

Technical Evaluation Report
“Recommended TA FSW and Operations Changes Based upon the
TAACOS Phase I Reports for the FUV and NUV Channels”

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1. BACKGROUND

The goal of the "Target Acquisition Analysis for the Cosmic Origins Spectrograph (TAACOS)" software simulation project is to ensure that the algorithms and procedures defined for COS Target Acquisition (TA) are sufficient to accurately place a science target at the proper location in the aperture.

During the months of March 2000 - February 2001, a large number of TA scenarios were examined and simulated for the FUV and NUV channels using TAACOS. The results of these simulations are described in the documents COS-11-0016, "TAACOS: Phase I FUV Report", and COS-11-0024 "TAACOS: Phase I NUV Report". Those interested in the full discussion and results of the simulations should examine these two documents. There exists the possibility that TA FSW may be needed to help correct OSM1 rotation step errors during NUV exposures. This possibility is addressed in COS-11-0028, "TAACOS: OSM1 Positional Verification FSW."

The purpose of this brief document is to summarize the recommended changes to the TA Flight Software (FSW) and Operations (OPS) based upon the Phase I simulations.

2. RECOMMENDED CHANGES FOR TA FSW

2.1 EVEN-ORDERED SEQUENCES FOR SPIRAL SEARCH PATTERNS

The Target Search (TS) phase of TA for both the FUV and NUV channels should support an even-ordered sequence of dwell points (e.g., 2x2, and 4x4 search patterns). The implication of supporting an even-ordered sequence of dwell points is that the starting point for the spiral search pattern should be offset from the initial, target coordinates. Furthermore, the target coordinates should be at the center of the spiral search pattern. Consequently, the TA FSW must be able to request a small, offset slew to place the telescope at the first dwell point of an even-ordered sequence of dwell points. This initial offset slew should be selectable with an ON/OFF option, with a default value of ON.

2.2 FLUX-WEIGHTED CENTROID THRESHOLDS

For the TS and Peakup in the Dispersion Axis (PD) phases of TA for both the FUV and NUV channels, the flux-weighted centroid (FWC) calculation should have the following thresholding capabilities, which can be used individually or in conjunction with one another, but when used in conjunction should be executed in the following order:

2.2.1 GLOBAL THRESHOLD

GLOBAL THRESHOLD compares the total number of counts summed over all the dwell points versus a minimum count value multiplied by the total number of dwell points. The idea behind this threshold scheme is that if the sum of the counts from the dwell points does not exceed the computed GLOBAL THRESHOLD, then the target was either not in the dwell pattern, or is sufficiently fainter than was expected. As such, the results of the search, in the case of TS - or the peakup, in the case of PD - are deemed unreliable. In this case, the telescope should be returned to the initial coordinates of the observation. (Note: This does not necessarily imply returning to the first dwell point - see Section 2.1 above.) The GLOBAL THRESHOLD capability should be selectable using two patchable values - i.e., zero values would effectively disable the GLOBAL THRESHOLD.

$$\text{Global_Threshold} = \text{Number_Dwell_Points} * (\text{GC}_0 + \text{GC}_1 * \text{ExpTime})$$

2.2.2 FLOORED THRESHOLD

FLOORED THRESHOLD reduces the number of counts in each dwell point by subtracting a constant value from the number of counts in each of the dwell points. The idea behind this threshold scheme is to reduce the contribution of 'background' or 'noise' counts into the FWC calculation. The FLOORED THRESHOLD capability should be selectable as ON or OFF and when it is ON the threshold value should be the minimum number of counts measured from any of the dwell points. Note: The science header contains space for reporting the total counts at each dwell point. As such, the total counts at each dwell point should be reported in the science header BEFORE performing the floored threshold (if floor thresholding is enabled). [By having the FSW store the counts at each dwell point before flooring, the ground system can find the minimum value and thus know what the floor was, without its value being separately reported].

2.2.3 LOCAL THRESHOLD

LOCAL THRESHOLD excludes dwell points from the FWC calculation whose total counts are below a minimum value. The idea behind this threshold scheme is to remove those dwell points from the FWC calculation which do not contain any appreciable flux from the target. The LOCAL THRESHOLD capability should be selectable, but should also independently choose its threshold value from the largest value computed from two different methods. One method computes the threshold as the sum of a patchable count value plus a second macro-parameter specified count value multiplied by the exposure time. The alternate method uses a patchable percentage of the maximum count value measured from any of the dwell points. In equation form:

$$\text{Local_Threshold} = \text{Maximum}(\% \text{ of Max. Dwell} ; LC_0 + LC_1 * \text{ExpTime})$$

Note: Either method of the LOCAL THRESHOLD capability can be made selectable by setting the appropriate patchable constants to zero. Consequently, separate LOCAL THRESHOLD Enable/Disable options for either method are not required.

