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The Cosmic Origins Spectrograph Pre-flight Aperture Model and SIAF.dat File

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ABSTRACT
This Instrument Science Report documents the derivation of the final pre-flight COS aperture locations and geometries. It also describes the spreadsheet model and SIAF.dat file containing them. These data will provide the operational pointing parameters for initial COS observations during Servicing Mission Orbital Verification 4 (SMOV4). A future report will describe the on-orbit calibration results for COS and subsequent revisions to the spreadsheet model.

1. Introduction

The Cosmic Origins Spectrograph (COS) Science Instrument (SI) is to be installed on the Hubble Space Telescope (HST) during the upcoming Servicing Mssion 4 (SM4). COS is designed to perform high sensitivity, moderate- and low-resolution spectroscopy of astronomical objects in the 1150-3200 Å wavelength range.

This ISR documents the instrument's pre-flight aperture locations and characteristics which comprise the ground system's Science Instrument Aperture File (SIAF). The definition of the SIAF file and the requirements for the information it contains are levied in ICD-26-partIII (1989). The derivation of the final pre-flight values is described, as are the contents of the spreadsheet model and the general process for producing the SIAF-format file from updated basic calibration information.

The audience for this document is primarily the Instruments Division (INS) and the Operations and Engineering Division (OED) at STScI, as these are the two groups involved in determining and updating SIAF parameters. It can also be of interest to COS's Instrument Definition Team (IDT) involved with SMOV, and in some cases to the COS General Observer who should consider http://www.stsci.edu/hst/cos as the central source of all support information.

2. Metrology

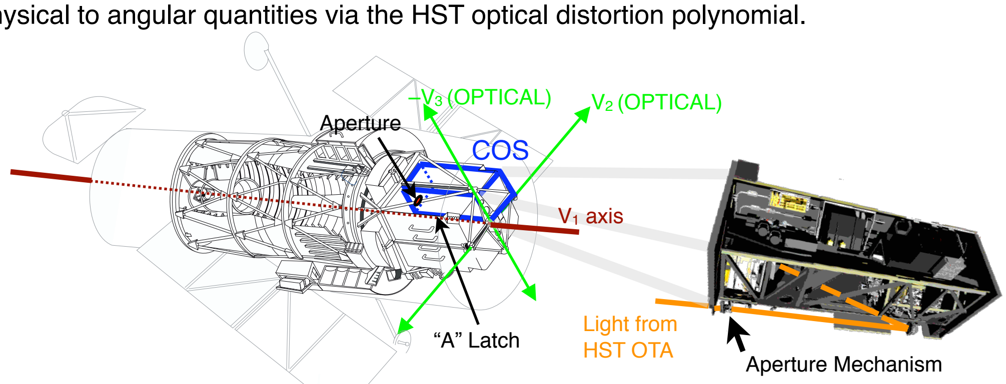
This section discusses only those COS characteristics that served as the basis for our determination of the pre-flight SIAF parameters. For a comprehensive description of COS see the COS Instrument Handbook: http://www.stsci.edu/hst/cos/documents/handbooks/current/

Light from the sky enters COS through two 0.700mm diameter circular field stop apertures, each subtending approximately 2.5″ on the sky. The Primary Science Aperture (PSA) transmits 95% of the light from a well-centered spherically aberrated point-source image delivered by the HST optics. The Bright Object Aperture (BOA) contains a neutral density filter (~ND2) and is used for observations requiring flux attenuation. These apertures were drilled 3.70mm apart (center-to-center) into a single plate which is translated via the Aperture Mechanism (apM) to place either aperture at a single, common, fixed location in the HST Focal Plane. In science operations, therefore, both the PSA and the BOA share the same V2,V3 coordinates in HST's optical V frame when being utilized. *Note:* unless otherwise indicated, references to V2,V3 in this document apply to the "optical" V-frame, whose V2 & V3 components are roughly anti-aligned with the mechanical V2 & V3.

