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CAL-003

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ABSTRACT

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THE SPACE TELESCOPE
CALIBRATION DATA BASE
(PRE-LAUNCH EFFORT)

RALPH BOHLIN

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Scat'l

Scat'l

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The purpose of this document is to communicate the details of the level of support to the relevant quarters and to begin the formal effort to get the job done within reasonable costs and schedules. The requirements stated here can be expected to evolve through continuing interaction with the Instrument Scientists and the Development Teams.

Many value judgements need to be made regarding priorities of the calibrations and techniques used to make the measurements. The attached list should be regarded as our detailed first cut proposal of the high priority items that the ST Sci should be prepared to deal with in the launch epoch. In order to meet this schedule, in addition to software development and data base management expertise. Further support is assumed from SDA's in the form of the standard modules as identified in the Tables below.

A working definition of a calibration might be: any number or set of numbers pertaining to an instrument that is needed to fully interpret ST scientific data. An example is the wavelength scales for HRS, which depend upon order number and carrousel position. All of the indirect effort will be included here, such as the collection of the astronomical flux distributions for the ST standard stars. In order to make the plan tractable and well defined, all contingency calibration effort will be deferred, despite the fact that experience has shown that the unplanned effort in calibrating astronomical satellite data is much larger than what can be planned with certainty. As a first cut, only those calibration activities deemed essential will be planned at this time. Very useful information, such as point spread functions, may have to be derived after the first year of operation.

The requirements are detailed, and these individual estimates are summed. The estimated totals are useful for organizing the required resources and for setting priorities. The effort involves research coupled to considerable software development. The separation of the research from the software and the distinction of SDA's from non-SDA's software is a difficult but useful intermediate goal.

Our goal is to estimate the overall magnitude of the ST pre-launch calibration effort, which includes the analysis of laboratory calibration data and the generation of the parameters necessary to deal with flight data is costed, but the actual analysis of calibrations obtained after launch is excluded. Thus, those calibration parameters that can be derived from lab data should be in the data base at launch. Also, the research and software development needed to be ready to analyze flight data are included here.

II. DETAILED REQUIREMENTS

The organization is by instrument, plus a general section. For every instrument, each calibration function is listed and described. Following each of these items, there is a breakdown of the work estimates by research time and by required software. Software needed to perform the research is not separately identified, but software needed to generate specific entries in the calibration data base is listed. The breakdown of the software is by: 1) Those SDAS modules that are explicitly listed in SO-03, in which case only the reference to the appropriate section of SO-03 is cited. 2) Those modules that are implicit in SO-03, in which case a brief elaboration of our needs are stated in addition to the referenced section. The purpose is to be certain of the details of the SDAS support, but we have costed no effort here beyond that of aiding SDAS personnel to correctly address the problem. 3) The software not previously planned as part of SDAS in which case we have attempted to estimate the total effort required.

A. Common Among All Instruments

1. Calibration Data Base

One general requirement is the software to manage the Calibration Data Base (CDB) itself. The contents of the data base will be primarily alphanumeric with brief descriptive information about the particular calibration parameter, cross references to relevant publications, and complete definitions of the expected uncertainties. The actual numerical values of the calibration should be in a separate data set which is only referenced in the CDB, in order to avoid updating two separate data sets every time a calibration is changed. An automatic record of previous calibrations and their applicable dates should be kept every time a calibration is updated. A special print program that would allow any GO to list any current (or past) calibration or subsets by instrument is needed. This print program should recognize the data set name for the numerical calibration values and list the calibration values themselves along with the alphanumeric information.

Since this concept of an ST calibration data base is intimately connected to the data base required by the SOGS software, considerable effort will be needed to coordinate the development of the data base with TRW.

The publications that document the calibration parameters are essential in communicating to the astronomical community the processes by which the calibrations are obtained as well as estimates of their accuracy. Since the prime responsibility for calibration falls on the ST SCI only after launch, a minimal effort for prelaunch documentation and publication is listed below. Much more work will be required after launch.

a. PHYSICAL DATA - Currently planned physical data which will be needed to drive the RSDP consists of:
 (1) Pt-Ne spectrum, low to medium dispersion in the ultraviolet. This will be suitable for wavelength scale calibration of the low and medium dispersion modes for HRS and for the uv gratings on FOS.

Included in the calibration data base effort is the software and research necessary to assemble a body of physical and astronomical data which will be used to provide calibrations for the various science instruments. This data is termed reference data to distinguish it from the calibration data which is used in RSDP. The reference data base will normally not be used directly by the pipeline. Instead, these data plus raw ST data will be used to generate the standard calibrations used in normal data processing.

3. Reference Data Base

Work Details	
Study of format documentation.	200
Write a read program or homogenize IDT software for each of the five SI's.	0.2
	0.3
<u>M-YR</u>	<u>0.1</u>

b. Many calibrations, or preliminary calibrations, will be derived from lab data. The ST SCI should have the capability of analyzing and verifying all calibrations derived from lab data, especially if we need software to repeat similar analyses soon after launch using flight data as input.

a. All calibration software designed to operate on flight data must be tested before launch, if we have any expectations of correct execution using flight data as input. The best tests are done using real data from the flight instruments operating in the lab.

Modules are planned in SDAS for reading both raw and reduced SI data from the routine data processing pipeline. However, data from the SI lab calibrations are in a different format, which is not currently supported by SDAS. The ability to read lab data is essential to the calibration effort for two reasons:

2. Software to Read SI Laboratory Data

Work Details	
Little research given an experienced system programmer.	600
System programming to set up data base and coordinate with SOGS	50
Updating program	100
Print program.	--
Formal documentation	--
<u>M-YR</u>	<u>1.75</u>
	1.0
	0.1
	0.05
	0.6

- (2) Pt-Ne-Cr spectrum, low to medium disperions, in the visible for use with FOS data.
- (3) Pt-Ne spectrum, high dispersion for use with the HRS echelle gratings.

