Chapter 6

FOC Calibration

In This Chapter...

This chapter describes the FOC calibration pipeline, discusses possible reasons for recalibrating your data, and shows you how to rerun the calibration tasks. It covers not only the calibration steps that are performed, but also the FOC image characteristics that are being calibrated and the derivations of those calibrations.

6.1 FOC Pipeline Processing

All data received by STScI from the Space Telescope Data Capture Facility pass through the Observation Support and Post-Observation Processing Unified System (OPUS)—referred to as the *pipeline*—to be processed and calibrated. The calibration software the pipeline uses is exactly the same as that provided within STSDAS under the **hst_calib** package (calibration software for Faint Object Camera is in the subpackage **stsdas.hst_calib.foc.focutility.calfoc**), enabling you to recalibrate any FOC data just as the routine calibration pipeline does. The calibration files and tables are taken from the Calibration Data Base (CDBS) at STScI and are usually the most up-to-date calibration files appropriate for the instrumental configuration used in the observation. (For additional details on the reference files used in the past, see also *FOC Instrument Science Report (ISR)* 082, available through the FOC pages on the World Wide Web).

The FOC calibration software (**calfoc**) takes as input one image: the raw `.d0h` file, and it produces two output images:

- A geometrically corrected image (`.c0h`).
- A geometrically corrected *and* flatfielded image (`.c1h`).

In addition, the calibration software takes as input any necessary calibration reference images or tables, and some engineering files. The calibration software determines which calibration steps to perform from the values of the calibration switches in the header of the raw data (`.d0h`) file (see also Table 6.1). Likewise, it selects the reference files to use in the calibration of the data by examining the reference file keywords. The appropriate values of the calibration switches and reference file keywords depend on the instrument configuration used, the date when the observations were taken, and any special pre-specified constraints. These parameters were set in the headers of the raw data file in the RSDP pipeline during the creation of the `.d0h` image.

6.2 FOC Calibration Switches

This section describes each of the FOC calibration steps, how they were determined, and how the pipeline task **calfoc** carries them out. Pipeline calibration of FOC imaging data:

- Dezooms zoom-mode images to produce square calibrated images.
- Determines the absolute sensitivity of the instrument configuration and sets photometry keywords allowing count rates to be converted to flux units.
- Corrects the geometric distortion of the image via interpolation of the data onto a rectified grid, creating a `.c0h` file.
- Applies a flatfield correction to the data that removes large-scale spatial non-uniformities, creating a `.c1h` file.

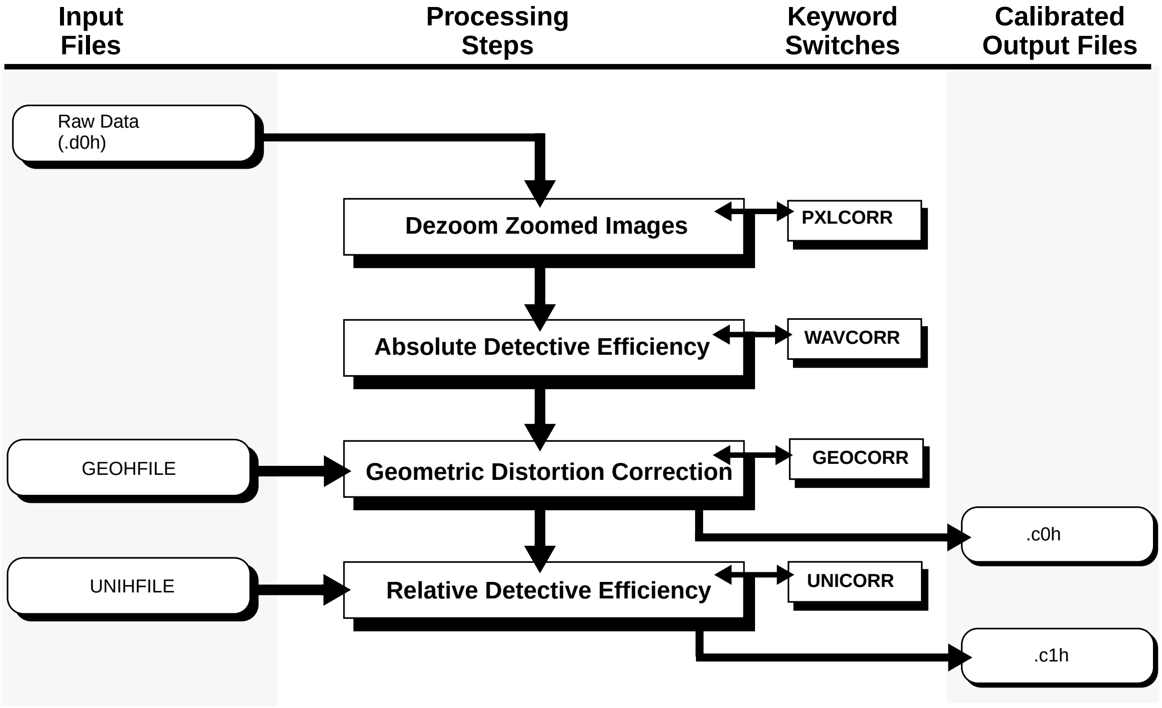
The flowchart in Figure 6.1 shows the steps of the **calfoc** pipeline process and the related calibration switches.