Light passing through the aperture at this V2,V3 position then ultimately falls onto either a FUV Cross Delay Line (XDL) device similar to that used on FUSE, or an NUV MAMA of the type used in STIS. The NUV MAMA is 25.6mm square (active area) and is divided into 1024 × 1024 pixels. The XDL is a photon counter comprising two segments, butted along their short axes, separated by 9mm, each with an 85mm × 10mm active area. When the locations of detected photons are digitized, they are placed into an array of 16384 × 1024 virtual pixels per segment. Spectra will fall along both segments, each representing a separate science image.

Lastly, a fundamental metrology value of 90.544mm was given by Hartig (private communication, 2006), and was used to determine the base location of the COS apertures in the HST FOV. This value represents the design distance from HST's mechanical V1 axis to the aperture when the SI is latched into the HST Focal Plane Structure Assembly (FPSA). This distance provided is along the diagonal of the COS enclosure, dictating that the V2 & V3 components have equal absolute magnitudes. Variations in the A-latch mechanical interface will introduce a source of error in the actual number, but is expected from prior SI replacements and from mechanical analysis to be less than ~ 0.5mm.

Figure 1: Light from the target of interest enters COS through an aperture located at a given V2,V3. In the pre-flight model this lies along the diagonal of the SI enclosure, ~90mm from the A-latch corner, which sits nearest the V1 axis. The aperture location is transformed from physical to angular quantities via the HST optical distortion polynomial.



3. Aperture Locations and Characteristics

3.1 Location in V-frame

This fundamental SIAF value is utilized by HST operations (pointing and science keyword generation). We derived this coordinate by first solving for the angular displacement of the aperture from the mechanical V1 origin using the provided physical offset from the metrology, along with the HST focal surface model describing the spherically aberrated Ritchey-Chretien focal surface specific to HST given by Burrows (1990)

$$(1) \qquad Y = 16.758712\,\theta - 0.5049494\,(\theta/10)^3$$

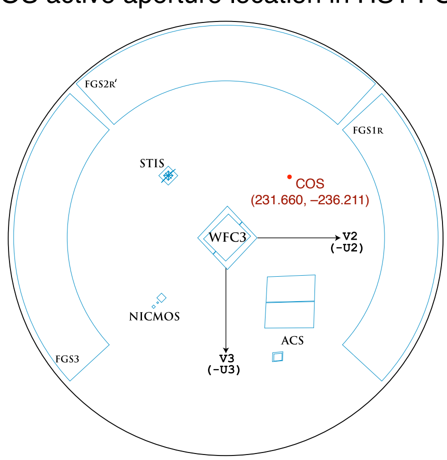
Using the given 90.544mm offset for Y, we solve for field angle θ, obtaining 5.40757 arcminutes (324.4540 arceconds). We estimated but did not apply a second order effect of field curvature to the angle computation since it was insignificant. Since the COS aperture has been built to lie along the SI's diagonal, and COS is latched to align with HST's +V2,–V3 quadrant (optical), the field angle θ resolves to V2,V3 = $(\theta/\sqrt{2}, -\theta/\sqrt{2})$ = (229.4236, –229.4236).

This location, however, is valid only for the original optical V frame, whose V1 axis was aligned with the mechanical V1 axis. When HST was put into orbit, the optical V frame was tied to an observing instrument. FGS2 was chosen originally, and after SM3A, FGS3 became the fiducial. Since the locations of the FGS fields of view trend, so has the V frame, with the largest changes seen shortly after HST deployment.

We have applied a correction of (2.236,–6.788) to the V2,V3 location determined above to transform to the new frame. This delta was determined by analyses from the author with Lupie, Cox, and Kimmer (private communications, 1997) of data from 1990-1996. It represents a geometric mean of shifts determined at each quadrant of the HST FOV. The V frame has been stable since 1997, and its prior evolution was largely a translation, with rotation insignificant for this purpose. Therefore currently this delta is practically independent of time or location in the FOV. It was applied successfully in SM2 to both STIS and NICMOS, giving < 2″ error compared to on-orbit measurements (after excluding NICMOS deformation). In SM3B, 2002, it was applied to ACS, also getting within < 2″ of the on-orbit location. For SM4 this same offset is applied to both the WFC3 and COS.

