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COS Target Acquisition Guidelines, Recommendations, and Interpretation

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ABSTRACT

Based upon analysis of SMOV and Cycle 17 observations through April 2010, this ISR expands, updates, and supersedes recommendations and information provided about target acquisitions (TA) in the COS Instrument Handbook version 2.

This ISR provides an overview of COS TA, presents general guidelines and recommendations for crafting COS TAs, establishes COS TA centering accuracy requirements to achieve COS photometric, velocity, and resolution objectives, and summarizes the performance of the COS on-board TA modes as compared to these centering requirements. Updated TA strategy recommendations are given where appropriate, a user-oriented table lists where to find important quantities for the analysis and interpretation of COS TAs, and a brief appendix with additional supporting information is included.

An overview of COS TA strategies is provided in Section 2 and Table 1; important updates to `ACQ/SEARCH` *requirements and* `SEARCH-SIZE` *recommendations as a function of target coordinate accuracy are given in Tables 2 and 3; COS TA performance by mode is described in Section 5; important header keywords that are useful for evaluating the quality of COS TAs are listed in Table 5 along with where to find them; Table 6 gives a summary of COS TA modes, options, and recommended values; Section 7 summarizes updated recommendations and guidelines for COS TA; and Appendix A provides additional useful COS TA information.*

Contents:

This document is based upon and summarizes the results of COS TIR 2010-03(v1), "Details of On-Orbit Target Acquisitions with HST+COS" (Penton & Keyes, 2010). Please consult this TIR for further in-depth technical details about the requirements, operation, and on-orbit perfomance of COS Target Acquisitions.

1. Introduction

This ISR supplements and updates the information contained in the COS Instrument Handbook version 2 (IHB, Dixon and Niemi 2009) concerning performing target acquisitions (TA) with the Cosmic Origins Spectrograph (COS). The revised and improved recommendations and guidelines presented in this ISR are derived from lessons learned from the analysis of observations made during the Servicing Mission Observatory Verification (SMOV) of June-October, 2009, the October 2009 to February 2010 Cycle 17 GO and GTO period (referred to hereafter as the SMOV/ C17 sample), and following an important COS-to-FGS alignment update in March 2010 through April 2010. Recommendations and guidelines presented in this ISR supersede those of the COS IHB version 2.

1.1 Quick Guide to Information in this ISR

An overview of COS TA strategies is provided in Section 2 and Table 1; `SEARCH-SIZE` recommendations for `ACQ/SEARCH` as a function of target coordinate accuracy are given in Tables 2 and 3; COS TA performance by mode is described in Section 5; important header keywords that are useful for evaluating the quality of COS TA are listed in Table 5 along with where to find them; Table 6 gives a summary of COS TA modes, options, and recommended values; Section 7 summarizes updated recommendations and guidelines for COS TA; and Appendix A provides additional useful COS TA information.

2. COS Target Acquisition Overview

COS has four target acquisition modes:

- **ACQ/IMAGE** obtains an NUV image of the target field, moves the telescope to center the object, and secures a second NUV image as a confirmation (details are in Section 2.1). This is generally the fastest and most accurate method of target acquisition, but covers a limited area on the sky.
- **ACQ/SEARCH** performs a search in a spiral pattern by executing individual exposures at each point in a square grid pattern on the sky (details are in Section 2.2). This mode can use either dispersed-light (grating spectral element) or imaging (mirror spectral element) exposures.
- **ACQ/PEAKXD** determines the centroid of the dispersed-light spectrum in the cross-dispersion (XD) direction and moves the telescope to center the object in the XD direction (details are in Section 2.3).
- **ACQ/PEAKD** centers the target in the along-dispersion (AD) direction by executing individual exposures at each point in a linear pattern along the AD direction (details are in Section 2.4). ACQ/PEAKXD should always precede ACQ/PEAKD, and the two should always be performed together.

Coordinate accuracy and target brightness will determine choice of TA strategy and optional parameters. Each TA mode may be used more than once, if desired, and while technically these four types of COS TA could be performed in any order, the recommended basic strategies are given in Table 1.

Table 1: Basic COS Target Acquisition Scenarios

Type	Step 1	Step 2	Step 3
Imaging (excellent coordinates)	ACQ/IMAGE	none	none
Imaging	ACQ/SEARCH	ACQ/IMAGE	none
Dispersed-Light (excellent coordinates)	ACQ/PEAKXD	ACQ/PEAKD	none
Dispersed-Light	ACQ/SEARCH	ACQ/PEAKXD	ACQ/PEAKD
Either Imaging or Dispersed-Light	ACQ/SEARCH	2x2x1.767 ACQ/SEARCH	none

In particular, imaging acquisitions can be fast and accurate, but the restrictions on local count rate (see IHB) can be a factor, even with MIRRORB. We suggest evaluating the options in the following order:

1. NUV imaging target-acquisition sequence (ACQ/SEARCH and/or ACQ/IMAGE) with the fastest allowable aperture and mirror combination even if the science to follow is performed with the FUV channel.
2. Dispersed-light acquisition using the same configuration as for the first science exposure that follows the acquisition, if it will use less time overall.
3. Dispersed-light acquisition with a different configuration, if it will use less time overall.

The basic scenarios outlined here are for isolated point source objects. See the Appendix for additional information regarding crowded or complex fields and offset target TAs.

In the next four sub-sections we will examine each of these modes in detail, particularly when the TA centering accuracy depends upon the proper choice of TA mode options. A summary of the recommend values for all user-selectable TA mode options is given in Table 6 in the Summary section. Each TA mode also uses TA flight software (FSW) parameters that are not specifiable by the user. These FSW parameters are not discussed in this document, but are described in detail in COS TIR 2010-03.

2.1 ACQ/IMAGE

COS `ACQ/IMAGE` acquisitions may use either the primary science aperture (PSA) or the bright object aperture (BOA) and may use either the MIRRORA or MIRRORB optical element with either aperture. MIRRORB is not a physically separate optical element but is instead MIRRORA oriented so that the order-sorting filter in front of the mirror reflects light onto the detector. Additionally, light reflecting off the back of this filter forms a secondary peak with approximately half the intensity of the primary peak and displaced by 20 pixels (about 0.5 arcsec) in the along-dispersion (AD) direction. The signal in the primary MIRRORB image is diminished by approximately a factor of 20 relative to an equivalent MIRRORA image. The recommended S/N for MIRRORB acquisitions (see Table 6) refers only to the primary image; the COS Exposure Time Calculator[1] (ETC) performs this calculation appropriately.

