Cassini ISS In-Flight Calibration Plan

R. West and A. McEwen

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Introduction

This document describes the objectives, observational plan and analysis tasks for in-flight calibration of the Cassini ISS cameras. We begin with a summary list of in-flight calibration tasks in this section and then describe in more detail the goals, observational strategy, and scope of work for each of the tasks individually. A list of tasks with estimates of desired calibration frequency, special targets required and filters are given in Table 1.

Table 1
Summary of In-Flight Calibration Tasks

Calibration	Frequency	Special Targets	Filter Combinations
Absolute Sensitivity	1/Yr.	Moon, standard stars	All
Absolute Sensitivity Monitor	3/Yr.	Standard stars	5/camera
ADC Bit-Weighting	1/Yr.		
Anti-Blooming pixel pairs	1/Yr.		
Charge Transfer	1/Yr.	Bright/dim double	1
Compression performance	Once		
Dark Current	Variable		
Flat fields	1/Yr.	Venus, Titan, Saturn Cal lamp	All
Focal length and geometric distortion	Once	Star cluster	3/NAC 6/WAC
Gain ratios	3/Yr.		
Linearity and shutter	Twice	Saturn or Titan	
Noise (incoherent and coherent	Variable		
Point spread function	Once	Bright stars	All
Polarization	Twice	Moon, Saturn at 0 phase	Several
Residual Bulk Image	1/Yr.	Light flood and bright object	Several
Sensor blemishes	Variable		

Table 1, Continued

Calibration	Frequency	Special Targets	Filter Combinations
Stray light	Several	Sun, Moon, other satellites/planets	TBD

Notes: These calibrations will be performed for both WAC and NAC, although the Cal-lamp calibration is for the WAC only. All filters means all 81 useful filter combinations planned for observation of celestial objects (see Table 2). Frequence 1/Yr. is for the tour with some additional during cruise.

Table 2
ISS Common Filter Combinations

Imaging Objective	Filter Combinations
NAC:	
Faint objects	CL1 + CL2
Atmospheric sounding	CL1 + UV3-BL2-CB1-MT1-CB3-MT3-CB2-MT2 CL2 + UV1-UV2-BL1-HAL
Color Imaging	CL1 + GRN-UV3-IR1-IR3 CL2 + UV1-UV2-BL1-RED-IR2-IR4
2-filter bands	UV2+UV3, RED+GRN, RED+IR1, IR2+IR1, IR2+IR3, IR4+IR3
Visible Polarization	P0-P60-P120 + BL2-UV3-GRN–MT1-CB1-MT2-CB2
IR polarizer	IRP0 + MT3-CB3-IR1-IR3
Number of expected combinations	50
WAC:	
Faint objects	CL1 + CL2
Atmospheric sounding	CL1 + VIO-BL1-GRN-HAL CL2 + MT2-CB2-MT3-CB3
Color Imaging	CL1 + IR1-RED-GRN-BL1-VIO CL2 + IR2-IR3-IR4-IR5
IR Polarization	IRP0-IRP90 + IR3-IR4-IR5-CB3-MT3-CB2-MT2-IR2
Number of expected combinations	31

Objectives, Observational Strategy and Analysis

Absolute Sensitivity

Absolute sensitivity can change with time if the cold detector window becomes coated with outgassed volatiles or as radiation damages the detector or optics. These processes occur over long time scales (months to years). During the orbital tour absolute sensitivity calibrations should be made at least once per year. Absolute sensitivity calibrations should be made also during cruise to establish camera sensitivity, for Jupiter science, and to provide accurate data for exposure planning. In order to provide for accurate exposure estimates absolute sensitivity calibration needs to be done prior to design of sequences. This will not be possible for the Venus and Moon exposures except for filters used during instrument checkout (ICO). It may be possible for a broader range of filters for Jupiter as part of the Jupiter encounter design.