Wavelength tables will be stored with wavelengths, references, identifications, and a flag indicating for which gratings this line is to be used in determining the dispersion constants.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Identification of unblended candidate lines	--	.1
Collection of wavelength data	--	.15
Software to enter line library into the data base	200	.2
Entry of data into data base	--	.05
Software to read the line library	SDAS	
Software to print contents of the line library	<u>100</u>	<u>.1</u>
	300	.6

- b. ASTRONOMICAL DATA (STANDARD OBJECTS) - Standard stars are needed to absolutely calibrate all of the instruments. Standard emission line objects are needed for external wavelength standards for all spectroscopic modes. The polarimetric capabilities of the various instruments will also need to be calibrated. Since no on-board calibration sources for these modes are available, in flight calibration using astronomical sources will be required. Astrometric standard fields are needed to define plate scales and to calibrate geometric distortions. At the launch the following standard object libraries will be needed.

- (1) near infrared (8000-12000 A) standard star photometry
- (2) visual photometry of standard stars
- (3) ground based spectrophotometry of standard stars
- (4) uv spectrophotometry of standard stars
- (5) polarimetric standards
- (6) selected emission line standards (preferably diffuse objects)
- (7) standard astrometric fields

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Evaluation of criteria for standard objects (from instrumental requirements)	--	.1
Selection of candidate standard objects to be suitable for as many instrumental modes as possible.	--	.1
Evaluation of available data (literature and unpublished) for candidate standard object list.	--	.1
Software to enter standard object data into the data base (at least 3 modules)	600	.6
Collection of reference data	--	.3
Data entry	--	.15

The SOGS CDR raised the question of data quality flags in the case of telemetry dropouts. Since this is a larger problem involving all science data, the ST SCI is in the unique position of proposing a

6. Data Quality Flags

Work Details
Pre-flight data librarian

1.0
M-YR

As long as the ST data archives reside on multiple volumes of magnetic tape, sets of calibration data of one type will probably have to be extracted and maintained separately. Otherwise, too many tape mounts would be required to analyze all of a given set obtained over the years. Most of this work falls in the trend analysis category that is not costed in this launch epoch effort. For example, photometric changes in the sensitivity can be deferred, but analysis of the instrumental background data is needed immediately to understand how the operations should proceed, especially with regard to faint sources. In order to be ready to properly organize and collect data early in the program, a person should be trained in managing lab data starting about a year prior to launch.

5. ST Data Collection

Work Details
Research on the basis of IUE calibration
IUE observing and data reduction
Solution of the time change of IUE calibration
Documentation of results

0.2
M-YR
0.2
0.2
0.1
0.1
0.1
0.6

A valuable goal is to have all of the ST instruments calibrated on the same fundamental photometric scale. To accomplish this task, a set of standard stellar flux distributions is needed over the dynamic range and wavelength coverage of the ST Observatory. The IUE satellite spectra in the UV will be used in the wavelength regions that are missed from the ground. ST personnel including C.-C. Wu, C. Blades, A. Holm, and R. Bohlin are involved in IUE observing programs with the stated goal of providing the ST calibration in the UV. Since the basis of the IUE calibration could be significantly improved, some research time should be devoted to this fundamental effort. The collection of suitable ground based standard stars is being studied by the FOC, HSP, and WPC teams. Only the collection and reformatting of the ground based data is costed although ground based observations of a set of ST standards may be done by ST staff members, if required in the future.

4. ST Photometric Standard Stars

Software to print information in the
standard object header files
Preparation of documentation on the
standard objects

SDAS
--
600

1.60
0.25

solution that would be acceptable for every SI. In addition to telemetry dropouts, other examples of data that should be flagged are bad detector elements, saturated data, reseaux, and cosmic ray hits. The detailed definition of these flags are a natural consequence of the examination of SI data for calibration purposes.

To the best of our knowledge, only FOC and HRS have proposed solutions to this problem. The HRS has a 16 bit "epsilon" array (ref. ST SCI SOGS comments to SE-06-1, p. 48), which has a value for every data point in a spectrum. FOC suggests similar solution with only 4 bits of data quality indicator per image pixel, in order to minimize the total bits in the data products.

As a compromise between flexibility and total data storage, the plan is for an 8 bit data quality indicator for each sample obtained from each of the 5 instruments. The main impact on data volume is for WFPC, where the 8 bits will add 50% to the existing storage of the 16 bit image arrays.

Since only 8 conditions of data quality can be flagged as independently present or not present with 8 bits, the approach will not be to flag each condition. Instead, a hierarchical ordering will be established, such that if two data quality problems arise for the same pixel, then the flag with the higher numerical value will be chosen as the more severe error condition. For example, if a telemetry dropout (flag = 180), occurred on a pixel that is normally bad (flag = 200), the final output flag in the quality array would be 200. The proposed flag values are spaced within the 0 to 255 possibilities so that newly arising conditions can be given an appropriate severity ranking after the initial set is chosen. The severity level of 100 might be construed as our judgement of where the data is worth publishing below 100 and generally not valid above 100.

The following table of actual codes for anomalous conditions should be regarded as an example, or starting point for the detailed calibration work.

<u>Flag value</u>	<u>Error Condition</u>
250	General catchall for totally unusable data not otherwise specified.
200	Permanently bad detector element or gross noise problem.
190	Location on data array that is completely vignetted.
180	Telemetry dropout.
170	Reseau mark location.
160	FOS and HRS case where the sampling of the data point is less than one-half of the expected integration time, such as for bad diodes or the ends of a spectrum, where the overscanning is insufficient.
150	Full saturation at the maximum limiting count rate.
140	Saturation of count rate such that the error bar is greater than 20%.
130	Probable overflow in counting electronics.
120	Cosmic Ray hit.

Specifications
 Total for all Requirements Analysis: 1.93

Work Details (per analysis)	.050
Determination and documentation of instrument characteristics relevant to calibration methodology	.025
Determination of calibration methodology	.025
Reference data requirements derived	.025
Calibration software requirements derived	.050
Documentation of requirements	.175
Total	1.93

- o absolute photometric calibration
- o linearity corrections
- o flatfield corrections
- o echelle blaze correction
- o aperture size & location
- o background dark corrections
- o wavelength calibrations
- o spatial distortions and plate scales
- o polarimetry calibrations
- o instrument operational parameters
- o other data corrections

Before software can be designed, tested or coded, or reference data collected it is essential that the science instrument design and operation be understood. From this analysis will come the calibration methodology, software requirements, and reference data requirements. At this time the following requirements analyses are planned.