When the BOA is used, the slight wedge shape of its neutral-density filter produces a chevron-like image whose peak is displaced in both the dispersion and cross-dispersion directions. When the BOA is used with MIRRORB, two distorted peaks result. There is some overlap in this configuration between the wings of the primary and secondary peaks, but they are well enough separated to allow for reliable acquisitions.

Please refer to the COS IHB or TIR 2010-03 for illustrations of images obtained with the PSA/BOA and/or MIRRORB. Due to the complex shape of images obtained through the BOA, a S/N of ≥ 60 in the primary image is recommended to center the target with that aperture (see Table 6).

An `ACQ/IMAGE` exposure consists of the following steps:

- An exposure of the internal Pt-Ne lamp is obtained through the WCA aperture. The onboard COS Flight Software (FSW) chooses the exposure time for the lamp exposure automatically. The centroid of the WCA image is calculated by the FSW. Using the known offset between the center of the WCA and the science apertures (PSA or BOA), the location of the center of the science aperture on the detector is computed.
- The shutter is opened and a TA image of the initial telescope pointing is obtained. (Acquisition images obtained through the PSA should strive for a minimum S/N = 40; those obtained through the BOA should have S/N ≥ 60.) The telescope is not moved, meaning that an acquisition using `ACQ/IMAGE` will be successful only if the target lies within or near the aperture. An area of 170x170 pixels, which corresponds to approximately 4x4 arcsec, centered on

[1] The COS Exposure Time Calculators (ETC) can be found at http://etc.stsci.edu.

the aperture, is then read out. This image is recorded and downlinked, and becomes part of the archived data package (as the dataset contained in the first extension of _rawacq).

- A 9x9 pixel checkbox array is then passed over the 170x170 pixel image. First, the checkbox with the most counts is identified. In the unlikely instance that two checkboxes have equal counts, the first one encountered is used. The brightest 9x9 array is then analyzed using a flux-weighted centroiding algorithm to calculate the target position.
- Finally, *HST* is moved to place the calculated centroid at the center of the selected aperture, as calculated above. Another exposure, identical to the initial image, is taken and recorded for later downlink as a confirmation of the centering (as the dataset contained in the fourth extension of _rawacq). Note that NUV `ACQ/IMAGE` exposures require two minutes plus twice the exposure time specified for the acquisition image.

See Section 5.1 for a discussion of the on-orbit performance of `ACQ/IMAGE` including a discussion of centering accuracy.

2.2 ACQ/SEARCH

In `ACQ/SEARCH` mode, the telescope is moved in a spiral pattern on the sky to cover a square grid up to 5x5 steps in size. At each scan point, the telescope stops and an integration is taken. After completion of the full *n* x *n* pattern, the target position is calculated, and the telescope is moved to center the target.

Target coordinate uncertainty determines the size of the `ACQ/SEARCH` search pattern. Table 2 presents the Cycle 17 recommendations for `ACQ/SEARCH SCAN-SIZE` as a function of coordinate uncertainty. We also include Table 3 below, which contains the revised recommendations for the Cycle 18 Phase II preparation period.

If the uncertainty in target coordinates is ≤ 1 arcsec in the GSC2/ICRS reference frame, then a 3x3 search using a `STEP-SIZE` of 1.767 arcsec is recommended, and should work well (see Tables 2 and 3).

Table 2: Cycle 17 Recommended ACQ/SEARCH SCAN-SIZE values as a function of coordinate quality

Recommended SCAN-SIZE	Coordinate uncertainty (arcsec)	STEP-SIZE	CENTER method
2	$\sigma \leq 0.4$	1.767[a]	FLUX-WT
3	$0.4 < \sigma \leq 1.0$	1.767[b]	FLUX-WT-FLR
4	$1.0 < \sigma \leq 1.3$	1.767[b]	FLUX-WT-FLR
5	$1.3 < \sigma \leq 1.6$	1.767[b]	FLUX-WT-FLR

[a] This is the default STEP-SIZE value, and is the largest pattern to cover the search area while directly sampling the entire search area without holes or gaps.

[b] If target coordinate uncertainty is on the low edge of the given range, STEP-SIZE may be reduced slightly (e.g., 1.5 arcsec) to improve target centering accuracy by sacrificing the total area of the sky covered by the search pattern.

Table 3: Cycle 18 Recommended ACQ/SEARCH SCAN-SIZE values as a function of coordinate quality

Recommended SCAN-SIZE	Coordinate uncertainty (arcsec)	STEP-SIZE	CENTER method
0	$\sigma \leq 0.4$		
2	$0.4 < \sigma \leq 0.7$	1.767[a]	FLUX-WT
3	$0.7 < \sigma \leq 1.0$	1.767[b]	FLUX-WT-FLR
4	$1.0 < \sigma \leq 1.3$	1.767[b]	FLUX-WT-FLR
5	$1.3 < \sigma \leq 1.6$	1.767[b]	FLUX-WT-FLR

[a] This is the default STEP-SIZE value, and is the largest pattern to cover the search area while directly sampling the entire search area without holes or gaps.

[b] If target coordinate uncertainty is on the low edge of the given range, the STEP-SIZE may be reduced slightly (e.g., 1.5 arcsec) to improve target centering accuracy by sacrificing the total area of the sky covered by the search pattern.

Note. — SCAN-SIZE equal to zero implies that the observer is bypassing ACQ/SEARCH altogether and proceeding directly to ACQ/IMAGE or ACQ/PEAKXD+ACQ/PEAKD.