2.3 IMAGING TA USING THE TA1 MIRROR

Based upon simulations described in COS-11-0027 we recommend the creation of two new TA routines for performing NUV imaging TA. Optical element ‘wobble’ and rotational inaccuracies of the OSM mechanisms require that the detector location corresponding the center of the aperture in use be determined for each TA. The first routine (LTAIMCAL) is designed to determine the NUV detector location of the spatial centroid of an image of the calibration lamp shown through the calibration aperture. This mode is performed in TIME-TAG data acquisition mode. The second routine (LTAIMAGE) determines the location of the target in the aperture by obtaining an ACCUM image of the sky, determining the centroid of the target image, and relating this via the plate scales and the LTAIMCAL calibration image centroid coordinates into slew amounts which will place the target in the center of the aperture. The specifics of these modes follow: With the external shutter closed, slew HST to the initial target coordinates.

- 1) Rotate OSM1 and OSM2 to the desired settings (this could be in the “Rear View Mirror Mode” (RVMM)).
- 2) Determine if the mode of operation involves the RVMM. Two sets of four patchable constants (PC) determine rectangular detector subarrays of detector coordinates to consider. One set is appropriate for RVMM procedures, and another for normal (NORM) operations. These PCs are integers that can have values of 0-1023. The mode of operation determines which rectangular subarray to use. All events outside this subarray are ignored. The subarray is commanded by the ground system before activating LTAIMCAL. The ground system is also responsible for ensuring that the detectors are active and ready for TA.
- 3) Perform LTAIMCAL (Locate Calibration Image). The macro inputs to this procedure are:
 - a. the calibration lamp choice (Platinum-Neon Lamp 1 or Platinum-Neon Lamp 2),
 - b. the lamp current setting (low, medium or high), and
 - c. the exposure duration.

The LTAIMCAL outputs are the X and Y detector coordinates of the centroid of the calibration lamp image. Specifically, the LTAIMCAL steps are:

- a. Turn on the commanded calibration lamp at the commanded current for the commanded duration. Read out the detector in TIME-TAG mode. The normal bright object protection (BOP) is applied.
 - b. Use a median algorithm to determine the X and Y centroids of the calibration lamp image. Only the first 4000 counts need to be considered.
 - c. Compare the number of counts received to a fifth PC. If the total number of counts detected is below the fifth PC, the calibration image is not within the specified subarray. Under these circumstances, an error is issued and the remainder of the TA and science program is aborted.
 - d. Store the X and Y median centroid coordinates in floating point pixels (accuracy to tenths of a pixel are sufficient), for subsequent use in LTAIMAGE.
- 4) Perform LTAIMAGE (Locate Target Image). Once again, the ground system should determine if the mode of operation involves the RVMM. As before, two sets of four patchable constants (PC) determine rectangular detector subarrays of detector coordinates to consider. These PCs are integers that can have values of 0-1023. The mode of operation, as determined by the ground system, determines which rectangular subarray to use. All events outside this subarray are ignored. The macro input to this procedure is the exposure time; the stored LTAIMCAL X and Y centroids are used during the execution of LTAIMAGE. LTAIMAGE computes the X and Y slew amounts, in arcseconds, required to center the target in the aperture, and commands this slew. When LTAIMAGE completes execution, the target should be centered in the aperture. Before executing LTAIMAGE, the ground system should ensure that external shutter is open, and that the NUV detector is active. Specifically, the LTAIMAGE steps are:
- a. Perform the BOP check.
 - b. Perform the exposure for the commanded duration in ACCUM mode
 - c. Add two PCs (one in X [dY] and one in Y [dY]) to the stored X and Y coordinates of the LTAIMCAL centroid. This defines the position (X', Y') on the detector corresponding the center of the aperture with the current OSM1 and OSM2 settings.
 - d. Create a new subarray (the 'small box') whose lower right corner is, in (X, Y) coordinates, (X'-PCX, Y'-PCY) and whose upper left corner is given by (X'+PCX, Y'+PCY). PCX and PCY are integer PCs of the range 1 to