The observing strategy will be to image photometric standard stars as primary absolute calibration standards and to use images of solar system targets such as the moon as secondary photometric standards. Use of photometric standard stars is only good to 5% absolute from Galileo SSI experience, worse near the wavelength extremes (Klaasen *et al.*, Inflight performance characteristics, calibration, and utilization of the Galileo solid-state imaging camera, *Opt. Eng.* **36**, p. 3001-3027, 1997).

Lunar calibration and calibration using icy satellites of Jupiter or Saturn will be used primarily to establish accurate relative sensitivities for nearby filter combinations. Spectral slopes of regions on the lunar surface are known very accurately ($\sim 1\%$) from previous ground-based work and also from recent photometric observations of the moon by H. Kieffer. It is expected that our understanding of relative sensitivity will be quite good after analysis of the lunar images, at least for those filters used to observe the moon and whose passbands fall within the range of the Kieffer ground-based study. Ultraviolet filters do not fall within that range.

The analysis of photometric data will be a complex task whose ultimate objective is to improve our understanding of absolute sensitivity of the instrument. There are at least two factors which contribute to complexity. First, various photometric sources such as the moon and standard stars each need special treatment. For stars the image falls only on a few pixels and the relative calibration of these pixels to all the others needs to be well-understood. Photometric standard stars have spectral gradients which are often quite different than solar system targets and so band-integrated observations need a sophisticated spectral analysis to interpret the results.

Light from the moon will fall on many pixels but a mapping operation is needed to interpret image brightness in terms of the information residing in Kieffer's database which has different spatial and spectral resolution and possibly different lighting or viewing angles. Photometric accuracy for each source is a function of wavelength. A weighting scheme needs to be developed to combine data from different sources taking into account the uncertainties of each, including uncertainty in known flux or intensity and observed signal/noise from each. The weighting scheme meeds to take advantage of the highly accurate relative spectral calibration from the moon for a limited number of filters.

Absolute sensitivity calibrations using stars can be improved if the star is allowed to drift across a significant portion of the frame. A smeared image samples more of the frame thereby reducing sensitivity to dust near the focal plane and improves signal/noise by allowing longer exposures. This technique can be used to advantage with only some of the filters (those having spectral response and passband allowing for exposure great enough to smear the image). Smearing can be done passively by taking advantage of the attitude drift of the spacecraft or actively by commanding a slow turn. The disadvantage of active commanding is the added design and uplink cost. The disadvantage of passive smearing is the stochastic nature of spacecraft attitude control which makes it hard to know how long a stellar image will remain on one pixel. At the present time we do not know enough about spacecraft pointing stability to reliably design for passive smearing, although a limited amount (attitude control by thrusters only) of this information may be available after ICO-1.

The final and perhaps trickiest part of the analysis will be to determine how to make changes to the various factors (CCD QE, optics transmission, filter transmission, gain) which contribute to absolute sensitivity. We need to assign a spectral dependency to any sensitivity correction we make. Suppose one of the broad-band filters darkened due to exposure to charged-particle fluence, but others did not. Our analysis should be sophisticated enough to modify only the transmission for the one filter while keeping the CCD QE and optics transmission fixed. Deciding how to make changes like these will require detailed covariance analysis of sensitivity trends for many filters. An estimate of the tasks associated with this effort and associated work hours is given in Table Table 3 in the Appendix.

The scope of the work for this task can be listed as a series of sub-tasks as follows.

- Design Image Sequence. The designer will select a target or multiple targets (eg. Moon or standard stars or cluster) based on the mission phase and knowledge of the brightness and spectral and photometric data on the potential target. Initially some research must be done to identify photometric standard stars having the required photometric precision, brightness and spectral properties suitable for calibration. If any clusters satisfy the criteria an optimal pointing location must be determined. The designer will then use the PT to calculate exposure times and design an image sequence which fits the available time and SSR resources. For new targets or for new filter combinations we should plan 10 hours for this activity. We should plan for at least 3 stellar or star cluster targets to accommodate broad and narrow-band filter combinations and to test the calibration process with stars having different spectral slopes. For previously used targets and filter sequences the designer should be able to rely on saved sequences and so the design time should be much less, probably 2 hours.