To determine the calibration steps applied to the data and the calibration reference files used to calibrate the data, look at the values of the calibration switches in the header of the raw (or calibrated) data. Before calibration, the calibration switches will have the value OMIT or PERFORM. The calibration process sets the switches for completed steps to COMPLETE in the header keywords of the calibrated data file.

6.2.1 Dezooming of Zoomed Images (PIXCORR)

A somewhat unfamiliar aspect to using the FOC is that the pixel size can be doubled in the *x* direction, with a corresponding increase in the field of view and a decrease in the horizontal resolution. This process is known as *zooming*. If an image has been taken in zoom mode, the first processing step is to invert this zooming process by splitting the data values along the first image axis (the sample direction). The length of the first axis (NAXIS1) is doubled, and the length of the second axis (NAXIS2) remains unchanged. If the zoomed image contained *n* rectangular pixels (50 x 25 microns each) in the sample direction, the dezoomed image contains 2*n* square pixels (25 x 25 microns), each with half the flux of the

Figure 6.1: Flowchart of the Calibration Process for FOC Data



original rectangular pixel. No attempt is made to do anything more sophisticated. The keyword PXLCORR is set to COMPLETE when this step is done, and to OMIT when the image is taken using normal pixels.

6.2.2 Absolute Sensitivity Correction (WAVCORR)

This step does not modify the data itself, but instead computes a constant that can be used to convert the data values in the `.c1d` file to absolute fluxes. This constant is saved in the `.c1h` header file as the value of the PHOTFLAM keyword. The keywords that describe the absolute sensitivity (PHOTFLAM, PHOTMODE etc.) are derived using **synphot** (see page 3-16) applied to the photometric mode calculated using the instrument parameters. The photometric mode now includes the effect of format-dependent sensitivity (since May 18, 1994).

The sensitivity curve for the *f*/96 camera, often called the Detector Quantum Efficiency (DQE) curve, was derived from observations of a spectrophotometric standard through many of the medium and narrow band filters spanning the useful wavelength range of the detector. The DQE curve is combined with the filter transmission curves to derive the PHOTFLAM values or with **synphot** to convert measured counts into absolute flux values. The DQE derived for the *f*/96 relay is based on the flux that falls in a 1” radius aperture. This aperture size does not encompass all the flux from the star, especially in the UV. Note that this definition of the DQE treats all side diffracted or scattered light that falls outside the aperture as lost. If you wish to apply the DQE to different apertures or other photometric