- 255 which give the half extent of the small box subarray in X and Y respectively.
- e. Trim the ACCUM image to the small-box given by this subarray. This "small-box" image will be referred to as the SBI. The SBI should be retained in buffer memory.
 - f. Use a moving box plus flux-centroid (MBPFC) to determine the X and Y centroids of the target image. The general steps of the MBPFC are:
 - i. Scan an NxN pixel box across the SBI, one pixel at a time through all possible $(2*PCX-N)*(2*PCY-N)$ locations.
 - ii. Determine the NxN pixel box with the maximum counts. If multiple locations contain the same number of counts, select the first one encountered.
 - iii. Determine the X and Y flux-centroid (mean) locations (XC and YC) within the NxN pixel box location with the maximum counts. The XC and YC centroids will be floating point numbers over the range 0-1023.
 - g. Compute the required ΔX and ΔY pixel shifts required to move the MBPFC centroids to the desired (X', Y') detector location ($\Delta X = X' - XC$, $\Delta Y = Y' - YC$).
 - h. Compute the required X and Y slews in arcseconds on the sky. This is performed by multiplying ΔX and ΔY by two PCs representing the X and Y NUV+TA1 plate scale in units of arcseconds per pixel. The PCs representing the TA1+NUV subarrays should be in the range (-0.1 to 0.1 with accuracy to five decimal places required [to achieve a round off error of $< 0.001''$]). Convert these detector instrument coordinate system slews to HST V2 and V3 slews. Request HST to perform the calculated V2 and V3 pointing improvements.

At this point, the target should be centered in the aperture¹. If desired, a science, or target verification, ACCUM or TIME-TAG exposure can be performed at this time. This, however, is not part of the LTAIMAGE or LTAIMCAL routines. After this is

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¹ There exists the possibility that the LTAIMCAL centroid coordinates will need to be used to correct for OSM1 rotational step errors. This possibility is explored in COS-11-0028.

complete, OSM1 or OSM2 will need to be rotated to insert the desired grating into the optical path.

2.4 MEDIAN VALUES FOR CAL-APERATURE, XDISP-PEAKUP AND TA1

For the Calibration Aperture Location (CAL), Peakup in the Cross-Dispersion Axis (PCD), and TA1 (See Section 2.3 above) phases of TA, the use of a median gives consistently more accurate answers than a mean - especially for the MAMA Detector, whose high background rate adds a significant 'noise' component to the mean. Therefore, if available memory and processor speed exists to perform a median on approx. 2000-4000 photon events - it is recommended that the TA FSW for both the FUV and NUV channels be modified to include the capability of performing a median. Furthermore, the use of a mean or a median should be independently selectable for the CAL, PCD and TA1 (in the case of the NUV channel) phases of TA.

2.5 USE AVERAGE CROSS-DISPERSION PLATE SCALES FOR LTAPKXD

As determined in COS-11-0016 (Rev A) and COS-11-0024, the average cross-dispersion (XD) plate scales across the bandpasses for the FUV and NUV gratings are listed in the following table.

Channel	Grating	Cross-Dispersion Plate Scale
FUV	G130M	9.02 p/''
	G160M	10.12 p/''
	G140L	9.48 p/''
NUV	G185M	-41.85 p/''
	G225M	-41.89 p/''
	G285M	-41.80 p/''
	G230L	-42.27 p/''

The question at hand, is whether TA needs to use the precise XD plate scale for the grating in use, or is it acceptable to use a single plate scale for each channel. The average XD plate scale for the three FUV gratings is 9.54 p/'', and for the four NUV gratings, it is -41.95 p/'' (the sign refers to direction on the sky, an NUV +X detector motion corresponds to a -Y move in the aperture coordinate system.)

During LTAPKXD, the XD location of the target spectrum is measured and compared to the known XD location of a well-centered target. A single calculation using the plate scale determines the magnitude and direction of the XD centering maneuver. Since the target must already be within 2'' of the center of the aperture to shine any light upon the

detector, this is the maximum allowable shift. For the FUV channel, the XD plate scale of the G160M is farthest from the average plate scale, and provides the worst-case estimate. For the NUV channel, the G230L provides the worst-case estimate. This worst-case error introduced by using the average XD plate scale instead of the individual plate scales (ΔXD) can be calculated as :

$$\Delta XD(FUV) = (10.12 p/'' - 9.54 p/'') * 2'' = 1.2 p = 0.12''$$

$$\Delta XD(NUV) = (42.27 p/'' - 41.95 p/'') * 2'' = 0.6 p = 0.01''$$

These worst-case errors are well within the allowed XD budget of 0.3'', and we recommend using single plate scales averages for LTAPKXD for each of the channels. The average XD plate scales derived above, are repeated in the following sections.