For an ACQ/SEARCH, the user must specify:

- The aperture to use, either PSA or BOA.
- The spectral element (grating or mirror) to be used and the central wavelength setting (if a grating is employed). In general, for a spectroscopic ACQ/SEARCH this will be the same grating and central wavelength to be used for the science observation. However, an observer may use ACQ/SEARCH with a different grating + central wavelength combination or a mirror if there are advantages to doing so.
- The SCAN-SIZE, which is 2, 3, 4, or 5, corresponding to spiral patterns of 2x2, 3x3, etc.
- The STEP-SIZE, or spacing, between grid points. A value of 1.767 arcsec is recommended.
- The exposure time per dwell point.

- For FUV searches, users may choose to use just one of the segments, A or B, but the use of both (the default for all but G140L) is recommended.

Once the integrations are complete, the flight software determines which point in the array contains the source. There are three centroiding options:

1. The first option is `CENTER=FLUX-WT`, which uses a flux-weighted centroiding procedure to determine the center of light, and is the default for `SCAN-SIZE=2`.
2. A variation on `CENTER=FLUX-WT` is `CENTER=FLUX-WT-FLR`. In this case, a floor is subtracted from the counts at each dwell point before the centroid is computed. The floor is taken as the minimum number of counts seen in any one dwell point. `FLUX-WT-FLR` has the advantage of removing background counts, but leaves one or more points in the array with zero. This can cause computational problems; as a result, `FLUX-WT-FLR` should not be used with `SCAN-SIZE=2`.
3. The last option for centering is to use `CENTER=BRIGHTEST`, which simply centers the dwell point with the most counts. This is straightforward but not as accurate as the other centroiding methods. `CENTER=BRIGHTEST` is appropriate if coordinates are uncertain and the `ACQ/SEARCH` is followed by a second `ACQ/SEARCH` using flux-weighted centering or an `ACQ/IMAGE`; or if the source is extended and it is only desired that the brightest point is in the aperture.

For all values of `SCAN-SIZE` greater than 2, we recommend `CENTER=FLUX-WT-FLR`, as `ACQ/SEARCH` stages using `CENTER=FLUX-WT-FLR` are slightly more accurate due to better sky and detector background suppression. Large `SCAN-SIZE` values should be used only in cases where the target coordinates have large uncertainties (see Table 6). A 3x3 pattern should be adequate in virtually all cases. Note that the even `SCAN-SIZE` values (2 or 4) trigger an additional overhead because of the telescope motion required to displace the aperture by half of a `STEP-SIZE` in both the dispersion and cross-dispersion directions, so that the overall pattern remains centered on the initial pointing.

The `STEP-SIZE` parameter determines the spacing, in arcsec, between dwell points in the pattern. It may be any value from 0.2 to 2.0 arcsec ("), but we strongly recommend using the default value of 1.767 arcsec. This value has been chosen so that no part of the sky is missed, given the 2.5 arcsec diameter aperture (2.5"/√2 = 1.767").

<u>Centering accuracy</u>: A single `ACQ/SEARCH` stage, using one of the recommended parameter combinations, generally places a source within 0.3 arcsec of the aperture center in both the AD and XD directions; however, depending where in the `ACQ/SEARCH` pattern the initial pointing places the target, residual centering errors large enough to affect photometric accuracy or spectral resolution are possible. For this reason, as noted in Table 1, we recommend that all COS TAs which employ an `ACQ/SEARCH` follow up the initial `ACQ/SEARCH` with either an `ACQ/IMAGE`, `ACQ/PEAKXD+ACQ/PEAKD`, or a second 2x2x1.767" `ACQ/SEARCH`.

See Section 5.4 for a discussion of the on-orbit performance of `ACQ/SEARCH` including a discussion of centering accuracy and the influence of detector background on the centering of faint sources. See Table 6 for a summary of ACQ/SEARCH parameter choices.

2.3 ACQ/PEAKXD

To improve centering in the cross-dispersion (XD) direction after an initial ACQ/SEARCH, an ACQ/PEAKXD sequence may be used. The steps executed in an ACQ/PEAKXD sequence are:

- A short exposure of the Pt-Ne wavelength calibration lamp through the WCA aperture is obtained, the centroid of the spectrum is calculated, and the desired XD location of the target spectrum in the chosen aperture is computed.
- A target spectrum is recorded for the user-specified time using a sub-array tailored to each grating and central wavelength (to remove edge effects and airglow lines).
- The target XD location is then measured via a median (NUV) or a mean (FUV). For the FUV, the data are in raw coordinates (without thermal or geometric distortion) and the XD location is therefore more difficult to measure with high precision. In addition, FUV segment B events must be mapped to the segment A coordinate system before a merged mean XD location is determined. For these reasons, FUV ACQ/PEAKXD XD determinations are less accurate than NUV determinations.
- The slew required to move the target spectrum in the XD direction to the center of the aperture is computed.
- The telescope is slewed by the calculated offset to center the target in the XD direction.

The user must specify the aperture (PSA or BOA, typically the same as for the science exposure), the grating and central wavelength, and the exposure time. The use of MIRRORA or MIRRORB is not allowed. For NUV ACQ/PEAKXD acquisitions, the stripe (SHORT, MEDIUM, or LONG, corresponding to stripes A, B, or C) to use for the computations is specified; however, the default stripe B (MEDIUM) is recommended as it achieves better centering than the other stripes. For FUV ACQ/PEAKXD acquisitions, either one of the segments, A or B, may be used, but use of the default (both, except for G140L) is recommended. For G140L the default is segment A only.

We recommend a minimum S/N = 40 for ACQ/PEAKXD exposures. STScI calibration programs routinely use up to S/N=100 to minimize the influence of Poisson noise and background when very precise pointing is required.

See Section 5.2 for a discussion of the on-orbit performance of ACQ/PEAKXD including a discussion of centering accuracy. See Table 6 for a summary of ACQ/PEAKXD parameter choices.

2.4 ACQ/PEAKD

ACQ/PEAKD is used to improve centering in the along-dispersion (AD) direction after an initial ACQ/SEARCH and an ACQ/PEAKXD. ACQ/PEAKD works very much like ACQ/SEARCH except that, instead of a spiral, the spacecraft is moved linearly along the AD axis between exposures. The centroid is computed, and the telescope is moved to center the target in the AD direction in the aperture.