- Calibrate Images. The first step will be to use the current calibration files and procedures to derive flux information which will be compared with expected flux (expected on the basis of the flux or intensity reported in the literature for the target). This requires a standard calibration (eg. removal of dark and bias, flat-fielding, and corrections for nonlinearity, bad pixels, etc.) and removal of cosmic ray artifacts. If we assume that three images will be obtained per filter combination (for better statistics and to mitigate against the effects of cosmic ray hits and location of dust) the total number of images could be as high as 790 (30 darks plus 150 on the target times 3 targets for the NAC and 30 darks plus 31 times 3 times 3 for the WAC). This sub-task should require 20 work hours to identify the frames and write a batch processing file. An additional 40 hours should be allotted the first time to write and test code to handle cosmic ray removal, although that task may be budgeted under some other code development work plan since it will be needed for routine processing.

- Next the analyst will extract flux values from the target area. If there is more than one target (star) in the image the analyst will need to identify each in the image and create a listing for each. New code needs to be written to handle that task efficiently. New coding for a star or cluster target should require 40 work hours, a one-time charge. Coding to handle lunar images will be more complex. Perhaps 80 hours should be allocated to that task. Some user intervention will be needed to run the code (to initially identify the targets). The analyst will then compare the observed DN values with those expected from a forward-model calculation where the target flux or intensity is multiplied by the current best values for CCD QE, optics transmission, etc. and an expected DN is produced. This procedure is straightforward for star images (except for charge transfer issues mentioned next) but would be more complicated for an extended target like the moon because the target model is complicated and the exact placement in the FOV needs to be taken into account. The code for point or small sources needs to take into account charge transfer which will deplete charge according to location on the chip. Assuming the process can be automated to some extent (eg. the user initializes the target IDs and then the code identifies the targets in subsequent images) the task should require about 20 hours of user time per run. It is difficult to estimate the user time needed to do this task for a lunar or planetary/icy satellite target.

- The next step is to compare predicted DN with observed DN, then to perform an analysis which leads to a decision on how to adjust the various components (CCD QE, optics transmission, filter transmission, gain state, etc.?) which contribute to any change implied by the new results. This task will require some new code (to perform a correlation analysis, for example) and some thinking to define the best approach. We estimate the initial cost of this activity to be about 30 hours for conceptual development and 80 hours for code development. Subsequent runs will cost less, perhaps 20 hours per run for this part.

- The final step is to document and archive changes made to calibration files. Every time a change is made in the calibration files or procedures the change must be documented, including the types of changes made and the rationale with backup analysis material, and the updated files need to be archived in the calibration database. This activity should require 30 hours of time for a task as major as this one. A summary of the anticipated labor effort is given in Table 3.

Absolute Sensitivity Monitor

The purpose of this calibration is to discover and track any changes to absolute sensitivity that occur over short time scales due to volatile deposition onto or evaporation from the CCD window or changes in the signal chain.

The observing strategy will be to image one or two reference stars or star cluster(s) before and after CCD decontamination and at regular intervals (approximately three per year) beginning as soon as resources permit. The image sequence will be identical each time. The sequence will make use of only 5 filter combinations per camera, including the shortest and longest-wavelength filters for each camera. Optics contamination will be most readily apparent in the UV1 filter, while changes in the CCD properties will be most apparent at the longest wavelengths. The target(s) need to be well out of the part of the sky affected by stray light from the sun at any time during the mission. The star Spica is a likely candidate since we will have data as early as ICO-1 which will be valuable for understanding the long-term behavior of the instrument.