2.6 RETURN TO BRIGHTEST MINIMUM THRESHOLD

The LTASRCH and LTAPKD TA algorithms can also be commanded into a Return To Brightest (RTB) mode. In this mode, the telescope is commanded to the dwell point with the maximum counts. If the number of counts in the brightest dwell position is below a minimum value, then the search fails. The original FSW design called for a single patchable constant for this minimum value regardless of exposure time, or optical channel. However, the driver for the minimum counts are the detector backgrounds, which are functions of exposure time (ExpTime) and detector (NUV or FUV). We suggest that the minimum counts RTB threshold be replaced with the value used during the local threshold portion of the flux-centroid (FC) algorithm, specifically,

$$RTB_Threshold = LC_0 + LC_1 * ExpTime.$$

As with the FC algorithm, LC_0 and LC_1 are a function of the optical channel in use. As the purpose and use of these constants is identical in the FC and RTB algorithms, the same values of the patchable constants are appropriate.

3. PATCHABLE CONSTANT VALUES AND BOUNDS FOR THE TA FSW

The following table (Table 1) contains reasonable estimates of the minimum and maximum values, by patchable constant (PC) type, and the number of decimal points of accuracy for the TA FSW parameters discussed in the previous sections. In some cases multiple PCs share common ranges and types. In this case, the number of recommended PCs are given in brackets ([]), and explained in footnote. In addition to the PCs, appropriate subarrays for LTAIMCAL and LTIMAGE must be specified.²

Table 1 – Patchable Constant Minimum/Maximum and Accuracy Requirements

§	Parameter Name Or Type	Data-type	Units	Accuracy ³	Min	Max
2.2.1	GC ₀	Int	counts (cts)	0	0	20000
2.2.1	GC ₁	Float	cts/second (s)	2	0	500
2.2.3	% Max Dwell	Int	%	0	0	64
2.2.3	LC ₀	Int	cts	0	0	20000
2.2.3	LC ₁	Float	cts/s	2	0	500
2.3	Min LTAIMCAL Counts	Int	cts	0	0	2000
2.3	Target-Cal Offsets [2] ⁴	Float	pixels (p)	1	-1023	1023
2.3	Small-Box Half-Size [2] ⁵	Int	p	0	0	255
2.3	MBPFC Box size (N)	Int	p	0	1	170
2.3	NUV+TA1Plate Scale [2]	Float	m ^{"/p} ⁶	2	-50.0	50.0
2.5	NUV XD Plate Scale	Float	m ^{"/p}	2	-50.0	50.0
2.5	FUV XD Plate Scale	Float	m ^{"/p}	2	-200.0	200.0

Table 2 contains initial estimates of the TA FSW patchable constants (PCs) discussed in the previous sections. In addition to the PCs, the NORM and RVMM subarrays must also be specified for the LTAIMCAL and LTAIMAGE procedures.⁷ The “% Max Dwell” is

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² The subarray bounds can be for LTAIMCAL or LTAIMAGE, RVMM or Normal, upper or lower, left/right, X or Y. Sixteen total PCs are used for subarray for TA1 image mode TA.

³ Accuracy = Required number of decimal places to the right of the decimal point.

⁴ One PC for the calibration to science aperture offset in each X (PCX) and Y (PCY).

⁵ One in X (dX) and one in Y (dY).

⁶ Milli-arcseconds per pixel (m^{"/p}).

⁷ The LTAIMCAL and LTAIMAGE normal (NORM) and RVMM subarrays are specified by 4 positive integers, which define a rectangle on the detector. These subarrays are specified in COS-01-0001. Current initial values were identified in COS-11-0027.

included, although it is not a FSW PC, but is instead a ground system macro parameter. The current FSW constant names are given in ()'s.