The user must specify the aperture, grating and central wavelength, and the exposure time at each dwell point. The use of MIRRORA or MIRRORB is not allowed. The number of steps may be 3, 5, 7, or 9. We recommend using NUM-POS=5 as this covers a larger area of the sky than NUM-POS=3 for the recommended STEP-SIZEs and uses the more robust CENTER=FLUX-WT-FLR centering method. The preferred STEP-SIZE depends on the number of positions sampled. If NUM-POS=3 is chosen, we recommend STEP-SIZE=1.3 arcsec, and if NUM-POS=5, we recommend STEP-SIZE=0.9 arcsec. If NUM-POS=7 or 9 then STEP-SIZE=0.6 arcsec is recommended (see Table 6).

As with the ACQ/SEARCH TA stage, there are three options for the centering algorithm, CENTER=FLUX-WT, FLUX-WT-FLR, and BRIGHTEST, and they work just as described in Section 2.2. We recommend the use of the special parameter CENTER=DEFAULT, which uses CENTER=FLUX-WT if NUM-POS=3, and CENTER=FLUX-WT-FLR if NUMPOS=5, 7, or 9.

For FUV ACQ/PEAKD acquisitions, one of the segments, A or B, may be used, but use of the SEGMENT=DEFAULT (both, except for G140L) is recommended.

We recommend a minimum S/N = 40 for ACQ/PEAKD exposures. STScI calibration programs routinely use up to S/N = 100 to minimize the influence of Poisson noise and background when very precise pointing is required.

See Table 6 for a summary of ACQ/PEAKD parameter choices. See Section 5.3 for a discussion of the on-orbit performance of ACQ/PEAKD including a discussion of centering accuracy.

3. HST Blind Pointing

We have estimated the initial (blind) pointing accuracy of HST+COS observations by reverse engineering all of the TAs of the SMOV/ C17 sample of observations. Through the end of February 2010 we observed an initial pointing bias of [AD,XD] = [-0.22 ± 0.47, -0.17 ± 0.49]".

In general, the 1σ coordinate accuracy of the guide stars in the GSC2 is ~40 mas, so the standard deviation of our blind pointing is slightly higher than the guide star accuracy due to target coordinate uncertainties. The initial pointing bias of [-0.22, -0.17]" is, however, not expected and must be the result of a minor FGS-to-COS misalignment.

A check (12/2009) of this alignment was performed in HST program 11878. In this project, targets in well-defined astrometric fields in the open cluster M35 were observed using guidestars with positions determined to ~20 mas. For COS, the star 206W3 was observed using the same guide stars as all other HST science instruments. The MIRRORA ACQ/IMAGE of this target required an [AD,XD] slew of [0.108, 0.225]", indicated a FGS-to-COS bias ([-0.108, -0.225]") comparable to that seen in the average of all COS TAs ([-0.22, -0.17]"). Comparing the HST program 11878 bias to only those COS TAs taken with a MIRRORA ACQ/IMAGEs and FGS#1 as the dominant FGS is a little more consistent at [-0.17±0.56, -0.23±0.81]", but, again, with a large standard deviation likely impacted by the cumulative influence of guide star and target coordinate uncertainties.

Some COS TAs have been performed with FGS#3 as the dominant FGS. There is no evidence that FGS#3 blind pointings are different that FGS#1 pointings. The blind pointing error for the GO observations alone, [-0.21±0.62, -0.23±0.64]", is also consistent with the FGS-to-COS pointing bias determined in HST program 11878.

Until this blind pointing bias was corrected via a Science Instrument Aperture File (SIAF) update in March 2010, COS TAs had to be sufficiently robust to account for this additional R~0.3 arcsec systematic offset, hence the Cycle 17 requirement of `ACQ/SEARCH` as the first stage of a COS TA sequence. In early March 2010 the SIAF was updated with an adjustment of [0.106, 0.222]". Analysis of subsequent acquisitions through April, 2010 indicates a residual pointing uncertainty of [-0.10,-0.01]", which of course again includes the cumulative influence of guide star and target coordinate uncertainties, and which is consistent with a May 2010 re-check of COS-to-FGS alignment. As a result the following important COS TA recommendation has been implemented:

Subsequent to the March 2010 updated FGS-to-COS alignment, we now recommend for Cycle 18 Phase II programs that `ACQ/SEARCH` *is no longer required for targets with coordinate accuracies of 0.4 arcsec or better (see Table 3).*

4. COS Centering Accuracy Requirements and Data Quality

For COS TA, the required centering accuracy in the cross-dispersion (XD) is 0.3 arcsec in order to provide optimum photometric accuracy and spectral resolution. Velocity requirements apply to the TA centering accuracy required in the along-dispersion (AD) direction (±15 km/s for the medium resolution modes, ±150 km/s for G140L, and ±175 km/s for G230L). Since the AD requirements are in units of km/s, they are detector and wavelength dependent. Assuming that the wavelength error budget is split evenly between the COS TA and wavelength scale accuracy, the strictest pointing requirements are ±0.041" for the NUV channel and ±0.106" for the FUV channel (COS TIR 2010-03).

4.1 Centering Accuracy and Photometric Precision

The relative transmission of the PSA as a function of the displacement of a point source from the aperture center for each of the FUV and NUV gratings begins to be vignetted at displacements greater than 0.4 arcsec from aperture center (COS TIR 2010-03).

4.2 Centering Accuracy and Wavelength Accuracy

To achieve a wavelength accuracy of ±15 km/s, the target should be centered to within about ±0.041–0.061" for NUV observations and ±0.106–0.175" for FUV observations (approximately 2 pixels for the NUV and 4 pixels for the FUV, or 2/3 of a resolution element). A single `ACQ/SEARCH` acquisition, whether spectroscopic or imaging, provides a centering accuracy of 0.3 arcsec only 75% of the time (see Section 5.4). Therefore, additional peak-up acquisitions in both the XD and AD directions are required.

As noted above, the throughput of COS is not affected by centering errors of less than 0.4 arcsec, so high centering precision is not strictly necessary if science goals do not require an absolute wavelength scale. For example, the spectra of some objects may include foreground interstellar or inter-galactic absorption lines that can be used to establish relative velocities.