Table 6.1: Calibration Switches in calfoc

Switch	Processing Step	Reference File
BACCORR	Remove instrument background by subtracting a dark count image; it is never done, for reasons given in the section titled “Background” on page 7-11.	bachfile
ITFCORR	Multiply by format-dependent inverse flatfield; it is never done, as will be explained in “Format-Dependent Effects” on page 7-9.	itfhfile
PXLCORR	Dezoom zoomed pixels by splitting each zoomed pixel in the sample direction into two pixels, each having half the flux of the original. Done only (but always) for data taken in zoom mode. Produces square pixels.	none
WAVCORR	Compute absolute sensitivity using throughput tables appropriate to observation mode (PHOTMODE). Names of actual throughout tables used are determined from graphtab and comptab tables. Names of throughput tables used are written to history section of calibrated data header. This step does not alter pixel values, it writes inverse sensitivity (PHOTFLAM), RMS bandwidth (PHOTBW), zero point magnitude (PHOTZPT), pivot wavelength (PHOTPLAM), and observation mode (PHOTMODE) to header of calibrated data.	graphtab and throughput tables
GEOCORR	Perform geometric correction to rectify optical and detector distortion using geometric correction reference file.	geohfile
UNICORR	Correct for large scale detector non-uniformity by multiplying by the uniform detector efficiency file, which is reciprocal of a highly-smoothed flatfield. Done only for images.	unitab, unihfile
SDECORR	Flatfield and compute absolute sensitivity for spectrographic data. At the moment, this step is not done.	sdecorr

methods, you should normalize your results to that aperture size using an appropriate PSF (see “Point Spread Function” on page 8-2).

The *f*/48 detector, for various reasons, has not been adequately calibrated in orbit. Only the pre-launch DQE curve has been used for the *f*/48 camera. On-orbit measurements taken in December 1993 showed that the measured fluxes from a spectrophotometric standard were about 60% of those expected. The *f*/48 curve was not updated with this information.

Multiplying the data values in the calibrated image by the value of PHOTFLAM and dividing the result by the actual exposure time (EXPTIME) converts the values to flux density F_λ in units of ergs $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \text{Å}^{-1}$. The current CDBS filter transmission, mirror reflectivities, and detector quantum efficiency curves are used to compute the conversion factor (PHOTFLAM) between detected count rate and a source flux F_λ averaged over the bandpass. The pivot wavelength, rms bandwidth, and zero-point magnitude are also saved in the header as the values of PHOTPLAM, PHOTBW, PHOTZPT, respectively. Finally, the observation mode (PHOTMODE) is written to the header, and this mode is used by **synphot** to determine the inverse sensitivity.

Status of Sensitivity Files

All COSTAR-corrected data taken before October 22, 1994, used the predicted DQE curve for the FOC+COSTAR sensitivity, with the measured DQE curve being applied to images taken after October 22, 1994. Therefore, the PHOTFLAM keyword will be incorrect for images taken prior to that date and should be recalculated if needed for data analysis. The actual files used to calculate these keywords are recorded in the HISTORY records at the bottom of the `.c0h` header file. The DQE file appropriate for COSTAR-corrected *f*/96 observations is `foc_96_dqe_004.tab.`

The DQE file appropriate for pre-COSTAR *f*/96 observations is `foc_96_dqe_003.tab`.

6.2.3 Geometric Correction (GEOCORR)

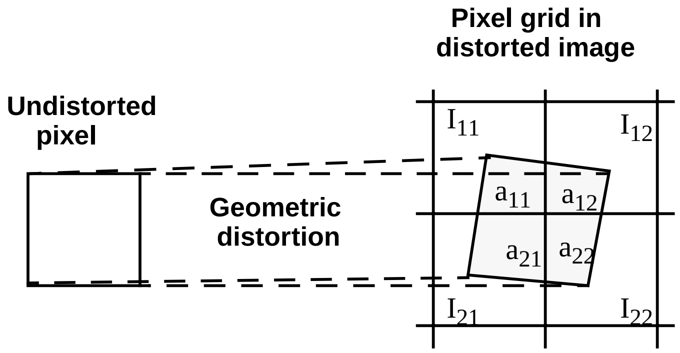
This correction removes both the *optical distortion* that arises in the telescope and the *detector distortion* produced by the electronic imaging system of the FOC. Optical distortion occurs upstream from the detector itself and arises primarily from the off-axis position of the FOC. Detector distortion occurs within the FOC's electronic imaging system, which consists of a three-stage image intensifier optically coupled to an Electron Bombarded Silicon (EBS) target TV tube.