Data analysis and reduction should be straightforward. The data will be calibrated (dark and bias subtraction, flat field division, an accounting for charge loss in traps) in the standard way. The summed DN values will be extracted and plotted as a function of time to reveal short and long-term trends. This analysis will help the ISS team determine how often full absolute calibrations should be done and will provide better time resolution needed to determine cause and effect relationships if changes in absolute sensitivity are found. A summary of the anticipated labor effort is given in Table 3.

ADC Bit-Weighting

The analog-to-digital (ADC) conversion favors some digital values at the expense of others. This effect was calibrated before launch but is thought to be sensitive to changes in the thermal or electrical environment during flight, and also depends on gain state. In-flight calibrations are needed periodically to keep bit-weighting tables up to date.

Two types of data will be used to assess uneven bit-weighting. Images of extended targets (the moon, Jupiter, Saturn, Titan) obtained for science objectives can also be used to examine uneven bit-weighting tables. No special sequencing is needed for this but the data returned for these objects must be analyzed in a statistical way to look for uneven bit weighting. A second type of data can also be used. While the decontamination heaters are on the CCD is warm. Frames of the dark current at this time provide information on uneven bit weighting. A sequence of frames during cool-down or warm-up would provide a more thorough basis for examining uneven bit weighting.

The work force associated with this task would be dominated by the work required to analyze the data. A small amount of work would also be required to plan exposures during warm-up or cool-down or while the CCD is warm. A summary of estimated work hours is given in Table 3.

Anti-Blooming Pixel Pairs

We expect that bright/dark pixel pairs created during long exposures with Anti-Blooming ON will be stable during flight but additional ones may be created as the number of traps in the CCD increases as a result of exposure to cosmic rays. This should be checked periodically in flight.

A statistical evaluation of images obtained for science may be all that's required for this calibration unless there are not enough long exposures on extended targets with anti-blooming ON. If that is the case a special sequence for this will need to be generated.

To assess the effects of pixel pair charge redistribution several images of extended sources are required having long exposures (several minutes at least). Titan at UV wavelengths is a likely target for this process. Pixel pairs are discovered by comparing images with anti-blooming ON and OFF. Some new software will be required to combine many images to form a statistical mean. This software is also required for the flat-field calibration listed below and will be budgeted under that item. Estimated work hours are given in Table 3.

Charge Transfer

Absolute calibration and analysis of temporal sensitivity variations (the first two tasks listed in Table 1) will depend significantly on analysis of photometric standard stars. As the image of the star is transferred down the column and across the row of the CCD some of the electrons will be left behind in traps. The number of electrons depleted in traps will depend on the location of the star image on the chip and can change with time due to degradation from cosmic ray damage. It is therefore important to calibrate this effect in order to use star images for absolute calibration. We need to know how much charge is lost as a function of location on the chip.

To address this goal we need to take many images of the same star or group of stars and to raster the FOV across the field so that many locations on the chip are sampled. If space on the SSR is tight we may want to do multiple shutters for each read operation. This type of observation will need to be designed.

The data analysis should be relatively straightforward, although some new code is needed. Work hour estimates are given in Table 3.

Compression Performance

An in-flight test is needed to verify that the lossless and lossy compressors are operating as expected. There is no reason to expect changes during the mission so a one-time analysis effort is all that is required. The estimated work hours are given in Table 3.

Dark Current

Dark current can change with time due to damage by cosmic rays. In addition to the conventional form of dark current which at launch was very small there is charge which is generated by light flood. Most of the charge generated by light flood is swept out of the chip during the erase cycle just before the exposure but some is caught in traps and gradually leaks out over time. The spatial distribution and time constants for this residual bulk image (RBI) couple with the residence time on the chip which is a function of location on the chip and parameters which determine how fast the chip is read.

The complexity of this process has thwarted efforts thus far to estimate RBI for each pixel for each exposure time and for a set of parameters which determine the residence time on the chip. Without such a formula to predict RBI we must rely entirely on observed RBI and dark current. We have only a limited amount of this information (unsummed images only) from thermal-vac calibration and for most of the parameters which effect residence time we must obtain new data during flight. The number of images to be obtained could be very large (multipliers are exposure time, summation mode, compression parameters and data packet rate). Instead we hope to rely on a subset of images which can be interpolated to obtain an accurate dark frame for each exposure. In this way we can limit the range of the multipliers listed above.

