of wavelet filters, choice of number of segments, and choice of number of decompositions on radiometric precision and accuracy. Test of 2-D and multispectral compression should be performed. Also, the robustness of ICER to data dropouts must be assessed.

5.3.2. Auto Exposure Performance

Test automatic exposure algorithm on targets with a variety of entropy characteristics, from flat to very complex (with specular reflections and/or dark shadows). Determine and document optimum algorithm parameters for each type of target.

5.3.3. Bias Levels and Dark Modeling Subtraction Capabilities
Test commandable bias level circuit at various temperatures. Acquire dark current images with target image data and compare results of subtracting entire dark frame with correction using "extra pixel" values.

5.3.4. Bad Pixel Correction
Construct bad pixel map and table. Confirm that algorithm corrects all bad pixels.

5.3.5. Readout Smear (Electronic Shutter) Correction
Test algorithm at various integration times, from minimum to smear threshold derived from standalone calibration (section 3.11). Confirm that FSW correctly recognizes when integration time is below threshold and automatically acquires and subtracts a zero-exposure frame.

5.3.6. PMA Pointing and Deployment
Verify ability to position and point Pancam at wide variety of targets. Target geometry should include extremes of PMA azimuth and elevation workspace.

5.3.7. Subframing
Acquire full frames and subframes of high-entropy target to confirm that subframing software performs correctly.

5.3.8. Binning
Acquire full frames and binned frames of both high-entropy target and integrating sphere to confirm that binning software performs correctly. Sphere images could be from Standalone camera testing unbinned, and then run through FSW to bin at different levels.

5.3.9. Flat Fielding Correction
Load flat field correction image/table into memory, ensure that high-signal/noise target image is properly flattened.

5.3.10. Pixel Summing Capability
Acquire full image frame and summed frames to confirm that arithmetic is performed properly by pixel summing algorithm.

5.3.11. Command Execution Time
Log execution time of all Pancam-related commands.

5.4. Responsibilities
PEL: Approval of test plan, evaluation of data quality, acceptance of test results.
FSW team: Approval of test plan, code modifications, configuration control.

6. In-Flight Pancam Calibration Activities

In order to verify the accuracy of preflight calibration and to identify changes in camera performance, acquisition of a limited amount of inflight calibration data is planned. Analysis of these data will enable updating of calibration parameters if necessary, perhaps improving Pancam calibration. Anticipated inflight calibration activities are described below.

6.1. Darks

During cruise to Mars, Pancam dark current images will be acquired and returned to Earth. These dark frames should be acquired at different temperatures if possible and losslessly compressed. This will serve as a functional test and permit the dark current model to be verified and/or updated. Additional dark data from the "extra pixels" on each CCD will also be acquired and returned during the landed mission.

6.2. Calibration Target Imaging

During surface operations, frequent images of the Pancam calibration target (Figure 2.2.1) will serve to verify calibration stability and to provide a second method (along with pre-flight calibration) of performing an absolute calibration of the Pancam images. Any changes with respect to preflight calibration data will be analyzed and may be used to modify Pancam command sequences. Calibration target images will also be used to correct for atmospheric scattering effects in Pancam images of the Martian surface.

6.3. Sky Flats

Pancam images of the Martian sky through all non-solar imaging filters may be used to verify flat field calibration and perhaps update it in the event of dust contamination to the Pancam optics.

6.4. Stellar/Satellite Imaging

Pancam nighttime images of bright standard stars and/or the Martian satellites Phobos and Deimos may provide an additional method for verification of the accuracy and stability of the radiometric calibration of the instrument.

7. Calibration Data Format and Archiving

All calibration data will be acquired in the PDS file format, so that it can be archived directly into the PDS without having to go through a file conversion. Calibration file labels and the details of the format itself will be defined by the Athena Data and Archives Working Group (DAWG) and are described in the MER Archive Generation, Validation, and Transfer Plan (MER 420-1-200; JPL D-19658).

Within 6 months of the completion of ATLO calibration activities, the Pancam PEL will deliver a detailed Pancam Calibration Report to the Principal Investigator that fully documents the procedures that were followed and the results that were obtained. A single report shall contain the detailed calibration data and algorithms for all four MER-A and MER-B flight Pancams. This calibration report will be archived in the PDS.

8. Calibration and Test Schedule and Staffing

The Pancam standalone camera tests requiring thermal/vacuum conditions will be performed in chambers in JPL building 168 and other locations TBD. The schedules as of Oct. 25, 2001 for science camera (Pancam and MI flight units) standalone thermal/vacuum testing for MER-A and MER-B are shown in Tables 8.1 and 8.2. These schedules are not finalized. The first 6 items in each schedule are in preparation for calibration. However, it will be possible to perform a limited number of tests during various parts of this pre-calibration period (for example, observing targets through the chamber window while the camera is going through its 24 hour temperature dwell tests).

Table 8.1. MER-A Pancam Standalone Camera Calibration Schedule

Activity	**Starting date**	**Ending date**	**Days**
Chamber Setup	2/25/02	2/26/02	2
Pump-down	2/27/02	2/27/02	1
Bake-out	2/28/02	3/5/02	6
Non-operating Thermal	3/6/02	3/7/02	2
Operating Functional	3/8/02	3/11/02	4
Thermal Cycle/Dwell	3/12/02	3/18/02	7
Radiometric Calibration	3/19/02	4/1/02	14
Monochrometer Setup	4/2/02	4/3/02	2
Spectral Calibration	4/4/02	4/9/02	6
Other Calibration Tests	4/10/02	4/11/02	2
Required at ATLO	**5/1/02**		

Table 8.2. MER-B Pancam Standalone Camera Calibration Schedule

Activity	**Starting date**	**Ending date**	**Days**
Chamber Setup	n/a	n/a	--
Pump-down	4/12/02	4/12/02	1
Bake-out	4/15/02	4/18/02	4
Non-operating Thermal	4/19/02	4/22/02	4
Operating Functional	4/23/02	4/24/02	2
Thermal Cycle/Dwell	4/25/02	5/1/02	7
Radiometric Calibration	5/2/02	5/15/02	14
Monochrometer Setup	5/16/02	5/17/02	2
Spectral Calibration	5/18/02	5/23/02	6
Other Calibration Tests	5/24/02	5/28/02	5
Required at ATLO	**6/7/02**		

The Pancam ATLO calibration and test schedule is still TBD, but is expected to occur in late 2002 to early 2003.

Staffing for calibration activities includes JPL engineering, science, and calibration team support plus science team support from the PEL, Athena Co-Is, Athena team affiliates, and their graduate and undergraduate student helpers as needed. A staffing plan will be generated for each calibration run assuring that the science team will be prepared to support 24/7 calibration activities with up to 3 shifts consisting of at least 3 science team members or affiliates/designates per shift.