7. Scientific Functional Specifications

Flag Value	Error Condition	Lines of Code	M-Yr
110	Partially vignettted, such as WFPC neutral density spot. Suspicious detector element, such as minor excess noise or minor blemish.	400	.4
90	Saturation, such that the expected error is between 5 and 20%.		
80	FOS and HRS case where the multiplexing has provided integration times between 50 and 90% of the total.		
70	Abnormally large uncertainty for the wavelength in a spectrum.		
60	No special condition present.		
0	Definition of appropriate flags for each SI		
	Software to define flag data sets, eg. find Cosmic Ray hits		

B. FGS

1. Dark Signal

Thermionic emission and particle radiation will cause a dark count background that is probably a function of geomagnetic coordinates (B,L). This dark count will need to be measured in orbit with the sky shuttered off the PMT's, since the sky may be a significant signal. Hopefully, the background dark will always be insignificant compared to the sky signal. In this case, no actual dark calibration is needed, however, the difficulty of determining the sky background routinely may make the use of the FGS for photometry of faint stars impossible.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-Yr</u>
Observing plan for study of dark counts	--	.05
Special reduction software	50	.05

2. Linearity (paired pulse)

This is similar to the FOS, HRS, and HSP problem.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-Yr</u>
Observing Plan	--	.05
Special Software	50	.05

3. Aperture Sizes

This is similar to item 5 of the HSP.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-Yr</u>
Software and data entry	50	.05

4. Filter Transmissions

See WFPC, item 4 with no added software.

5. Absolute Sensitivity

See HSP item 7.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-Yr</u>
Special Reduction Module	50	.05

6. Koester Interferometer

The transfer characteristics, polarization dependence, the extended source response, and the orientation need to be determined. The level of effort and details are TBD.

<u>Work Details</u>
TBD

7. Spatial Geometric Distortion
 This fundamental determination of the relation between readout (X,Y) position and location in the sky will be required to do astrometry with the FGS. Details are TBD.
Work Details
 TBD

C. FOC

To obtain a minimum estimate of the software required to calibrate the FOC, the assumption has been made, for this section that new code will be required. IDT software, of unknown content, will be available to the Institute. See Section III for details.

1. Dark Signal

The FOC in flight will detect background counts due to a variety of sources, including thermionic emission from the various photocathodes in the intensifier chain, particle radiation, and persistent phosphorescence of the phosphors of the intensifier following overexposure or passage through the SAA. The calibration effort will be to prepare to analyze all of the flight background data and to define lookup tables to accurately subtract any diffuse components of the background that can be parameterized as functions of the geomagnetic coordinates (B,L).

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Specialized Software	200	.2

2. Linearity (ITF)

The FOC response to incident flux levels becomes non-linear at high incident flux rates due to saturation of the camera electronics. The functional form of this non-linearity varies from pixel to pixel. This means that a full intensity transfer function must be created for each pixel independently. This is done by assembling a suite of flatfield images taken with the on-board calibration lamp at known ratios of intensity or exposure time. The interpolation of the intensity levels of the ITF may be from a polynomial fit with 5 coefficient values per pixel.

Photometric Standard Stars will be used to confirm linearity in the visual.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Main Module	100	.1

3. Flat Fields (Relative Detector Q. E.)

The relative response of pixels in different parts of the field of view to monochromatic radiation of known and uniform intensity must be removed from the data if any relative or absolute photometric studies are to be made with the FOC. The general shape and fine structure of a flat field are both functions of wavelength. Cosmic ray spikes will be removed from the flat fields.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Main Module	100	.1

The intensifier and TV cameras used in the FOC suffer from geometric distortion of the image as a result of magnetic focussing in the intensifier chain and in the TV readout. In order to measure the degree of geometric distortion, a grid of fiducial marks has been printed on the initial photocathode. The geometric calibration will

7. Geometric Distortion
Spatial
Main Module & data entry
Work Details

Lines of Code 50
M-YR .05

Precise plate scales and checks on geometric distortion calibration can be determined from observations of the standard ST astronomical fields.

6. Plate Scale

Analysis of Problem
Main Module
Computation and convolution
Work Details

Lines of Code --
M-YR .1
 .05
 .05

Once the relative sensitivity is determined and verified, the absolute sensitivity can be determined by exposures of stars of known flux after the launch. The software needed at this stage should be similar to that of WFPC.

5. Absolute Sensitivity

Work Details
Create Filter Transmission Library

Lines of Code 100
M-YR 0.1

The FOC f/96 and f/48 modes are equipped with a variety of filters for wide, intermediate and narrow band photometry in the visual and ultraviolet. Absolute photometric calibration of these filters requires that the transmission characteristics of these filters be known as a function of wavelength. This measurement will be made in laboratory calibration.

b. Interference Filter Transmission Curves

The FOC f/96 mode is equipped with 5 neutral density filters for observation of relatively bright fields of view. The transmission characteristics of these filters must be known for absolute photometric calibration of the FOC. The transmission characteristics of these filters will be measured in the laboratory.

a. Attenuator Transmission Curves

The FOC has two varieties of filters: Attenuators (neutral density) and bandpass filters.

4. Filter Transmissions

FOC

identify these reseaux, and compute the transformation necessary to remove the distortion from the science data. At present whether this calibration will be done as part of SOGS or as part of the launch epoch calibration effort is uncertain.

8. Long Slit Spectroscopy

In the f/48 mode the FOC has an optional long slit spectrographic capability. A total of 3 gratings may be used with the slit to provide data in 4 orders in the visual and ultraviolet.

- a. ITF: The long slit spectrograph will be used in the 512x1024 zoom pixel mode and will require a specialized intensity transfer function. It has been determined in laboratory measurement that the intensity transfer function is independent of wavelength, so that the on-board LED's can be used to determine this ITF, as is the case for a normal intensity transfer function. No additional software is needed to generate this special ITF.
- b. Special Wavelength Dependent Flatfield: The pixel-to-pixel sensitivity of the FOC detectors is a function of wavelength. Any spectroscopic observations made with this instrument will have the detector wavelength sensitivity convolved with the flatfield response. The approach taken to solve this problem and provide the necessary calibration data is TBD.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Research		--.1
Special Flatfield Software	TBD	TBD

- c. Dispersion Calibration: The dispersion of the long slit spectrograph will have to be determined or at least verified in flight. The FOC has no onboard line emission source for wavelength calibration, so some research is needed to identify suitable astronomical calibration sources.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Main Module	50	.05
Interactive Line Identification	30	.03

- d. Absolute Sensitivity: The absolute sensitivity of the f/48 with the long slit spectrograph will be determined in flight from observations of ST standard stars.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Main Module	50	.05
Computation	TBD	

- e. Scattered Light Properties: The scattered light characteristics of the FOC will be most accurately determined during laboratory calibration.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Main Module & Data Entry	50	.05

f. Slit Dimensions and Plate Scale: The dimensions of the slit and plate scale of the observations will be needed for scientific interpretation of the long slit spectrograph data.