4.3 Centering Accuracy and Spectroscopic Resolution

Targets centered within the central 0.4 arcsec of the science aperture will achieve maximum spectral resolution. Centering errors larger than 0.4 arcsec will lead to progressively poorer resolution. Targets at the edge of the aperture have approximately half the throughput and spectral resolution of well-centered targets.

5. COS Target Acquisition Performance

5.1 On-Orbit ACQ/IMAGE Performance

By comparing the target locations in the initial and confirmation images, we can directly determine the initial target centering error before `ACQ/IMAGE`s. Based upon our SMOV/ C17 sample, the average `ACQ/IMAGE` centering maneuver was [AD,XD]= [0.107±0.266, 0.122±0.262]".

By comparing the final location of the targets in the confirmation images with the desired locations determined by the onboard algorithm, we can directly measure the centering accuracy of on-orbit `ACQ/IMAGEs`.

Centering Accuracy: The average [AD,XD] centering accuracy for all S/N > 25 `ACQ/IMAGEs` in our SMOV/ C17 sample was an impressive [−0.006 ± 0.015, −0.008 ± 0.012]". This mean includes all S/N > 25 PSA, BOA, MIRRORA, and MIRRORB `ACQ/IMAGEs`. Table 4 shows the detailed breakdown of mean centering accuracies for the various combinations of aperture and mirror, as well as summary overall means.

Table 4: Measured `ACQ/IMAGE` centering accuracy for all combinations of aperture and mirror

Aperture	Mirror	AD Centering Accuracy	XD Centering Accuracy	Number of ACQ/IMAGES
PSA	MIRRORA	-0.007±0.008"	-0.017±0.006"	35
PSA	MIRRORB	0.002±0.010"	-0.003±0.010"	42
BOA	MIRRORA	-0.011±0.009"	-0.008±0.010"	23
BOA	MIRRORB	-0.018±0.026"	-0.003±0.016"	16
ALL	MIRRORA	-0.009±0.009"	0.013±0.009"	58
ALL	MIRRORB	-0.003±0.018"	-0.003±0.012"	58
ALL	MIRRORA+B	-0.006±0.015"	-0.008±0.012"	116

5.2 On-Orbit ACQ/PEAKXD Performance

In all of the measured cases in our SMOV/ C17 sample, `ACQ/PEAKXD` always follows a spectroscopic `ACQ/SEARCH`. The mean PSA `ACQ/PEAKXD` centering adjustments are 0.05± 0.08" for the NUV (41 centerings) and 0.11±0.12" FUV (71 centerings).

BOA ACQ/PEAKXD centering slews were only slightly larger in magnitude at 0.07"[2] (NUV) and 0.21±0.18" (FUV). Including all NUV, FUV, PSA and BOA centerings, ACQ/PEAKXD corrected ACQ/SEARCH errors by an average of 0.051± 0.132". See Section 5.4 below for more detailed information concerning ACQ/SEARCH performance.

By examining COS spectra, we can directly measure the final XD accuracies achieved by ACQ/PEAKXD.

Centering Accuracy: For the NUV channel, we find 1σ centering accuracies of 0.6±1.14p (0.03") for the M gratings, and 1.77±0.82p (0.02") for G230L. For the FUV gratings, post ACQ/PEAKXD 1σ centerings average 0.023±0.125" (G130M), 0.247±0.177" (G160M), and 0.021± 0.164" (G140L). Future target acquisition parameter adjustments should improve the G160M XD centerings.

NOTE: Until improvements in ACQ/PEAKXD parameters can be made, G160M ACQ/PEAKXD should be avoided for any COS observation that requires high photometric accuracy. Target acquisition with another grating or ACQ/IMAGE should be employed for these cases. This recommendation is included in Section 7 (Summary and Recommendations).

5.3 On-Orbit ACQ/PEAKD Performance

As documented in COS TIR-2010-03, the average SMOV/ C17 sample ACQ/PEAKD along-dispersion target adjustment was 0.005 ± 0.122". This average adjustment was measured from a sample of greater than 110 nominal[3] ACQ/PEAKDs. There were no obvious differences among the initial offsets encountered by NUV, FUV, PSA, or BOA ACQ/PEAKDs. After the initial spectroscopic ACQ/SEARCH, NUV observations were already centered in the AD direction to the strictest NUV requirement (0.041 arcsec) 41% of the time. For the looser FUV requirement of 0.106 arcsec observations were already centered by the prior spectroscopic ACQ/SEARCH to the required accuracy 82% of the time.

Centering Accuracy: Until improved COS wavelength solutions are implemented in the CALCOS pipeline and verified by Cycle 17 calibration, it is not possible to directly ascertain the along-dispersion (AD) accuracy of a COS TA from examining the wavelength of known spectral features.

Therefore, an alternative approach, which is thoroughly documented in COS TIR 2010-03, was employed to characterize the accuracy of ACQ/PEAKD acquisitions. The results of all SMOV/ C17 sample ACQ/PEAKD exposures were combined to fully map the throughput versus AD offset profile for the COS PSA. Simulated ACQ/PEAKD exposures were performed using the on-orbit determined throughput profile to determine the best ACQ/PEAKD parameter combinations.

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[2] Only one NUV BOA ACQ/PEAKXD has been performed, so there is no standard deviation available.

[3] `Nominal' is defined by an ACQ/PEAKD with SCAN-SIZE ≥ 5 and CENTER=FLUX-WT-FLR and 0.6" ≤ STEP-SIZE ≤1.5".

The results of these simulations and an evaluation of on-orbit performance including recommendations for optimum parameter choices are :

1. No CENTER=BRIGHTEST ACQ/PEAKD simulations were able to center observations to the required NUV or FUV accuracies.
2. All CENTER=FLUX-WT-FLR simulations were able to center the target to the strictest NUV and FUV requirements for appropriate ranges of SCAN-SIZE. The best centerings were achieved with CENTER=FLUX-WT-FLR, SCAN-SIZE=7 or 9, and 0.4" ≤ STEP-SIZE ≤ 0.8" (0.6" recommended).
3. The fastest procedures to reliably meet the strictest centering requirements are CENTER=FLUX-WT-FLR, SCAN-SIZE=5, and 0.7" ≤ STEP-SIZE ≤ 1.25" (0.9" recommended).
4. CENTER=FLUX-WT, SCAN-SIZE=3 and 1.2" ≤ STEP-SIZE ≤ 1.5" simulations were also able to marginally exceed the NUV centering requirements for observations with good initial ACQ/SEARCH centerings in low-background (i.e., short and non-SAA) exposures (STEP-SIZE=1.3" recommended).