The final pre-flight determination for the location of either the PSA and the BOA aperture when selected is V2,V3 = (231.660, –236.211)

Figure 2: COS active aperture location in HST FOV (pre-flight).



3.2 Orientations

The SIAF data specifies relationships and aperture details in the following three frames:

SI Aperture System (SIAS): The SIAS frame is associated with an OPUS undrizzled science image, or USER frame. Units are in pixels.

SI Corrected System (SICS): Distortion-free frame in units of arc-seconds. Origin is at the specific aperture reference point. SICS & POS TARG frame are identical for COS.

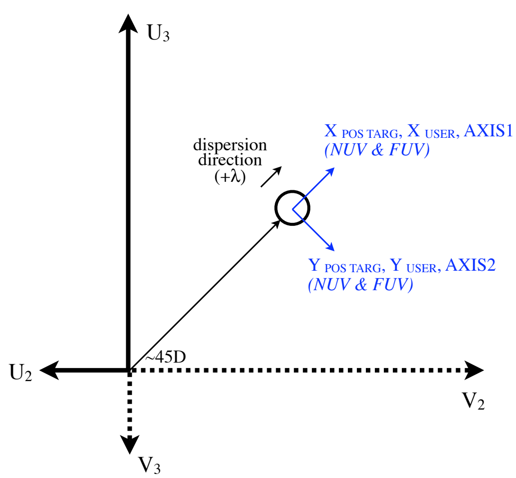
ST Optical V System (V-frame, or V2,V3): Distortion-free frame in units of arc-seconds. NOTE: The V2,V3 frame used in SIAF and discussed throughout this document is an evolution of the optical V frame. The sense of this V2,V3 is opposite the mechanical V2,V3 (utilized for example during Hubble Servicing).

To support target positioning and the science data WCS information, the SIAF file contains the relationship with respect to V2,V3 of the POS TARG frame and the SIAS (or science image frame).

We have been given from the metrology that both detectors are aligned at a nominal 45 degrees to the V2,V3 axes. Additionally, the STScI COS team has chosen to follow the HST spectrograph convention, specifying that wavelength in the dispersed image increase with increasing x-pixel in the science product, and that a +X POS TARG motion moves a given wavelength toward increasing x-pixels. This is to be true for both NUV and FUV detectors, regardless of their inherent orientation and read directions. HST convention also holds that POS TARG Y axis be aligned with science image Y.

The angles adopted in the SIAF file for consistency with these requirements are as follows: βx=135, βy=45, θ=45, and parity=+1. The β values define the angle from V3 to the science image axis in question (measured in direction towards V2). The θ specifies the angle from V3 to the Y axis of the always-orthogonal POS TARG frame. The positive parity indicates the frame is left-handed (i.e. same sense as V2,V3). Figure 3 illustrates the current frame alignments represented in the SIAF file.

Figure 3: Spectral sense and direction, POS TARG, and science image frame shown with respect to the HST-based frames, viewed as projected onto the sky. The designation “user” or “axis1,axis2” refers to the science image axes to reduce confusion with a raw detector image frame. It is also referred to as the “IRAF” frame, or the SI Aperture System (SIAS). The U frame shown is used during proposing and is equivalent to the mechanical V frame.



3.3 Scale & Distortion

The SIAF file captures plate scale at the SI in arceconds / pixel. It also contains coefficients for a distortion polynomial, but in the case of COS currently only the linear scale terms are non-zero. The SIAF scale terms are used by OPUS to determine the CD matrix keywords used to map science image pixels onto RA & Dec when an SI imaging mode is used without drizzling. Note that the spectral dispersion distortions are not part of the SIAF.