Table 2 – Patchable Constant Initial Values

Parameter Name	Configuration	TA Procedure(s)	Initial Value	
GC ₀ (pcta_FUVGC0)	FUV Channel	LTASRCH ⁸ LTAPKD ⁹	0 cts	
GC ₀ (pcta_NUVGC0)	NUV Channel		0 cts	
GC ₁ (pcta_FUVGC1)	FUV Channel		1.24 cts/s	
GC ₁ (pcta_NUVGC1)	NUV Channel		40.00 cts/s	
% Max Dwell (macro parameter)	FUV Channel		10 %	
% Max Dwell (macro parameter)	NUV Channel		10 %	
LC ₀ (pcta_FUVLC0)	FUV Channel		0 cts	
LC ₀ (pcta_NUVLC0)	NUV Channel		0 cts	
LC ₁ (pcta_FUVLC1)	FUV Channel		1.24 cts/s	
LC ₁ (pcta_NUVLC1)	NUV Channel		40.00 cts/s	
X Calibration to Science Aperture Offset (pcta_XImCalTargetOffset)	NUV+TA1 Mirror		LTAIMAGE	392.0 p
Y Calibration to Science Aperture Offset (pcta_YImCalTargetOffset)	NUV+TA1 Mirror			59.6 p
NUV+TA1 Plate Scale ¹⁰ X (pcta_NUVMilliArcsecsPerPixelX)	NUV+TA1 Mirror	-23.50 m"/p		
NUV+TA1 Plate Scale Y (pcta_NUVMilliArcsecsPerPixelY)	NUV+TA1 Mirror	-23.55 m"/p		
Small-Box X Half Size (pcta_SmallBoxXHalfSize)	NUV+TA1 Mirror	85 p		
Small-Box Y Half Size (pcta_SmallBoxYHalfSize)	NUV+TA1 Mirror	85 p		
MBPFC Box size (pcta_CheckboxSize)	NUV+TA1 Mirror	9 p		
Min LTAIMCAL Counts (pcta_ImageCalThreshold)	NUV Channel	LTAIMCAL		100 cts
FUV Average Plate Scale (pcta_FUVMilliArcsecsPerPixelXDisp)	FUV Channel	LTAPKXD	104.82 m"/p	

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⁸ The LTASRCH phase is also referred to as the Target Search (TS) TA phase in this document.

⁹ The LTAPKD phase is also referred to as the Pickup in the Dispersion direction (PD) TA phase.

¹⁰ Recall for the NUV Detector: X, Y-axis for detector pixels do not correspond to the X, Y-axis of the aperture (See Figure 6 of COS-11-0024).

NUV Average Plate Scale (pcta_NUVMilliArcsecsPerPixelXDisp)	NUV Channel		-23.84 m"/p
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4. RECOMMENDED CHANGES FOR TA OPS

4.1 FUV: SUBARRAYS TO EXCLUDE GEOCORONAL EMISSION LINES

For the TS and PD phases of TA in the FUV channel, subarrays of arbitrary - but fixed - size should be used to specifically exclude counts from those regions of the spectra that include bright, geocoronal emission lines.

For a given grating and OSM position, these subarrays can remain fixed for the entire TS and PD phases, i.e., "moving" subarrays are not required. Note: The bright, geocoronal line regions can be excluded with the existing requirement of supporting four unique subarrays per segment in the FUV channel. The specific pixel positions of the subarrays for the FUV Detector will be provided by the Instrument Development Team, as soon as the COS instrument hardware reaches a level of maturity such that these values can be reliably estimated.

4.2 FUV: SINGLE SEGMENT DATA FOR ALL PHASES OF TA

For ALL phases of TA in the FUV channel, the default configuration is to use both FUV detector segments. However, the capability should exist to use only the counts accumulated from one of the two detector segments - either by setting subarrays to exclude one of the two segments, and/or by lowering the HV to the HVLOW value on one of the two segments.

4.3 NUV: SUBARRAYS TO LIMIT DETECTED COUNTS FROM MAMA

For ALL phases of TA (including TA1 exposures, per §2.3 above) in the NUV channel, the capability should exist to set arbitrary - but fixed - subarrays such that only a portion of the MAMA is used to accumulate counts. The reason for using these subarrays is to minimize the effect of the MAMA's high background rate. Examples of using subarrays on the MAMA would be:

- 1) Place a subarray to include only counts from the region of the MAMA that is directly illuminated by the PSA (or, as appropriate, the BOA) during the TS phase;
- 2) Place a subarray around a single spectral stripe during the CAL and PCD phases of TA; and
- 3) Place a subarray to include only the PSA (or BOA) - as per (1) above - during the TA1 phase of TA.