CENTER=FLUX-WT-FLR, SCAN-SIZE=5, and STEP-SIZE=0.9" are the new values recommended for ACQ/PEAKD as this combination is the least sensitive to high or variable background rates and covers a large area on the sky to correct for possible target, blind pointing and guide star coordinate errors. Observers who wish to perform SCAN-SIZE=3 ACQ/PEAKDs are advised to always use CENTER=FLUX-WT with 1.1" ≤ STEP-SIZE ≤ 1.5" (1.3" recommended), while ACQ/PEAKDs with SCAN-SIZE ≥ 5 should always use CENTER=FLUX-WT-FLR as this gives much better centering accuracy. These recommendations are included in Table 6**.**

5.4 On-Orbit ACQ/SEARCH Performance

As previously mentioned, the total centering performed by all TA stages in the SMOV/ C17 sample is [AD,XD] = [-0.22 ± 0.47, -0.17 ± 0.49]". This is an excellent estimate of the average initial 'blind' pointing of COS observations in the sample time period.

The average ACQ/PEAKD and ACQ/PEAKXD centering maneuver is a good indicator of the centering accuracy following spectroscopic ACQ/SEARCHs, and the average ACQ/IMAGE centering maneuver is a good indicator of the centering accuracy following an imaging ACQ/SEARCH. Our SMOV/ C17 sample average post-spectrosopic ACQ/SEARCH centering moves were [AD,XD]=[0.005 ± 0.122, 0.051± 0.132]". The average post-imaging ACQ/SEARCH centering maneuver was [AD,XD]=[0.107±0.266, 0.122±0.262]".

These average post-ACQ/SEARCH centering slews indicate that ACQ/SEARCH is placing the target within the aperture, but that additional TA stages are necessary to refine the centering in order to achieve wavelength and photometric standards. These results are consistent with pre-launch estimates of the accuracy of the ACQ/SEARCH algorithm.

5.4.1 ACQ/SEARCH and Detector Backgrounds

The NUV detector background has risen from about 60 counts/s in May 2009 to 220-330 counts/s in February 2010. The NUV imaging and spectroscopic TA detector subarrays comprise ~13% of the NUV detector and are currently counting 31-46 counts/s of detector background. Under the simplifying assumption that during an `ACQ/SEARCH` the weakest background counts will be 1σ low and the brightest will be 1σ high, when using `CENTER=FLUX-WT-FLR` the target should be brighter than 2*sqrt(maximum background rate) to avoid significant pointing error due to background contamination. For normally distributed background events and observations away from the SAA, this corresponds to ~14 counts/s. Similarly, for cases using `CENTER=FLUX-WT`, the target should be brighter than or equal to the maximum expected background rate to provide adequate centering (e.g., count rate greater than 50 counts/s). Alternatively, detector background has no practical impact on FUV TAs.

<u>Summary:</u>

`CENTER=FLUX-WT-FLR`: target should be brighter than 14 counts/sec, which implies a dwell time of 120 sec or less for 1600 target counts (recommended S/N=40).

`CENTER=FLUX-WT`: target should be brighter than 50 cts/sec, which implies a dwell time of 35 sec or less for 1600 target counts (recommended S/N=40).

If the optical elements selected for the initial science observation do not yield a count rate high enough to allow a successful `ACQ/SEARCH`, consider using an alternate optical configuration for the `ACQ/SEARCH`. If the criteria can not be met by `ACQ/SEARCH` exposures for any combination of optical elements, then two alternatives exist:

1. Perform TA without an initial `ACQ/SEARCH`; at present this would require that the observer accept the risk of no repeated observation in the event of poor initial pointing due to target coordinate uncertainties. This risk can be minimized with high quality target coordinates (i.e., better than 0.4 arcsec) in the GSC2/ICRS frame. As noted previously, for `ACQ/SEARCH` may be omitted in Cycle 18 for targets with coordinate accuracies of 0.4 arcsec or better in the GSC2/ICRS frame.
2. Use an offset TA on a nearby brighter target.

6. Evaluating COS Target Acquisitions

Table 5 lists many quantities useful for the purpose of evaluating COS target acquisitions (TA), the relevant keywords containing these quantities, and where to find them in COS TA data products (_rawacq and _spt files). This table is a user-oriented condensed summary of the much more detailed presentation in Section 6 of COS TIR 2010-03 and is also an expanded update of any summaries in the COS Data Handbook (DHB, Shaw et al, 2009) version 1.

COS TA _rawacq files should contain user-oriented summaries of the most important quantities, such as final centering slew magnitudes, count levels, and image locations for all stages and components of COS TA stages. Note that several quantities are not currently reported in the _rawacq headers and are indicated by “No k/w” in the “_rawacq keyword” column in the table; updates to the ground system are currently in process to include these quantities in the _rawacq headers. The _spt files also present this information along with additional in-depth information concerning lamp exposures, predicted image locations, and success-status flags for the actions performed by the various TA steps, however, the relevant keywords can be more difficult to find in the _spt files. Table 5 provides a guide to the location of important keywords in the _rawacq and/or _spt files.