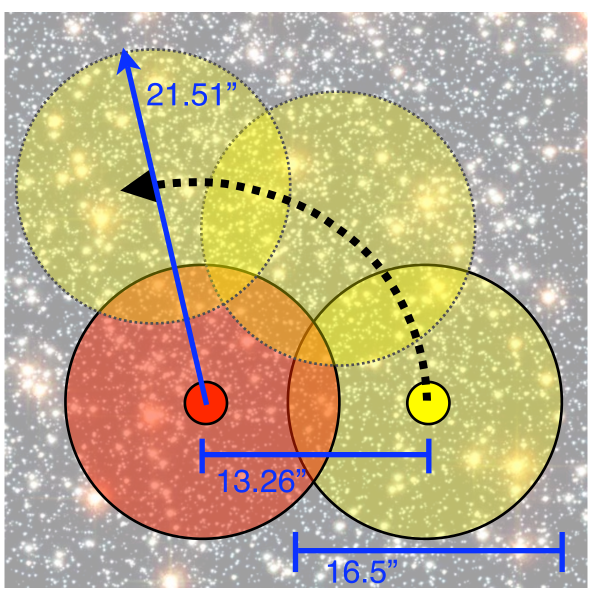
The pre-flight values for scale were obtained from the COS-OP-01 (2004) which gives:
FUV XDL: ~265 microns per arcsecond; 6x25 micron pixels
NUV MAMA: ~970 microns per arcsecond; 25x25 micron pixels
This results in scales of 0.0226 & 0.0943 (FUV X & Y directions respectively) and 0.0258 (NUV X & Y) in the pre-flight SIAF.

3.4 Bright Object Handling

The aperture being used for a give observation (PSA or BOA) will be positioned as discussed in 3.1. The design of COS, however, means that the unused aperture also is open to the sky, seeing light which enters the instrument and is also imaged onto the detector, constituting a potential bright object concern.

To support the Bright Object Tool (BOT) in APT, new apertures were created in the SIAF to represent the location in the HST Focal Plane of the BOA when the PSA is specified, and the PSA when the BOA is specified. These SIAF aperture entities are not proposable, but they allow the specific areas of the sky seen by the unused aperture to be assessed for bright object concerns in addition to the specified aperture.

Figure 4: From the metrology (Sec. 2) we know the two apertures are drilled 3.70mm apart perpendicular to the line to the V2,V3 origin. Using the HST transverse plate scale at the COS field angle, we obtain a 13.26″ separation on the sky. For a given placement of the proposed aperture (dark red) it is necessary to evaluate a radius around it (pale red). As well, the position forms the center of an annulus or part thereof (pale yellow) representing the area around the unused but open aperture (dark yellow) over some roll range, also needing to be cleared. In total, the 2.5″ COS aperture requires a 43″ diameter area to be evaluated.



The radius of the circle which must be evaluated around the physical aperture is 8.25″. This value simply represents the sum of the following quantities:

- 1.25″ Aperture radius
- 0.75″ Distance beyond the aperture edge where sources can still illuminate the detector due to the spherically aberrated beam supplied by the OTA (Friedman, private communication, 2007)
- 6.00″ Maximum value of guidestar pair fit error allowable for a “successful” acquisition
- 0.25″ Position error of target (~>1σ)

The resulting radius is the minimum that practically ensures the instrument’s health and safety regarding bright objects. Note that this value of 8.25″ is not captured in the SIAF file, since the APT BOT tool requiring this information only utilizes the SIAF file to obtain the locations of the apertures involved in a Bright Object check. The radius value was however delivered to the APT team and installed prior to Cycle 17 phase I proposing. The actual quantity used by APT BOT is referred to as the *padding* and is this radius minus the aperture radius, or 8.25 – 1.25 = 7″. The COS STScI team has been responsible for supplying the magnitude and throughput information to the APT BOT. Only the geometric values for the Bright Object contours were described above.