Both the image intensifiers and the TV-camera section of the image system contribute to detector distortion. Intensifiers rely on an electric field for accelerating, and a magnetic field for focusing photoelectrons, and any irregularities in the uniformity of either results in distortion. The source of distortion within the target or TV camera section arises from the scanning of the target. This scanning distortion is due primarily to variations in the speed of the scanning beam at the ends of the sweep (where it must change direction), and the fact that the beam carries out an angular sweep across a plane target, with imperfections in the scanning electronics adding secondary effects. For these reasons, each video format has its own peculiar distortion characteristics, so the distortion measured for one format cannot be used directly to correct an exposure taken in a different format.

To facilitate correction of geometric distortion, reference points called *reseau marks* were etched onto the first of the bi-alkali photocathodes in the intensifier tube. These reseau marks form an orthogonal grid of 17 rows and 17 columns with a separation of 1.5 mm (60 pixels), each reseau being 75 microns (3 x 3 pixels) square. The detector distortion was originally determined by illuminating the photocathode with an internal light source, i.e., an internal flatfield. The observed positions of the reseau marks, when compared to the expected positions, provided a map of the detector distortion across the field. The optical component of the distortion was determined independently from ray-tracing models of the HST and FOC optics and was applied to the reference reseau grid to give the expected positions.

Unfortunately, the detector distortion for the FOC clearly showed variations on spatial scales smaller than the spacing of these reseau marks, particularly near the scan line beginning, and therefore models based only on the reseau marks inadequately represent the true distortion. A new method of determining distortion based on overlapping observations of crowded starfields was developed to determine the net distortion (the optical distortion is naturally folded into this new method). These observations yielded a two-dimensional spline distortion model from which the new geometric correction files were generated. The new scheme removes distortion by transforming each pixel in an undistorted image to a quadrilateral virtual pixel in the distorted image using the derived distortion model. The flux within the distorted pixel is then calculated as the sum of the contributions from each pixel the distorted pixel covers, where the weightings are simply the areas common to distorted and undistorted pixels. This procedure is illustrated in Figure 6.2. Because the transformed pixels fit together with no gaps and cover the distorted image completely, the method is rigorously flux-conserving. The improvement in quality is most apparent for smaller formats where the small number of visible reseau marks prevented the determination of a good model.

Figure 6.2: Pixel Transformation



$$I_{resampled} = I_{11}a_{11} + I_{12}a_{12} + I_{21}a_{21} + I_{22}a_{22}$$

If you need the finest possible spatial resolution, bear in mind that this method applies a position-dependent smoothing to the data. You might find working with the raw uncorrected data more profitable if you need to preserve every detail.

The keywords PXFORMT, SAMPPLN, LINEPFM, SAMPOFF, and LINEOFF indicate the format in which the image was taken and therefore determine the appropriate geometric correction file. Geometric correction files exist for most formats listed in Table 4.2 and Table 4.3. The keyword GEOCORR tracks the execution of this step and is set to COMPLETE upon creating the `.c0h` file. In addition, the keyword GEOHFILE lists the geometric correction file that was applied to the image, which can be useful in making sure that the proper correction was applied.

Status of GEOHFILE

The new geometric correction files have been used in the calibration pipeline for *f*/96 data since March 19, 1995 (*f*/48 geometric correction files are still based on reseau marks). Only observers who want sub-pixel accuracy in position measurements or those who have used the 256 x 256 format should even consider reprocessing their old data with the new geometric correction files. For most observers, the improvements will not significantly affect positions or photometry.

6.2.4 Flatfield Correction (UNICORR)

This correction is referred to as the uniform detective efficiency (UNI) correction. It attempts to remove the effects of non-uniform efficiency of the detector, and its complicated name is really just another way of saying "flatfielding." The procedure first selects the appropriate correction file on the basis of wavelength. The pivot wavelength of the bandpass (OTA + filters + detector) is used to select the correction file with the closest wavelength (in the geometric sense). The UNI correction files are 1024 x 1024 images from which the appropriate sub-image is extracted to match the image format of the science image. For example, a science image taken in the standard centered 512 x 512 format will use the center 512 x 512 of the appropriate UNI correction file whereas a 512 zoomed x 1024 format science image will use the whole UNI correction file (recall that the science image has been dezoomed in the pipeline process). These files are heavily smoothed to correct large-scale features extending more than 20 pixels and are geometrically corrected with the current geometric correction file. The calibration is then performed by multiplying the science image by the UNI sub-image given by the keyword UNIHFILE. The UNICORR keyword is then set to COMPLETE when this step is finished, and OMIT if it is not executed.