<u>Work Details</u>	<u>Main Module & Data Entry</u>
50	50
M-YR	M-YR
.05	.05

9. Objective Prism

The FOC has the ability to insert an objective prism into the optical path of both the f/96 and f/48 modes. Calibration of data from such observations, which are a convolution of spectral data with image data, is a largely unsolved problem. Research will be necessary to determine the approach taken to calibration of this data. Calibration requirements include wavelength dispersion and an absolute calibration. An unsolved problem is the wavelength dependent flat field.

<u>Work Details</u>	<u>Research</u>	<u>Specialized software</u>
--	TBD	TBD
M-YR	M-YR	M-YR
.1	.1	TBD

10. Polarimetry

The FOC in f/96 mode has 3 polarizing prisms with directions of maximum transmission rotated by 60 degrees respectively. The approach taken to the calibration of this data is TBD. Calibration parameters required include polarization angle, instrumental polarization, and polarizer efficiency.

<u>Work Details</u>	<u>Research</u>	<u>Specialized Software</u>
--	TBD	TBD
M-YR	M-YR	M-YR
.1	.1	TBD

D. FOS

The IDT is providing no software independently of the ST SCI calibration effort. As a result, generation of the software is being fully costed as part of the effort required to assemble the launch epoch calibration data base

1. Discriminator Thresholds

The FOS has commandable lower level discriminator thresholds, which can be set to exclude noise while retaining the scientific data. Optimum levels must be determined both in laboratory and in flight calibration. Some of the lower level modules for this calibration can be shared with HRS and HSP.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Specialized software:		
FOS discriminator thresholds	100	. 1
main module - I/O and set up for each diode.		
Use HSP lower level modules for each diode.		

2. Dark Signal

Since the most scientifically interesting astronomical targets are often the faintest, instrumentation is usually pushed to the limits of its capabilities early in the operational program. The FOS, like the other instruments on board ST will suffer from two sources of background, or dark count. The first is instrumental, and is primarily due to thermionic emission in the digicon photocathode. The second source is environmental, and is a result of particle radiation. For the FOS, the background dark count can be measured with high statistical accuracy in approximately 2% of the observing time. This measurement should be made routinely, thus eliminating the need to produce background lookup tables as a function of geomagnetic longitude and latitude. The calibration work will entail studies of where on the detector photocathode to make the background measurement, and determining the scaling from the standard background position to each of the aperture positions. Several background measurements at each aperture position will be averaged together in order to measure the fine structure of the background with high statistical accuracy. There will be separate dark calibrations with and without the activation of the burst noise rejection mode.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Filter and average multiple background measurements	50	.05
Compute scale factors for relative response of standard background and aperture positions.	100	.10

FOS data is read out as a function of diode number, and the problem is to correct diode or diode substep, to a vacuum wavelength for all modes. Corrections, such as vacuum-to-air, are specified as part of SOGS in SE-06; and corrections to account for possible thermal effects would be undertaken as part of the post-launch trend analysis studies. The standard approach is to use a line library to identify these lines in the calibration spectrum and to fit a polynomial to the measured positions of the lines after accounting for any significant geometric distortion. The coefficients to the polynomial fits are known as dispersion constants. In order to generate these dispersion constants by a routine and automatic procedure after launch, a library of the appropriate emission lines is required as an ancillary data set in the reference data base. Any offsets between the calibration lamp spectra and astronomical spectra should be measured by the IDT, but we should have a similar capability to verify offsets using flight data.

5. Wavelength Scales

<u>Work Details</u>	
<u>Specialized Software:</u>	
Flatfield	
Lines of Code	100
M-YR	.1

The sensitivity of the FOS digicons to uniform illumination varies from point to point as a result of non-uniformities in the photocathode and in the diode array. Since the FOS will observe at only a few independent vertical positions on the photocathode, calibration of the flatfield response of the instrument will involve collection and reduction of flatfield spectra at each of these positions. This calibration is intended to remove high frequency variations from the data and will not compensate for slow trends in photocathode sensitivity. Laboratory measurements of this parameter is preferred, if lamps with smooth continua fully cover the wavelength range. Flight data will confirm or update the lab data. Some research is needed to identify suitable astrophysical sources.

4. Flat Field

<u>Work Details</u>	
<u>Specialized software dealing with potential difference of linearity among the diodes</u>	
Lines of Code	100
M-YR	.1

The FOS is a pulse counting instrument like the FOC, HRS, and the HSP in digital mode. At high flux levels, the response of the detector compared to the incident flux becomes non-linear. The FOS IDT will use the same model to describe the paired pulse calibration as the HRS, and therefore will be able to share lower level modules with that instrument. The upper level module will differ due to the different formats of the two instruments. Linearity will be checked in flight with a program of standard star observations.

3. Linearity (paired pulse)

Thus, the work required is to find an appropriate set of lines and to define preliminary "starting" dispersion constants. Next, the preliminary dispersion constants can be used to predict approximate locations for each line in the library. A centroiding module provides a precise location to a fraction of a sample. Dispersion constants and errors then result from a least squares regression analysis of the line positions vs. wavelengths. Perhaps, the procedure would need to be iterated in order to discriminate against the occasional noise blip that can throw off the automatic centroiding procedure. In lieu of trend analysis, the initial choice of default dispersion constants for a given observation might be an average of several sets of constants from independent spectra.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Main program to read data and access line libraries	50	.05
Line centroiding - SO-03 9.3.11.2.		--
Least square polynomial fitting SO-03 9.3.7.		
Program to average a set of dispersion constants and determine a scatter about the mean. - SO-03	6.1.5 6.1.17	

6. Absolute Sensitivity

In order to do spectrophotometry with the FOS, it is necessary to know the absolute sensitivity for all modes as a function of wavelength. This will be determined by observing standard stars with well known flux distributions. Comparison of the standard spectrum with the FOS spectrum will lead to generation of the sensitivity curve as a function of wavelength for each grating and the prism.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Specialized Software main module	70	.07
compute inverse sensitivity curve	70	.07

7. Aperture Sizes

The dimensions and areas of the various apertures available to the user of the FOS must be known for accurate sky subtraction and interpretation of diffuse source data. These measurements will be made during laboratory calibration.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Specialized software to enter aperture dimensions and areas into data base	50	.05

8. Plate Scale

The plate scale of the FOS will be needed in the accurate interpretation of the science data particularly for target acquisition. This will be measured in the lab and in flight using an astrometric field or precise slews.