4. Source spreadsheet model & logic

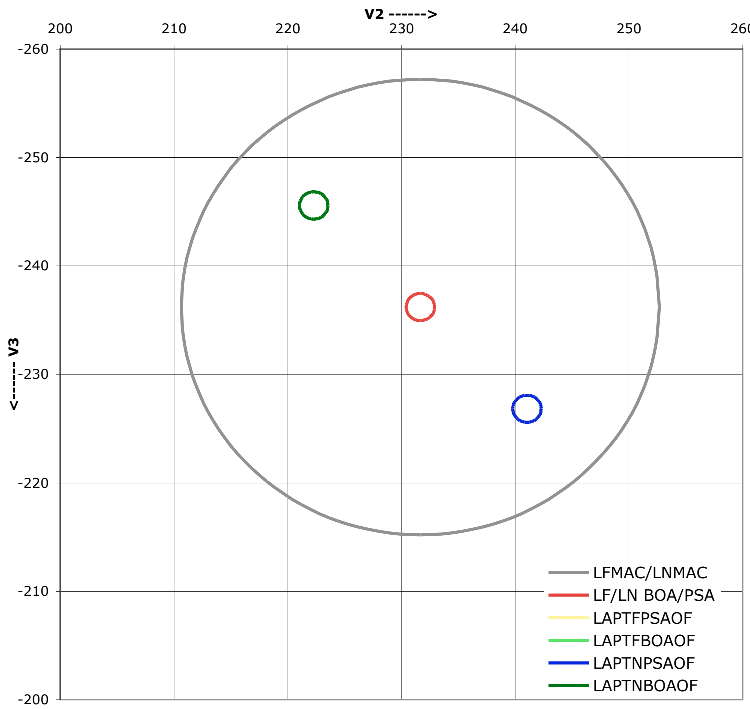
4.1 Overview

As for each SI, the COS aperture model is captured in an Excel spreadsheet maintained and updated as the instrument evolves or is better calibrated. This spreadsheet model of the SI contains the dependencies and logic that characterize and inter-relate the SIAF apertures associated with that instrument. The model allows changes to a particular parameter via metrology or on-orbit calibration to propagate as appropriate through to all dependent SIAF parameters. The output of this spreadsheet is the SIAF.dat and the CGG5 file (Sec. 5).

The spreadsheet model functions as the “working” source, while the resulting SIAF.dat and CGG5 files are the formally controlled sources of the operational data. Procedures within INS/Telescope’s Group dictate that when new SIAF and CGG5 products are delivered, the aperture model used to create them, along with the products themselves and descriptive information is preserved in a date-stamped directory on the STScI central store. From this method we have a complete history of all SIAF updates and their corresponding spreadsheet models for the current and future SIs.

The spreadsheets provide a degree of visualization, serving as a level of quality assurance before the formal process associated with delivery and installation of SIAF data into SCIOPSDB and the CGG5 data into OPUS. The plot in Figure 5 was generated within the COS pre-flight spreadsheet model. This particular plot displays the radii and reference points in the IMAGE frame making gross errors apparent prior to generation of the deliverables.

Figure 5: Plot contained in the COS spreadsheet model, showing the contours and positions of the apertures represented in the SIAF file.



In the context of SIAF, the term "aperture" is used in a broad sense, referring to any sufficiently unique fiducial required by HST science operations. Light through the same physical aperture that passes through different filters or falls on different detectors may be represented as separate SIAF apertures. Note therefore, that there is usually not a unique mapping between SIAF apertures and APT apertures used in proposing.

There are 10 apertures in the COS pre-flight SIAF, five for each side (FUV & NUV).

- 2 targetable apertures used for proposing: BOA & PSA
- 2 "offset" apertures, representing the unspecified aperture (Sec. 3.4)
- 1 "macro" aperture used by the HST front-end, SPSS. While obsolete, it is still required to be present in the SIAF and to encompass all other apertures.