Status of UNIHFILE

The current UNI files are derived from the same observations that produced the pre-COSTAR corrections; external observations taken at 1360Å, and internal flatfields at 4800Å, 5600Å, and 6600Å. The difference between the pre-COSTAR and post-COSTAR UNI files lies in the geometric correction. The installation of COSTAR changed the optical distortion of the *f*/96 field, which is rectified in the geometric correction step. The latest UNI files, for COSTAR-corrected *f*/96 observations, are the pre-COSTAR UNI files corrected with the post-COSTAR geometric correction file.

The pre-COSTAR UNI files are derived from pre-COSTAR observations taken at 1360Å, 4800Å, 5600Å, and 6600Å, to which we have applied the pre-COSTAR geometric correction file.

6.3 Reasons to Recalibrate

FOC data files retrieved from the Archive were calibrated with the best calibration reference files available at the time the data were taken. You can use StarView, as described in Chapter 1, to determine both the reference files used in the original observation and the reference files now considered the best for calibrating that observation. (See *FOC ISR* 082 for a complete listing of calibration reference files.). However, discrepancies between these lists do not always mean that it is necessary to recalibrate, because the effect on the data might be merely to redistribute the noise slightly rather than to add anything significant to the signal. It is worth emphasizing that *there are very few situations where recalibration will significantly improve FOC science data*. FOC calibration files do not change frequently, and the changes that do occur tend to be minor.

The five reasons why a user might want to recalibrate FOC data relate to:

- New sensitivity information for the OTA+COSTAR+FOC system (e.g., new format-dependent sensitivity ratios, re-calibration of the FOC DQE curve).
- New flatfield reference files.
- New geometric correction reference files.
- Redesigned pipeline or introduction of new calibration modes.
- User-derived calibrations.

6.3.1 Absolute Sensitivity Keywords

You can account for changes in sensitivity information without recalibrating the data. Instead you can run tasks in the **synphot** package using the PHOTMODE relevant to the data. For example, suppose you want to redetermine the absolute sensitivity of exposure `x28t0203t`, a 256 x 256 *f*/96 image taken in February 1994, shortly after COSTAR was inserted. At that time, the COSTAR keyword was not correctly inserted into the PHOTMODE string, nor was the format-dependent sensitivity correctly recorded. The PHOTMODE for this particular observation is “FOC F/96 F2ND F1ND F346M”, whereas it should read “FOC F/96 COSTAR F2ND F1ND F346M X96N256”. Also, the HISTORY records show that the pre-COSTAR DQE file was used (`foc_96_dqe_003.tab`) rather than the in-flight calibrated `foc_96_dqe_004.tab`. The resulting inverse sensitivity in the header was

```
PHOTFLAM =          7.635416E-17 / Inverse Sensitivity
```

Recalculating using the **bandpar** task in the **synphot** package with the correct PHOTMODE and the most recent DQE file gives:

```
PHOTFLAM =          7.811949E-17
```

(Note that the URESP parameter that **bandpar** calculates is identical to PHOTFLAM.) The difference is not large, but it consists of a 25% increase, due to the inclusion of the format dependent sensitivity for the 256 x 256 format, and a 23%

decrease, due to the inclusion of the COSTAR mirror reflectivities. The effect of the updated DQE curve is negligible at that wavelength.

Recalibrating the absolute sensitivity keywords is slightly more tricky for pre-COSTAR data, because you must then tell **synphot** that COSTAR is not in the beam and to use the pre-COSTAR absolute sensitivity file. The first item is simple to deal with: just insert the value “nocostar” in the PHOTMODE string, e.g.:

```
band(foc,f/96,nocostar,f486n,x96n256)
```

The second item is more difficult to address: you must edit the HST component table available through the calibration reference file screens in StarView (see “Identifying Calibration Reference Files” on page 1-19). The most straightforward way to proceed is to **tcopy** the component table to a local working directory, **tedit** the file so that the COMPNAME `foc_96_dqe` (on line 605 or so) has the FILENAME `crfoccomp$foc_96_dqe_003.tab`, and then write the edited file to a new version with a different name. Then the task **refdata** can be used to make a parameter file that has a component table that refers to the pre-COSTAR FOC sensitivity file. Subsequently, **calcphot** can be run with **refdata** pointing to that new parameter file.