Table 5: Useful _rawacq and _spt keywords for TA evaluation[a]

Type	Parameter	_rawacq keyword	_rawacq extension[b]	_spt keyword	_spt extension[b]
All	Acquisition Type	EXPTYPE	0H	SS_OBSMD	0H
	No. exposures in entire acquisition sequence	ACQ_NUM	0H	No k/w	
	Aperture	APERTURE	0H	SS_APER	0H
	Detector	DETECTOR	0H	SS_DTCTR	0H
	Imaging or Spectroscopic	OBSTYPE	0H	No k/w	
	Optical element	OPT_ELEM	0H	SS_GRTNG	0H
	Central Wavelength	CENWAVE	0H	SS_CWAVE	0H
ACQ/SEARCH	TA type (LTASRCH)	No k/w		LQTATYPE	1H
	Success status	No k/w		LQTASTAT	1H
	No. Dwell points, n	PEAKNPOS (Incorrect value currently)	0H	No k/w; calculate from LQTASCAN[c]	1H
	Exposure time	EXPTIME	1H	LQITIME	1H
	Spiral pattern size	SCANSIZE	0H	LQTASCAN	1H
	Spiral pattern step-size	PEAKSTEP	0H	LQTASTEP	1H
	Counts at each dwell point	COUNTS [0:(n-1)]	1D	LQTAFX01-n	1H
	Dwell positions	DISP_OFFSET, XDISP_OFFSET [0:(n-1)]	1D	No k/w; calculate from LQTASCAN, LQTASTEP	1H
	Centroid type	CENTER or PEAKCENT	0H	LQTACENT	1H
	Threshold floor	No k/w		LQTAFLOR	1H
	AD centering move	ACQCENTX	0H	LQTADPOS	1H
	XD centering move	ACQCENTY	0H	LQTAXPOS	1H
ACQ/IMAGE	Lamp TA type (LTAIMCAL)	No k/w		LQTATYPE	1H
	Lamp exp success status	No k/w		LQTASTAT	1H
	Lamp exposure time	No k/w	0H	LQITIME	1H
	Lamp AD centroid	No k/w		LQTAYCOR	1H
	Lamp XD centroid	ACQMEASY	0H	LQTAXCOR	1H
	Lamp Event total	No k/w		LQTATOTL	1H
	Target TA type (LTAIMAGE)	No k/w		LQTATYPE	4H
	Target exp success status	No k/w		LQTASTAT	4H
	Target exposure time	EXPTIME Populated with lamp exptime	0H	LQITIME	4H
	Desired AD location	No k/w		LQTADYCR	4H
	Desired XD location	ACQPREFY	0H	LQTADXCR	4H
	Target AD centroid	ACQCENTX (not populated)	0H	LQTAMYCR	4H
	Target XD centroid	ACQCENTY (not populated)	0H	LQTAMXCR	4H

Table 5 (continued)

Type	Parameter	_rawacq keyword	_rawacq extension[b]	_spt keyword	_spt extension[b]
ACQ/IMAGE (continued)	Target Event total	NEVENTS	1H	LQTATOTL (not populated)	4H
	AD centering move	ACQSLEWX	0H	LQTADSLW	4H
	XD centering move	ACQSLEWY	0H	LQTAXSLW	4H
	Initial TA image	SCI extension	1D		
	Confirmation image	SCI extension	4D		
ACQ/PEAKXD	Lamp TA type (LTACAL)	No k/w		LQTATYPE	1H
	Lamp exp success status	No k/w		LQTASTAT	1H
	Lamp exposure time	No k/w		LQITIME	1H
	Stripe used	No k/w		No k/w	
	Lamp XD centroid	ACQMEASY (not populated)	0H	LQTAXCOR	1H
	Lamp Event total	No k/w		LQTATOTL	1H
	Target TA type (LTAPKXD)	No k/w		LQTATYPE	4H
	Target exp success status	No k/w		LQTASTAT	4H
	Target exposure time	EXPTIME Populated with lamp exptime	1H	LQITIME	4H
	Desired XD location	ACQPREFY (not populated)	0H	LQTADXCR	4H
	Target Event total	No k/w		LQTATOTL	4H
	Target XD centroid	No k/w		LQTAMXCR	4H
	XD centering move	ACQSLEWY	0H	LQTAXSLW	4H
ACQ/PEAKD	TA type (LTAPKD)	No k/w		LQTATYPE	1H
	LTAPKD success status	No k/w		LQTASTAT	1H
	No. Dwell points, n	PEAKNPOS	0H	LQTADWLS	1H
	Exposure time	EXPTIME	1H	LQITIME	1H
	Linear pattern size	SCANSIZE	0H	LQTADWLS	1H
	Linear pattern step-size	PEAKSTEP	0H	LQTASTEP	1H
	Counts at each dwell point	COUNTS [0:(n-1)]	1D	LQTAFX01-n	1H
	Dwell positions	DISP_OFFSET [0:(n-1)]	1D	No k/w; calculate from LQTADWLS, LQTASTEP	1H
	Centroid type	CENTER or PEAKCENT	0H	LQTACENT	1H
	Threshold floor	No k/w		LQTAFLOR	1H
	AD centering move	ACQCENTX	0H	LQTADPOS	1H

[a] Several quantities are not currently reported in the _rawacq headers and are indicated by “No k/w” in the “_rawacq keyword” column in this table; updates to the ground system are currently in process to include these quantities in the _rawacq headers

[b] Key: 0H=Primary Header, 1H=1st extension header; 1D=1st extension data, etc

[c] No. of dwell points = LQTASCAN*LQTASCAN

7. Summary and Updated Recommendations

As the result of our analysis of the target acquisition (TA) performance in our SMOV/C17 sample we have adjusted many COS TA parameters and have refined our recommendations and guidelines for routine COS TA. We have presented these recommendations and guidelines in the previous sections, and summarize the most significant changes below. Table 6 provides our recommended values for optional parameters for each COS TA type. ***Table 6 and all recommendations and guidelines presented in this section supersede any previous recommendations including those found in the text and similar table in the COS Instrument Handbook version 2 which was published in December, 2009.***

Our updated recommendations are :