The names and conventions for the current COS SIAF apertures follow:
LFMAC, LFBOA, LFPSA, LNMAC, LNBOA, LNPSA, LAPTFPSAOF, LAPTFBOAOF, LAPTNPSAOF, LAPTNBOAOF
The leading "L" is COS's SI mnemonic used throughout the ground system. The "F" or "N" denotes the applicable detector. The SPSS macro apertures contain the string "MAC". The special apertures representing the unspecified apertures are distinguished by the string "APT" and end with "OF" to suggest their "offset" position. SIAF aperture names are limited to 10 characters. These are the SIAF apertures that were determined to be required for initial science operations. The model is extensible, and additional apertures can be added to fulfill functions not yet foreseen, based on the use and evolution of the SI.

4.2 COS Pre-Flight SIAF Contents

We present a table of the more important SIAF values, and discuss the current rules governing their interdependencies. The record of the complete pre-flight contents can be found in Appendix A2.

Table 1: Primary COS SIAF values

	V2ref	V3ref	Xscale	Yscale	betaX	betaY	Xref	Yref
LFMAC	231.6600	-236.2114	0.022600	0.094300	135.0000	45.0000	8192.0000	512.0000
LFBOA	231.6600	-236.2114	0.022600	0.094300	135.0000	45.0000	8192.0000	512.0000
LFPSA	231.6600	-236.2114	0.022600	0.094300	135.0000	45.0000	8192.0000	512.0000
LNMAC	231.6600	-236.2114	0.025800	0.025800	135.0000	45.0000	512.0000	512.0000
LNBOA	231.6600	-236.2114	0.025800	0.025800	135.0000	45.0000	512.0000	512.0000
LNPSA	231.6600	-236.2114	0.025800	0.025800	135.0000	45.0000	512.0000	512.0000
LAPTFPSAOF	241.0342	-226.8372	0.022600	0.094300	135.0000	45.0000	8192.0000	512.0000
LAPTFBOAOF	222.2858	-245.5856	0.022600	0.094300	135.0000	45.0000	8192.0000	512.0000
LAPTNPSAOF	241.0342	-226.8372	0.025800	0.025800	135.0000	45.0000	512.0000	512.0000
LAPTNBOAOF	222.2858	-245.5856	0.025800	0.025800	135.0000	45.0000	512.0000	512.0000

V2ref,V3ref: The derivation of these values was described earlier. As implemented in the spreadsheet model, the values for the non-"OF" apertures are being automatically calculated from a worksheet of the basic metrology data. These V2ref,V3ref values will be determined on orbit and at that time the calculation will be replaced with the empirically determined values, breaking the pre-flight dependency on metrology. For the OF(fset) apertures, they are populated based on a specific delta (calculated from the metrology) applied to the location of the science apertures. As the science aperture location is updated, the OF apertures will move in step. The assumption is made that the metrology-based offset is accurate since it is not possible to measure in-flight the unused aperture position. The MAC(ro) apertures inherit the same reference position as the science aperture.

Xscale, Yscale: Derivation described in Sec. 3.3. Values expected to be determined in-flight independently for FUV and NUV. Values will be updated for FPSA and NPSA, and by default inherited by all other SIAF apertures within that channel, unless otherwise directed. These values are meaningless for the OF and MAC apertures.

BetaX, BetaY: Discussed in Sec. 3.2. Values expected to be determined in-flight for FUV and NUV independently. SIAF treats each ordinate independently, not assuming orthogonality. Values will be updated for FPSA and NPSA, and by default inherited by all other SIAF apertures within that channel unless otherwise directed. These values are meaningless for OF and MAC apertures.

Xref, Yref: These values denote the SIAS pixel for which the V2ref, V3ref values refer. For the purposes of the pre-flight SIAF model, this has simply been assumed to be the center of the two active detector areas described in Sec. 2., with all apertures in a given channel by default inheriting their values from the FPSA and NPSA entries. Again, these data are irrelevant for the OF and MAC apertures.