6.3.2 Flatfields

When new flatfields based on new flatfield data are delivered, it might be profitable to recalibrate by reapplying the flatfield. However, the only new flatfield deliveries were those derived in the ultraviolet using the Orion nebula as a target and those constructed in 1990 using internal flatfields taken during the Science Verification phase immediately after the launch of HST. The new flats from March 1995 were basically the same as the old flats except geometrically corrected using the new geometric correction files.

6.3.3 Geometric Correction Files

Delivery of new geometric correction files often lures users into thinking that they need to recalibrate their data using the most up-to-date reference files. In fact, this correction is rarely necessary, because the main effect is in improving the astrometric accuracy of the data. The photometric quality barely changes, because the geometric correction algorithm rigorously conserves flux, so the new correction merely redistributes the noise. Users who need the utmost astrometric accuracy (e.g., for proper-motion studies) will want to take advantage of improved geometric calibration files. However, they will still be left with some time-dependent positional uncertainty (see page 7-9) unless they take their own internal flatfields and calibrate out the time dependence of the geometric distortion themselves.

6.3.4 Improved Pipeline Algorithms

The fourth item is a catch-all for those situations where STScI staff are able to improve on the pipeline correction algorithm. Such a situation occurred in November 1991, when the order of processing changed so that geometric correction is performed before flatfielding. A more thorough discussion of this change and the rationale behind it is described in *FOC ISR* 051. Note that all FOC files in the Archive reflect this change because the entire Archive has been reprocessed in the meantime.

6.3.5 User Calibrations

The last item is for those users who have decided that the pipeline calibration is not sufficient for their needs or has compromised the quality of the data. For example, 8-bit overflows in 512 x 1024 data can often be corrected by adding integral multiples of 256 to the pixel values in the `.d0h` file until the intensity distribution is correct. You cannot repair the pipeline-corrected data in this way because the geometric correction algorithm smooths the overflowed pixels and mixes them with their neighbors. In that case, you must repair the `.d0h` file first and then recalibrate.

Alternatively, you might need to flatfield using an unsmoothed flatfield. In that case, the images must be lined up very accurately so that features on the photocathode (reseau marks, blemishes etc.—see pages 4-7 through 4-10) divide out properly. Extreme care is required in order to avoid misalignment artifacts.

6.4 How to Recalibrate

Once you have determined that recalibration is necessary, you can either rerun **calfoc** using the correct reference files or rerun the individual STSDAS tasks that perform the desired operations. Before recalibrating, make sure you obtain the desired reference files. The easiest way to obtain calibration reference files is via StarView, as described on page 1-19.

To recalibrate using **calfoc**, first assemble your set of calibration reference files. You can then use the task **chcalpar** in the **stsdas.hst_calib.ctools** package to edit the header parameters in your `.d0h` file so that they point to the desired calibration files. After you have set these parameters, run the **calfoc** task, and it will produce recalibrated FOC data files.

If you would rather execute the individual steps using the appropriate IRAF tasks, these are the steps to apply:

- ***Dezooming***: Use **stsdas.hst_calib.foc.focphot.dezoomx**. This step is straightforward.
- ***Absolute sensitivity keywords***: Use **stsdas.hst_calib.synphot.bandpar** as described in “Absolute Sensitivity Keywords” on page 6-8 or **stsdas.hst_calib.synphot.calcphot** as described on page 3-16.

- ***Geometric correction***: Use **stsdas.hst_calib.foc.focgeom.newgeom**. Again, this step is relatively straightforward.
- ***Flatfielding***: Use **iraf.images.imarith**. Remember to use the appropriate subset of the full-format flatfield and to *multiply* the data by the reference file, unless of course the flatfield has been derived by the user and is not inverted. For a 512 x 512 normal format image the appropriate IRAF command might be:

```
fo> imarith image.c0h * flatfield.hhh[257:768,257:768] \
>>>  image.c1h
```