Special sequences need to be designed and data from these evaluated to assess how few frames will be required for dark frame calibration. A modest amount of effort is needed for this start-up phase. During flight we expect dark current to change only slowly and a much smaller effort will be needed to monitor changes and maintain dark files. Work estimates for these tasks are given in Table 3.

Flat Fields

Flat-field frames provide knowledge of the pixel-to-pixel relative sensitivity and are functions of filter combination. Various factors contribute to nonuniform spatial sensitivity, including nonuniformity in the manufacturing process, dust on and near the focal plane (on the CCD window, the quartz plug, and on the filters) and interference fringes for narrow-band filters combinations.

Images of extended and relatively bland objects such as Titan imaged at close range and low phase angle will provide data needed to assess flat fields. In addition the WAC cal lamp can be used for this purpose if only in a limited way. Since no observable object is spatially uniform an algorithm needs to be devised which makes use of a large number of images and blend them to achieve a statistically average flat target.

It is important to recognize that changes in flat-field response due to moving dust particles affect only small spatial scales in the images and these can be calibrated from images of targets with gradients over large spatial scales, provided any small-scale features on the target are removed by averaging.

The WAC cal lamp can be used to monitor changes in the WAC flat field response over large spatial scales even though the lamp illumination is not uniform. A proxy flat-field can be formed from the ratio of the lamp image to a true flat-field image, both obtained during thermal-vac calibration. If we assume the illumination pattern (spatial distribution of light on the CCD) of the cal lamp does not change over time, at least for low spatial frequencies, we can compare lamp images taken during flight to those obtained during thermal-vac, remove the high spatial frequencies from that ratio, and multiply it by the flat field file obtained during thermal vac to obtain one appropriate for flight. The method does not work for the high spatial frequencies since dust particles are illuminated differently by the lamp than by a distant target. The high spatial frequency part of the flat field will be obtained during flight as described above from bland targets like Titan.

It is likely that science images can be used for flat-field purposes, although for the WAC the ISS team needs to make sure images are obtained in many filters during close Titan flybys. The most work-intensive part of this task will be to devise an algorithm to statistically average many images. This can be a large task since suitable images need to be culled from a large database, and since flat field files will be needed for all 81 filter combinations identified above. Algorithm development is needed to handle large and small spatial scales differently and to combine them intelligently. Work estimates are given in Table 3.

Focal length and geometric distortion

The focal length and distortion should be the same for all wavelengths for the NAC reflective optics but are functions of wavelength for the WAC refractive optics. There are also small perturbations in focal length even in the NAC because the filters are not exactly parfocal. Calibrations in 3 filters spanning the wavelength range are recommended for the NAC and six filter combination are recommended for the WAC. These tasks need be done only once using a star cluster target. Estimated work hours appear in Table 3.

Gain Ratios

As part of the absolute calibration process we need to assess gain values and we need to ensure that images taken in different gain states show identical intensities of fluxes. In order to do this we will observe a target or targets in multiple gain states. Work force estimates are given in Table 3.

Linearity and shutter

This calibration deals with shutter offset as well as shutter mean exposure time and signal chain nonlinearity. Imperfection in the summation well of the CCD or in the ADC can produce a nonlinear response which does not depend pixel location or on which filter combination was used. During thermal vac operations the linearity calibration was conducted by changing exposure time for a fixed target and analyzing the linearity of the DN value as a function of exposure time. The same procedure could be adopted for flight calibration for a suitable target (an extended target whose appearance is not changing during the calibration). However, any errors in exposure time due to a change (since the last calibration) in the way the shutter operates could propagate error into the analysis of linearity.