5. SIAF.dat and CGG5 files

The SIAF.dat and the CGG5_COS files are the configuration-managed products that supply parts of the HST Science Operations Database (SCIOPSDB). The files themselves are specifically formatted ascii files which are delivered to OED/PRDB only by the HST Observatory Team within the Telescopes Group. The PRDB group then populates a number of different database tables across multiple systems (Appendix A1) with values extracted or derived from these source files.

The CGG5 file contains a history of a subset of the SIAF parameters with a time-stamp associated with various aperture characterizations. This provides "use-after" date information which govern which calibrations are used in the subsequent generation of science data, and OTFR. For a given aperture there may be several rows with different time stamps designating when some change (such as a redefinition of a reference pixel) went into effect. The pre-flight COS CGG5 file is given in Appendix A4. The assigned use-after date has been set to 1/1/2000.

A portion of the SIAF.dat file, and the more human-friendly SIAF.log counterpart is given below, followed by a description of the fields.

Figure 5: SIAF.dat file block for BOA with FUV (see Appendix A2 for complete file).

```
LFBOA      +231.66000     -236.21140    CIRC +2.5000000    NN     LFMCCAJ
               +0.46165000E-01 +4.9087000     +45.000000    Y         CAJ
 11 +8192.0000     +512.00000     -185.13920     -48.281600           CAJ
COS LF                                                                 AJ
        +0.            +0.            +0.            +0.              CAK
        +0.    +0.94300000E-01        +0.     +10.604450              CAK
+0.22600000E-01        +0.     +44.247790            +0.               AK
 +231.66000     -236.21140    +0.22600000E-01+0.94300000E-01           AM
 +135.00000     +45.000000     +8192.0000     +512.00000               AN
```

Figure 6: SIAF.log file equivalent (see Appendix A3 for complete file)

```
 LFBOA     SI: COS    SI  nme: L     Det: F            SHAPE: CIRC
          Mac Fl: N  Mac ID : LFMC  Br Fl : N  Br Th:  0.00
          MAJ:   2.5000000      MIN:   2.5000000      AREA:   4.9087000
          # X-PIX:     0            # Y-PIX:     0
          SICS Xso:  -185.13920     SICS Yso:  -48.281600
          SIAS Xao:   8192.0000     SIAS Yao:   512.00000
          X ref:   8192.0000        Y ref:   512.00000
          X inc:  0.22600000E-01    Y inc:  0.94300000E-01
          ASEC/PIX:  0.46165000E-01 THETA-V2V3:   45.000000
          Beta1:   135.00000        Beta2:   45.000000
          Ref V2:   231.66000       Ref V3:  -236.21140
          V2:    231.66000          V3:  -236.21140
          PARITY:  1 POLY DEG:  1   SIAS FL: Y
           1  A:          0.        B:          0.
           1A-1:          0.      B-1:          0.
           2  A:          0.        B:  0.94300000E-01
           2A-1:          0.      B-1:   10.604450
           3  A:  0.22600000E-01    B:          0.
           3A-1:   44.247790      B-1:          0.
```