- All TA modes are providing good centering. For maximum wavelength accuracy, use NUV imaging mode, otherwise use the mode that is fastest based upon STScI ETC simulation.
- Signal-to-noise (S/N) is important to an accurate TA; use S/N≥40 for PSA TAs, and S/N≥60 for BOA. STScI routinely uses S/N=100 for precision pointing with ACQ/PEAKXD and ACQ/PEAKD.
- A single ACQ/SEARCH is not sufficient to center a COS point-source target in the aperture, always follow up the first ACQ/SEARCH with an ACQ/IMAGE, ACQ/PEAKXD+ACQ/PEAKD, or a second 2x2 ACQ/SEARCH.
- Subsequent to March 2010, FGS-to-COS alignment has been improved such that ACQ/SEARCH acquisition stages are no longer required for targets with sufficient coordinate accuracy (0.4 arcsec or better) in the ICRS/GSC2 frame. Subsequent to March, 2010, especially for Cycle 18 Phase II preparation, Table 3 shoud be employed to determine the need for ACQ/SEARCH stages of target acquisition. Spending extra time to validate target coordinates is the best way to save TA time.
- NUV ACQ/SEARCH and ACQ/PEAKD acquisitions of faint sources may be affected by detector background. An alternate acquisition strategy should be considered for CENTER=FLUX-WT-FLR targets requiring ≥120 sec to achieve S/N=40 and for CENTER=FLUX-WT targets requiring ≥35 sec to achieve S/N=40.
- Use STRIPE=MEDIUM (stripe B) if at all possible for NUV spectroscopic ACQ/PEAKXDs.
- Until improvements in ACQ/PEAKXD parameters can be made, FUV spectroscopic TAs should avoid G160M ACQ/PEAKXD for any COS target that requires high photometric accuracy. Target acquisition with another grating or ACQ/IMAGE should be employed for these cases.

- SCAN-SIZE=5, STEP-SIZE=0.9, and CENTER=FLUX-WT-FLR for most ACQ/PEAKD centerings. For the most accurate AD centering possible, use SCANSIZE=9, STEP-SIZE=0.6, and CENTER=FLUX-WT-FLR. Where minimal TA time is required and lower centering accuracy can be tolerated, use SCAN-SIZE=3, STEP-SIZE=1.3, and CENTER=FLUX-WT.

Table 6: Summary of COS Target Acquisition Modes, Options, and Recommended Values

Acquisition Type	Description	SCAN-SIZE	STEP-SIZE (arcsec)	Optional Parameters	Recommended Values	Required S/N
ACQ/ SEARCH	Spiral pattern; multiple exposures	2	1.767	CENTER= FLUX-WT, FLUX-WT-FLR, BRIGHTEST For FUV: SEGMENT= A,B,BOTH	FLUX-WT	40
		3 [a]			FLUX-WT-FLR	
		4			FLUX-WT-FLR	
		5			FLUX-WT-FLR	
ACQ/ PEAKXD	One exposure			For FUV: SEGMENT= A,B,BOTH For NUV: STRIPE= SHORT, MEDIUM, LONG	SEGMENT=BOTH STRIPE=MEDIUM (These are the default values.)	40 to 100
ACQ/ PEAKD	Linear pattern; multiple exposures	3	1.3 [c]	CENTER= FLUX-WT, FLUX-WT-FLR, BRIGHTEST, DEFAULT [b] For FUV: SEGMENT= A,B,BOTH	FLUX-WT	40 to 100
		5 [a]	0.9 [c]		FLUX-WT-FLR	
		7	0.6 [d]		FLUX-WT-FLR	
		9	0.6 [d]		FLUX-WT-FLR	
ACQ/ IMAGE	Initial and confirm images					40 (PSA) 60 (BOA)

[a] Recommended value for SCAN-SIZE

[b] For ACQ/PEAKD, use of the special parameter CENTER=DEFAULT, is recommended. This parameter sets CENTER=FLUX-WT if NUM-POS=3, and CENTER=FLUX-WT-FLR if NUM-POS=5, 7, or 9 is used. See Section 5.3 for detailed discussion of recommendations for ACQ/PEAKD.

[c] Supersedes previously recommended value of 1.2 from COS IHB version 2

[d] Supersedes previously recommended value of 1.0 from COS IHB version 2

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Change History for COS ISR 2010-14

Version 1: 14 June 2010 - Original Document

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Appendix A: Additional COS Target Acquisition Information

The following sections contain additional useful information pertaining to crafting and assessing COS target acquisitions (TA). This information is drawn from various sources including the COS IHB version 2.

A.1 Early Acquisitions and Preliminary Images

In some situations, an observer may need to obtain an independent ultraviolet image of a region in order to assure that no objects violate safety limits and determine the target to be observed can be acquired by COS successfully.

A.2 Offset Target Acquisitions

In certain circumstances, notably involving very faint targets or complex fields, direct acquisition of the primary science target may be difficult or uncertain. In such cases usage of an offset acquisition procedure may be preferred in which a nearby, more easily acquired, field target is acquired followed by a short slew to the primary science target.

The size of the offset is limited by the requirement that the guide stars remain within the respective fields of view of their FGSs. Offset acquisition slews may routinely involve displacements up to one arcminute, and can be larger. Offset slews can typically be performed with an accuracy of ±0.003". The centering of the initial offset target should be refined (via either `ACQ/IMAGE` or [`ACQ/PEAKXD+ACQ/PEAKD`]) before the offset maneuver. For offset acquisitions, bright object considerations apply over the entire offset region. Refer to the COS IHB for a discussion of the modest overheads associated with the offset acquisition spacecraft movement.

In unusual cases, including very uncertain target coordinates or knotty, extended sources in combination with the need for high wavelength accuracy, use of an offset TA scenario followed by either an additional `ACQ/IMAGE` or [`ACQ/PEAKXD+ACQ/PEAKD`] on the primary target may be employed.

A.3 Acquisition Techniques for Crowded Regions

Acquiring targets that lie in crowded regions can be difficult. For the present, it is necessary to perform an offset acquisition of a nearby point source that is isolated enough not to cause problems (at least 5 arscec from another UV source) followed by an offset to the desired object. As described in Section A.2, the centering of the initial target should be refined (via either `ACQ/IMAGE` or [`ACQ/PEAKXD+ACQ/PEAKD`]) before the offset.

A.4 COS Acquisition Failure Actions and Diagnostics

Each stage of a COS TA reports success-status via a keyword recorded in the _spt file (see Table 5). If any stage of the TA should fail or a Local Rate Check (LRC) violation occur in a TA exposure, then the subsequent acquisition procedures in that visit (such as `ACQ/PEAKXD` or `ACQ/PEAKD`) will not be executed, but science exposures will be. Note that HST will be left pointing at the last commanded position, which may differ substantially from the initial pointing.