It should be possible to differentiate between nonlinearity in the signal chain and incorrect exposure times and shutter offset effects by exposing at a variety of exposure times and a variety of summation modes a target with many intensity levels. New code needs to be written to enable that analysis.

Noise

Incoherent and coherent noise was observed in thermal-vac calibration images. Algorithms used by Charlie Avis to look for both types of noise in thermal-vac images can be used for flight images as well. This task will rely on images obtained for other purpose, including dark frames. Effort will be directed toward understanding cause and effect relationships (eg. coherent noise may be correlated with operational modes of ISS or another instrument or spacecraft subsystem). It is difficult to predict what will be seen and what magnitude of effort will go into the analysis. Estimated work hours for the minimum effort of examining frames for noise are given in Table 3. Additional work hours may be needed if anomalies are found.

Point Spread Function

Point spread functions will needed for all filter combinations. These will be obtained from star images. Images of clusters provide multiple opportunities and provide greater dynamic range than for single stars. Single bright stars may be required for narrow-band filters or for filters in the UV or IR end of the spectrum. Multiple images in each filter combination are needed to sample variations in the placement of the star relative to the center of a pixel and to improve sampling statistics. Relatively long exposures (but not long enough to cause smear) of the brightest stars are needed to map the PSF at large distance from the image center. Because of the large number of filter combinations, multiple targets and multiple exposures, effort to analyze the images will be one of the larger in-flight calibration tasks. It should also be one of the first to be done when the opportunity for substantive calibration activities opens up. No new codes need to be developed if we make use of existing codes used by Charlie Avis. Task breakdown and estimated work hours are shown in Table 3.

Polarization

The purpose of in-flight polarization calibration is to provide a check on component-level polarization calibration done at JPL. The lunar surface and Saturn or Titan observed close to 0° phase angle provide targets whose polarization is known to within 1% which is the expected precision of our polarization measurements. The work effort will focus on combining two or three polarization images in each filter and comparing the derived polarization with that expected from component calibration. Estimated work hours are given in Table 3.

Residual Bulk Image

Residual bulk image is caused by charge trapping and is likely to increase over the coarse of the mission as traps are created by cosmic rays. RBI is also a function of wavelength because longer-wavelength photons penetrate deeper into the silicon and create photoelectrons closer to the traps. To understand the temporal and wavelength behavior we need to take calibration images which will consist of over-exposing a bright target like Saturn and measuring the residual image as a function of time over the coarse of 30 minutes. Estimated work hours are given in Table 3.

Sensor Blemishes

At launch only lines close to the edges of the frame displayed high dark current. It is expected that pixels anywhere on the CCD may become 'hot' after exposure to cosmic ray hits. These need to be mapped periodically. Data for this will come from the scheduled dark frame calibration images. There are additional types of blemishes for which accurate photometry is difficult, including low-full-well pixels and pixels under dust particles on the CCD. Analysis of CCD images taken for flat-field or linearity tests can be used to map these pixels. Software used for calibrating thermal vac images can be used for in-flight analysis. Estimates for work to analyze the images are given in Table 3.

Stray light

Stray light calibration can be a demanding endeavor if the team requires detailed mapping of stray light over a dense grid in angle and in many filter combinations. Voyager images of the inner solar system taken from beyond Neptune's orbit show caustic rays which have high-spatial-frequency power and depend sensitively on the both the angular distance to the sun and on the azimuthal angle in a coordinate system centered on the sun. If these need to be mapped for Cassini a calibration sequence needs to be designed to cover both radial and azimuthal angles around the sun. Solar stray light calibration does not sample radial angles less than 20°. For radial angles smaller than 20° we will rely on measurements of stray light close to the moon and other planetary bodies. New software needs to be developed to analyze the data. Work estimates are give in Table 3. In Table 3 is an item labeled 'Lunar analysis code development' for writing code to analyze stray light from lunar data. It is assumed that the code will be general enough to analyze stray light from other planetary bodies (Jupiter, Saturn, Titan). The sequence design time for the solar stray light images is more complex than most other types of sequences and that is reflected in the number of hours allocated. The item labeled 'Standard calibration' refers to the work required to organize the data set, do bias and dark subtraction, averaging, flat-fielding and conversion of DN to flux in each pixel.