Work Details
Plate scale - main module
(primary data entry and I/O)

Lines of Code 50
M-YR .05

9. Spectropolarimetric

The FOS has the ability to do spectropolarimetry with a Wollaston prism assembly which can be rotated into the optical path. Correct interpretation of the resulting data will require calibration of this mode so that the intrinsic instrumental contribution to any polarization is known. The polarization calibration parameters are the locations of the two orthogonal beams on the digicons, the waveplate retardations, the Wollaston angles, waveplate angles, polarizer efficiency, and instrumental polarization. The calibration of the FOS polarization mode is primarily from lab data with checks in flight on unpolarized stars and stars of known amounts of visual polarization. The calibration effort will be in understanding the lab calibration data, entering it into the Calibration Data Base, ensuring that it is correctly applied, and preparing for the analysis of the flight calibrations.

Work Details
Specialized Software

Lines of Code 200
M-YR .2

10. Scattered Light

The FOS, like most spectrographs, will scatter some of the light incident upon the gratings. The distribution of the scattered light, both in an order, where it potentially contaminates data corresponding to different wavelengths, and perpendicular to the dispersion direction, where it can potentially contaminate any background measurements, must be known. Both of these characteristics can be most easily measured during laboratory calibration. This calibration will be for information only, and will not be relevant to the pipeline data processing.

Work Details
Main module-data entry

Lines of Code 50
M-YR .05

E. HRS

The HRS team has developed an extensive set of analysis routines in the language of IDL. Those lines of code estimates flagged with a "+" below indicate that IDL code exists for this function. The level of effort to convert IDL into FORTRAN has been costed at the reduced rate of 15 lines of executable code per day.

1. Discriminator Thresholds

This calibration will determine the optimum lower level discriminator threshold settings for each diode. This process makes use of general curve fitting routines as well as interactive graphics.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Specialized software:	340+	.11
Threshold calibration	50	.05
I/O keyword entry		

2. Dark Signal

In flight, the HRS will detect background counts from a combination of instrumental sources (such as thermionic emission from the photocathode) and environmental sources (such as particle radiation). These sources of noise will be detected in the absence of light entering the instrument and will also be present in all spectra.

- a. The special diodes: The HRS has 12 special diodes which are intended for use as monitors of background levels, scattered light, and particle radiation. In particular, 2 diodes (one is inoperative) are gold plated and should respond only to particles with energies greater than those of typical photoelectrons. The sensitivity of the operating particle diode with respect to the other diodes in the array must be known so that this diode can be used as a particle monitor. Likewise, the response of the other special diodes with respect to the diodes in the linear array must be known.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Special diode - main module	50	.05

- b. Dependence of geomagnetic coordinates: Particle fluxes are known to depend strongly on geomagnetic longitude and latitude. At the altitude of ST's orbit, the spacecraft pass near the South Atlantic Anomaly on many orbits. Since the HRS may be able to operate during these periods of enhanced particle flux, it is necessary to know, both for data reduction and observation planning purposes, the count rates due to particles that can be expected. This calibration will consist of assembling the particle count rates into a look up table sorted by geomagnetic coordinates. HRS cannot always measure the dark background in the same way as FOS, because starlight or scattered starlight may be always present everywhere on the photocathode in the echelle mode.

<u>Work Details</u>	
Photocathode Response	SE-06 10.2.1.1.1.1
Paired Pulse Correction	SE-06 10.2.1.1.1.2
Diode Response Correction	SE-06 10.2.1.1.1.3
Geometric Correction	
368+	
<u>Lines of Code</u>	<u>M-YR</u>
	.12

b. Photocathode Response: In this calibration the relative sensitivity of the photocathode to flat field illumination is determined. The paired pulse, diode response, and geometric (mapping) corrections must be applied to the data before this calibration can be computed.

<u>Work Details</u>	
Diode Response	SE-06 10.2.1.1.1.50
Paired Pulse Correction	
I/O keyword entry	
492+	
<u>Lines of Code</u>	<u>M-YR</u>
	.16

a. Diode Response Function: In this calibration the relative sensitivity of each diode is computed using observations made with the on-board flatfield lamp. The paired pulse correction is applied to the data before the diode response function is computed.

4. Flatfield

The HRS IDT has broken up the flatfield calibration into a determination of the response of the linear diode array and the response of the two dimensional photocathode to incident radiation.

3. Linearity (paired pulse)

The electronics of the HRS digicons have a natural response time to a pulse, as well as a deliberate dead time following detection of a pulse. These two properties result in a non-linearity of detected count rate compared to true count rate. This calibration determines the values of these two parameters which will be used to convert detected counts back to linear counts in data reduction. As for POS, this calibration should be done by the IDT before launch, implemented in the RSDP, and checked in flight. Similar software will be used by both POS and HSP and is costed elsewhere.

<u>Details of Work</u>	
Analysis of Problem	--
<u>Lines of Code</u>	<u>M-YR</u>
	.05

c. Burst rejection calibration: The HRS has optional anti-energetic particle hits in the linear array of diodes. Differences in background level with this capability on or off must be determined in order to choose the proper background in the RSDP default background mode.

<u>Work Details</u>	
Geometric dark-main module	50
Analysis of Problem	
<u>Lines of Code</u>	<u>M-YR</u>
	.05

I/O keyword entry

5. Spatial Geometric Distortion

- a. Vertical Deflection: This calibration determines the relation between the digicon y-deflections perpendicular to the dispersion and the actual position on the photocathode. Since the y-deflection is basically an analog voltage applied to magnetic deflection coils some non-linearity, i.e. geometric distortion, is expected. Data must be partially reduced using the paired pulse and diode response corrections before this calibration can be made.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Mapping function - lines	260+	.09
Find edges of photocathode in digicon deflections	76+	.03
Paired Pulse Correction	SE-06 10.2.1.1.1.1	
Diode Response Correction	SE-06 10.2.1.1.1.2	.05
I/O keyword entry	50	

- b. Horizontal Deflection: This calibration determines the relation between digicon x-deflection and photocathode sample (horizontal component of the geometric distortion). Data must be partially reduced using the paired pulse and diode response corrections before this calibration can be made.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Mapping function-samples	336+	.11
Find edges of the photocathode (horizontal)	112+	.04
Paired Pulse Correction	SE-06 10.2.1.1.1.1	
Diode Response Correction	SE-06 10.2.1.1.1.2	.05
I/O keyword entry	50	

6. Wavelength scales

This calibration will determine the relation between digicon sample number and wavelength using spectra of the on-board Pt-Ne calibration lamp. This involves reading the line library, converting the wavelengths greater than 2000 A to vacuum values, and using either previous values of the dispersion constants, or interactive graphics to identify those lines in the library for regression analysis. The gross spectrum must be extracted from the raw data. Regression analysis is used to compute the new dispersion constants. This software is usable for both the single grating and echelle modes of the HRS. This software may also be used for the FOS and special spectrographic modes of the cameras, but this is still TBD and has not been allowed for in this estimate.

The sensitivity of an echelle system is a strong function of wavelength within each order and a weak function of order number. The method for fitting this variation is TBD. Spectra used to generate this calibration must be fully linearized, flatfielded and geometrically corrected.

10. Echelle Blaze (Ripple)

Work Details
 Create plate scale
 library & data entry

Lines of Code 50
 M-YR .05

9. Plate Scale

This calibration will determine the plate scale (arc-sec/mm) at the detector photocathodes.

Work details
 Create aperture area
 library - main
 module and data entry

Lines of Code 50
 M-YR .05

8. Aperture Sizes

The dimensions and areas of the large and small apertures are needed in order to use one aperture for object measurement and the other to measure the sky background and in order to interpret diffuse source data. Physical dimensions may be best measured on the ground.

Work Details
 Specialized software including
 the handling of multiple
 orders of the echelle

Lines of Code 100
 M-YR .1

7. Absolute Sensitivity

The final photometric calibration for HRS data is the conversion of fully reduced counts to flux. This absolute calibration is the ST ratio of the response of the instrument in a particular mode to a standard star with a known flux distribution.

Work Details
 Analysis of Problem
 Specialized Software:
 Main Module
 Extract Spectrum
 Geometric Correction
 Convert wavelength to
 Find positions of lines in
 new spectrum
 Interactively measure line
 positions
 Regression analysis
 Keyword entry

Lines of Code 476+
 SE-06, implicit 10.2.1.1.1.3
 80 +
 costed elsewhere
 costed elsewhere

M-YR .2
 .16
 .03
 .05

<u>Work Details</u>			<u>Lines of Code</u>	<u>M YR</u>
			TBD (est 300)	est. .3
Ripple determination				
Reduction of data	SE-06	10.2.1.1.1.1		
		10.2.1.1.1.2		
		10.2.1.1.1.3		
		10.2.1.1.2		
I/O keyword entry			50	.05

11. Scattered Light

The best measurements of the scattered light characteristics of the HRS in the direction of the spectra can be made during laboratory calibration. This data will not be used in the RSDP, but will be needed in the interpretation of the scientific data on cool objects.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Main module involving primarily data entry	50	.05

F. HSP
The HSP does not have a dedicated software development program for ST. All software in this estimate has been coded for development at the ST Sci.

1. Discriminator Thresholds

The electronics on HSP contain commandable lower level discriminators. Optimal settings for these can be determined by observing the count rate for a standard star with a variety of settings. Computing the derivative of this response vs. setting curve and searching for the first local minimum yields the optimal threshold.

<u>Work Details</u>	
Threshold calibration -	50
main module	50
Curve fitting and display	50
module	50
<hr/>	
<u>Lines of Code</u>	50
M-YR	.05
	.05

2. Dark signal

The HSP is subject to three major sources of noise in the absence of light input. The first is noise in the pre-amp, which is present even when no high voltage is applied to the detectors. The second source is thermionic emission from the detector photocathodes. The sum third will be caused by particle radiation. In practice, only the sum of these noise sources are relevant as the default background subtraction in RSDP. Since these noise sources may vary significantly with temperature, the separate determination of the pre-amp noise will be of interest and perhaps of use to routine reductions. In order to eliminate the need to model the background as a function of temperature and geomagnetic coordinates, a method can probably be found to routinely and efficiently measure the dark background (as well as the sky background) by using synchronous data from a larger area of the same detector that is recording the object or from another detector.

Work Details

Prepare plan for routine dark determination	50
Special software for cross calibration at different locations on the detectors	50
<hr/>	
<u>Lines of Code</u>	50
M-YR	.05
	.05

3. Linearity (paired pulse)

In digital mode, the response of the detectors to incident photons will depart from linearity due to pulse pile up. Some of the modules coded in this section may be used for the HRS and ROS.

Work Details

Paired pulse correction-main	50
Computation module	100
<hr/>	
<u>Lines of Code</u>	50
M-YR	.05
	.1

4. Analog to Digital Conversion

Since the HSP data can be either digital or analog for each mode, the conversion from current to true counts must be measured in order to avoid a second complete set of calibrations for the analog mode. Will this be λ dependent because of multiple p-e⁻? Two separate settings effect the analog output:

- a. High Voltage Setting on the Tubes: The tube high voltage can be set using an 8 bit level command, but the precise voltage on a tube (H) is measured by a digital voltmeter and telemetered down in the engineering data. This measurement of the actual H eliminates questions of aging and temperature effects and will be assumed available for use in the RSDP. The number of photoelectron events (true counts), C, is related to the tube gain, g,

by $C = i/(ge)$, where i is the actual

tube output current and e is the charge per electron. The gain g is linearly related to H, the current is linearly related to a voltage V_0 across a resistor, and e is a constant. Combining all constants into one A value,

$$C = A V_0/H$$

The calibration A consists of measuring both C and V_0 for a particular mode and for each tube. Checks can be made at different count rates and H settings, although H would not normally be changed except for the brightest sources.