Table 3

Work Estimates for In-Flight Calibration Tasks

Calibration	Frequency	Start-up Work Hours	Routine Work Hours
Generic Tasks			
Cosmic Ray Removal Code		40	
Absolute Sensitivity	1/Yr.		
Lunar analysis code development		80	
Target identification and flux extraction code		40	
Point source charge loss code		20	
Sequence Design		10 X 5 targets	2hr. X 3 targets
Standard calibration			20
Extract fluxes from target			15
Analysis of Lunar data		80	
Analysis of stellar data		40	20
Data archive and documentation			30
Absolute Sensitivity Monitor	3/Yr.		
Sequence Design			2
Standard calibration			3
Extract fluxes from target			3
Analysis of stellar data			3
Data archive and documentation			8
ADC Bit-Weighting	1/Yr.		
Sequence Design			2
Code development		40	
Data analysis		20	10
Data archive and documentation			10
Anti-Blooming pixel pairs	1/Yr.		
Sequence Design			2
Data analysis		20	10
Data archive and documentation			10

Table 3, continued
Work Estimates for In-Flight Calibration Tasks

Calibration	Frequency	Start-up Work Hours	Routine Work Hours
Charge Transfer	1/Yr.		
Sequence Design		10	2
Data analysis		20	10
Data archive and documentation			10
Compression performance	Once		
Data analysis		20	
Data archive and documentation		20	
Dark Current	Variable		
Sequence Design		40	2
Data analysis		80	10
Data archive and documentation		20	10
Flat fields	1/Yr.		
Image selection and statistical averaging code		60	
Sequence Design		20	4
Standard calibration			20
Venus analysis		80	
WAC lamp analysis		20	10
Tour image analysis		80	30
Data archive and documentation			20
Focal length and geometric distortion	Once		
Sequence Design		20	
Image analysis		80	
Data archive and documentation		20	
Gain ratios	3/Yr.		
Sequence Design			4
Image analysis			20
Data archive and documentation			10
Linearity and shutter	Twice		
Sequence Design		20	10
Image analysis		100	20
Data archive and documentation		20	10

Table 3, continued
Work Estimates for In-Flight Calibration Tasks

Calibration	Frequency	Start-up Work Hours	Routine Work Hours
Noise (incoherent and coherent	Variable		
Image analysis		20	10
Data archive and documentation		20	10
Point spread function	Twice		
Sequence Design		20	4
Image analysis		60	30
Data archive and documentation		30	20
Polarization	Twice		
Sequence Design		10	4
Image analysis		60	30
Data archive and documentation			20
Residual Bulk Image	1/Yr.		
Sequence Design		6	3
Image analysis		30	20
Data archive and documentation			20
Sensor blemishes	Variable		
Image analysis		20	10
Data archive and documentation			10
Stray light	Several		
Lunar analysis code development		60	
Solar analysis code development		60	
Sequence Design		15	5
Standard calibration			10
Analysis of lunar/planet data		40	20
Analysis of solar data		80	
Data archive and documentation		30	20

Passive Long-term Monitoring

In addition to the absolute sensitivity monitoring which will require sequence design and request for spacecraft resources there should be a program to monitor some or all of the ISS data returned for science or for scheduled calibration. Every dark frame should be examined for incoherent and coherent noise. This can be performed by an automated process which would report anomalies if found. The ‘dark band’ seen in thermal vac calibration on dark images is another feature that should be routinely monitored since it is an indicator of a CCD defect which could become worse during flight. A running histogram of DN values from all accumulated images will reveal changes in uneven bit weighting. For these types of activities we want to maintain a long-term database and to examine plots of how things change with time.