- b. Current to Voltage Converter (CVC): The CVC is a microammeter which converts the tube current output i to V with 5 separate ranges. The calibration consists of determining the 4 voltages relative to the 5th reference level V_0 for the same input source and for each tube. Tests need to be conducted for temperature effects on this calibration.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Analog to Digital Study	150	.15
and Software	150	.15
CVC study and software		

5. Aperture Sizes

In order to do accurate photometry, including correct subtraction of the sky background, the areas of each of the apertures must be measured. This will be done on the ground.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Main Module and data entry	50	.05

6. Filter Transmissions
See WFPC item 4 with no extra software.

7. Absolute Sensitivity

This calibration will account for the efficiency of all elements in the optical path including filters and the detectors. This calibration will be obtained from observations of standard stars through each filter/aperture/detector combination.

Work Details
Main module (including convolution of filter response with standard star) use FOC code to compute ratio
50
Lines of Code
M-YR
.05

8. Polarimetry

The HSP has a dedicated image dissector tube for polarimetric observations in 5 bandpasses in the near ultraviolet. Determination of the instrument sensitivity will be identical to the process outlined above for absolute calibration of the filter/aperture/detector systems. Once the relative sensitivity of the different aperture/detector combinations is known for a given filter, it will be necessary to verify the lab calibrations by computing the Stokes parameters for both unpolarized targets and targets of known polarization. The instrumental intrinsic polarization and the sensitivity to polarized light will be determined from flight calibrations.

Work Details
Research to understand reduction to Stokes parameters
data entry
100
Lines of Code
M-YR
.1
.05

G. WFPC

1. General Purpose Software

Software modules which are used in more than one calibration but are specific to the WFPC and are not currently included in the SDAS design are listed below. Software which is believed to be under development by the IDT has been indicated by a + and has been costed for translation at 15 lines of code per man-day.

Due to the presence of hot pixels in the calibration data which must be preserved, the ordinary SDAS blemish removal software will not be suitable for use in cosmic ray removal from the WFPC data. Instead, a new module will be developed which will work by examining corresponding pixels in a set of WFPC exposures of equal time on the same target. The distribution of signals at each location will show a distribution that differs from statistical expectations, if any cosmic ray hits are present. The bright cosmic ray portion of the distribution can then be ignored in computing the average signal for each pixel. This technique will be especially useful for long exposures on faint objects and for producing an average flat field for use in the RSDP. Note that the WFPC team has software in their system to do this sort of a task.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Cosmic ray removal +	100	.1

2. Dark Signal

The CCD's used in the WFPC are subject to a variety of noise sources which will provide a background to any astronomical observation and must be removed in the early stages of reduction of WFPC data.

- a. Zero Frame: A zero frame is a measurement of the detector read out noise and any dark counts recorded during the 13 second readout. The average of this noise level must be subtracted from all data, after any cosmic ray hits have been removed.
- b. Bias Frame: A bias frame contains the detector read out noise but with the addition of a short exposure using the on-board calibration lamp to ensure 300 electrons in each well (pixel). This is done to avoid trapping of astronomical data in the transfer gate which would result in a non-linear response to incident flux at low light levels. Cosmic ray hits must be removed from the average of this level before it can be used in data reduction. Either this frame or a zero frame (depending on the operational mode of the WFPC) must be removed from all WFPC data.

Spatial

6. Plate Scale and Geometric Distortion

An accurate plate scale is needed to interpret WFPC results and for use in aiding target acquisition for other instruments. The main WFPC-assisted-target-acquisition mode is expected to be blind offsets from bright to faint targets within a WFPC frame. The other instruments would center quickly on the bright star and do the blind offset, as measured from the WFPC image. The highest accuracy required is about 0.01 to center a target in the smallest (FOS) hole. Therefore, this calibration is not intended to be of the ultimate accuracy that would be useful for purposes of astrometry. The WFPC IDT has provided software that should be helpful in using a standard ST astrometry field to deduce the geometric distortion and plate scale.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Study problem	--	.1
Implement IDT software	400	.12

7. Objective Grating

The WFPC has an objective gratings mounted on the SOFA. As for the FOC objective grating, the calibration tasks are special flat fields, wavelengths scales, and absolute calibration. Again, the flat field is the big problem, if the pixel-to-pixel variation is a strong function of wavelength. The solution is TBD, and the main effort will be in coordinating the development of reduction algorithms with the IDT. The calibration of the objective grating is not a RSDP function. SDAS software is required for analysis following the standard pipeline reduction to a flat field at a TBD wavelength.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-YR</u>
Develop plan and Software for Flat Field	1500	.45

8. Polarimetry

The WFPC has polarizing elements with 3 orientations which can be used in conjunction with the other filters to do filter photo-polarimetry. Reduction will be identical to a normal image up through absolute sensitivity calibration. At that point it will be necessary to extract the data of interest from the relevant 3 images and compute the Stokes vectors both for the object of interest and for unpolarized targets. The algorithm for this reduction has not yet been selected.

<u>Work Details</u>	<u>Lines of Code</u>	<u>M-yr</u>
Understand details and write software	1500	.45

III. SUMMARY

A. Assumptions on Software Development

1. New Code

A number of assumptions have been made in estimating the amount of new software which will be required to calibrate the various science instruments. These are:

- a. Since calibration will be supported using the SDAS system, the capabilities required for SDAS in SO-03 have been assumed to be available. This has meant, in general, that lower level modules, such as matrix arithmetic, display, numerical analysis, and I/O using the SDAS GET's and PUT's have been assumed to be present. Higher level modules peculiar to the generation of a given calibration parameter are not required in SO-03, and have been coded in this document.

- b. I/O: all I/O will be done (where possible) using the SDAS utilities. Approximately 50 lines of code will be needed per calibration parameter in order to establish the keywords that are unique to that parameter and if necessary, enter values for those keywords.

- c. New code estimates have been based on assuming 100 lines of code per identifiable module.

- d. Manpower requirements have been coded at 5 lines of executable code per day. This includes software design through final testing but does not include any research time required to determine how the observational data for a given calibration can be obtained. Manpower needed to study a problem and develop the calibration algorithms is coded separately from the software.

- e. "Throwaway" code, which will be used for entering those calibration parameters which can only be measured in the laboratory is conventionally coded at 7 lines of code per day. Since the amount of such code in this effort is rather small compared to the uncertainties in the amount and nature of the software that will be required, it has been coded as new, maintainable code.

2. Use of Existing Code

In scoping a minimum effort to put together the launch epoch calibration data base, it has been assumed that wherever possible existing software has been used. Since the software developed by the various instrument teams is in a variety of languages, and will be documented to varying levels of completeness, effort is required to convert this code into FORTRAN-77 running under SDAS and meeting the requirements for delivery. Details:

- a. All existing code being brought into SDAS to support calibration is being costed at 15 lines of code per day regardless of the language or level of documentation of the incoming code.
- b. FOC: The IDT has generated approximately 5000 lines of executable FORTRAN-77 to support calibration. The contents of these lines of code is not known at present. It is estimated that approximately 2000 lines of code represent a minimal calibration software set for FOC.
- c. HRS: The IDT has generated approximately 2000 (with all I/O) lines of IDL to support their calibration effort. The number of lines of FORTRAN code running under SDAS corresponding to a line of IDL code is currently unknown but estimated to range from 2-4 lines of code. For comparison, the conversion factor for FORTRAN without the capabilities of SDAS is anywhere between 4 and 8. Costing in this effort has assumed 4 lines of FORTRAN per line of IDL code.

B. Cost Totals

Wherever reasonable, an effort has been made to share modules (i.e. wavelength calibration, discriminator thresholds, and linearity corrections) for similar instruments. This summary is incomplete in that the requirements for several of the calibrations have not been identified at the present time.

The lines of code and manpower estimates below represent the results of a cursory evaluation of the requirements. In general, the estimates assume that the instruments will behave ideally. Should instrument behavior differ significantly from the ideal, as is likely to be the case (note that several such deviations have already been noted by the IDTs, but have not been costed here since the solution to the deviations from ideal behavior has not been determined), additional software development and effort will be required. In general, information on how far this estimate falls short will not be available until laboratory calibration has been completed for all of the science instrument, and the results have been fully analyzed. USE THE NUMBERS IN THIS SUMMARY WITH EXTREME CAUTION. THEY ARE A LOWER BOUND ON THE EFFORT NEEDED TO CALIBRATE THE ST IN ORDER TO DO USEFUL SCIENCE.

1. Common Costs

	<u>Lines of Code</u>	<u>M-YR</u>
<u>Work Details</u>	750	1.75
Calibration Data Base	200	.3
Read Lab SI Data	900	2.2
Reference Data Base	--	.6
Standard Stars	--	1.0
Data Collection	400	.55
Data Quality Flags	--	1.93
Scientific Functional Specifications	2250	8.33
Common Total		

5. HRS Costs

	<u>Lines of Code</u>	<u>M-YR</u>
<u>Work Details</u>	390	.16
Discriminator Thresholds	100	.20
Dark Signal	--	--
Linearity	960	.38
Flatfield <i>Spatial</i>	834	.37
Geometric Distortion	600	.44
Wavelength Scales	100	.1
Absolute Sensitivity	50	.05
Aperture Sizes	50	.05
Plate Scale	350	.35
Echelle Ripple	50	.05
Scattered Light	<u>3484</u>	<u>2.15</u>
HRS Total		

6. HSP Costs

	<u>Lines of Code</u>	<u>M-YR</u>
<u>Work Details</u>	100	.10
Discriminator Thresholds	50	.10
Dark Signal	150	.15
Linearity	300	.30
Analog to Digital Conversion	50	.05
Aperture Sizes	50	.05
Absolute Sensitivity	150	.15
Polarimetry	<u>850</u>	<u>.90</u>
HSP Total		

7. WFPC Costs

	<u>Lines of Code</u>	<u>M-YR</u>
<u>Work Details</u>	100	.1
General Purpose Software	150	.18
Dark Signal	100	.13
Flat Field	-	-
Filter Transmission	-	-
Absolute Sensitivity <i>Spatial</i>	400	.12
Plate Scale & Geometric Distortion	1500	.45
Objective Grating	1500	.45
Polarimetry	<u>3750</u>	<u>1.43</u>
WFPC Total		

8. Cost Summation

Thus, a factor 2 increase in the above estimates would not be surprising in view of points 1- above. Calibration activities require a peculiar blend of motivation, astronomical understanding, and software experience. This blend of qualifications is often difficult to find. Thus, the problems of hiring experienced personnel, when combined with the usual frustration found in real data, make estimating man power requirements especially difficult. Experience has shown that an additional factor of two between estimates and reality could be possible.

- 1) This is a preliminary study and many items are TBD.
- 2) No contingency is included, especially with respect to potential instrumental problems that may require significantly more software development.
- 3) Lots of help from IDT software is anticipated without examining any of that code.
- 4) Some required calibrations, such as aperture locations with associated error bars and trend analysis, have been considered primarily the purview of OPD. An internal memorandum of understanding has formally assigned primary responsibility in these fringe areas.
- 5) Insufficient time has been budgeted for evaluation of the derived calibration results, especially since it is generally true that instruments never behave as one would like to expect them to perform.
- 6) No planning of ST calibration observations is costed here.
- 7) No extensive effort is budgeted to collect the astronomical data on standard sources. Support from the IDT's or the calibration working groups is assumed with only minor effort on evaluation and reformating for the SDAS system.
- 8) No programmatic support is included for such things as management and presentations.

The reader must be reminded that the above estimate are for the effort required to be ready for launch. The minimal essential calibrations are the only ones listed here. Others, such as the point spread function, are needed for refined scientific analysis, but their cost has been deferred to the post-launch calibration effort. Experience with other astronomical satellites has shown that post-launch calibration efforts are much larger than what can be done or anticipated before launch.

Additional specific reasons why the approximately 15 man year effort should be regarded as a lower limit are:

C. Discussion

Common Costs	Lines of Code	M-YR
WFC Costs		
HSP Costs		
HRS Costs		
FOS Costs		
FOC Costs		
FGS Costs		
200 + TBD		2250
880 + TBD		12404 + TBD
8.33		15.38
0.3 + TBD		1.43 + TBD
1.28 + TBD		2.15
		.99
		3484
		850
		3750
TOTAL COSTS		12404 + TBD