The specifications of the SIAF contents are documented and maintained in revisions to the HST interface control document "PDB to SOGS Interface Control Document" (ICD-26-partIII). For the purposes of this document, however, they are explained briefly here, using the specific case of the BOA/FUV combination shown in figures 5 & 6.

```
   AP_NAME: LFBOA
    Ref_V2: +231.66000 (location of reference point in the ST optical V frame)
    Ref V3: -236.21140 (location of reference point in the ST optical V frame)
     SHAPE: CIRC
       MAJ: +2.5000000 (Major axis. Blank if shape=quad)
    Mac Fl: N  (is the aperture a "macro" aperture?)
     Br Fl: N  (is it to be used for bright object checking?)
     Br Th: [blank] (magnitude threshold, if Br Fl=Y)
    Mac ID: LFMC (Macro aperture associated with this aperture if Mac_Fl=N)
       MIN: [blank] (Minor axis. Blank if shape=circ or quad)
     Scale: +0.46165000E-01 (geometric mean of Xscale & Yscale)
      AREA: +4.9087000  (aperture area in square arc-seconds)
     THETA: +45.000000 (angle from V3 to Ysics)
   SIAS FL: Y (Is the SIAS to SICS transformation defined?)
    PARITY: +1 (Is SICS & V2,V3 same handedness? Y=+1, N=—1)
  POLY DEG: 1 (Degree of the polynomial used to transform SIAS to SICS)
  SIAS Xao: +8192.0000 (SICS origin in SIAS frame; i.e. reference pixel number)
  SIAS Yao: +512.00000 (SICS origin in SIAS frame; i.e. reference pixel number)
  SICS Xso: -185.13920 (SIAS origin in SICS frame)
  SICS Yso: -48.281600 (SIAS origin in SICS frame)
    SI_mne: COS
SI_TLM_mne: L (each SI has its unique single-letter mnemonic used by the pipeline)
SI_DET_mne: F (each detector has a unique mnemonic used in aperture naming convention)
 SI_AP_mne: [blank: obsolete]
 SI_AP_pos: [blank: obsolete]
  Vertices: [blank for SHAPE=CIRC]
    Coeffs: SIAS-to-SICS transformation coefficients (AK records) Number will vary de-
            pending on POLY_DEG. For COS, this transformation involves only the linear
            terms relating to the X & Y scales.
        V2: +231.66000  (redundant with Ref_V2)
        V3: -236.21140  (redundant with Ref_V3)
     X inc: +0.22600000E-01 (mean X scale, "/pix)
     Y inc: +0.94300000E-01 (mean Y scale, "/pix)
     Beta1: +135.00000  (angle from V3 to SIAS X)
     Beta2: +45.000000  (angle from V3 to SIAS Y)
     X_ref: +8192.0000 (X SIAS value of ref. pix.; effectively redundant w/ SIAS Xao)
     Y_ref: +512.00000 (X SIAS value of ref. pix.; effectively redundant w/ SIAS Xao)
```

6. Errors and margin

The goal of the SIAF pre-flight aperture values is to support the COS “first light” observations contained in SMOV proposal 11468, *COS to FGS Alignment (NUV).* Among the parameters drawn from the SIAF file by the ground system, for this particular SI, only the V2,V3 location of the science aperture is important to the success of the proposal. Data taken during 11468 will provide for an in-flight measurement of the aperture location, which will then be captured in an update to the SIAF file. What initial pointing error can be expected, and how tolerant is the proposal to such error?

The first light observation will use COS’s ACQ/SEARCH mode to image the aperture field in a 5x5 step grid spanning ~9″ on a side. The target is an isolated astrometric star in NGC188. Due to the relatively sparse field and isolated target (the proposal also doubles as the COS optical alignment) the success of the proposal relies on imaging the target somewhere within the 9″ square field.

Errors on the apertures’ physical locations *within* the SI enclosure and the OTA distortion function amount to < 0.1″ total, much smaller than the A-latch error, which is the primary source of positional error with COS or any new axial SI in HST. The A-latch is the fixture primarily responsible for positioning the SI within the Focal Plane Structure Assembly (FPSA) and thus within the V frame. The metrology values for the COS aperture location were determined accounting for the known latch offsets as measured for bay 4 in the actual HST Focal Plane Structure Assembly (FPSA, the truss which fixes the axial science instruments). The informal error budget for any remaining unmodeled latch uncertainty is ~1mm, though total values of over ~0.5mm (latch plus any other dimensional changes) have not normally been seen in previously flown HST SIs. At an HST plate scale of ~3.6arcsec/mm, this amounts to less than 2″ pointing error for the latch uncertainty and other physical effects.

Errors on the V-frame evolution correction described in Sec. 3.1 are estimated to be ~10%, or ~ 0.7″. Assuming simply summing worst case 2″ on top of 0.7″, with an additional 0.3″ for bad-case target-guidestar error, the total of 3″ still allows 50% margin when using the +/–4.5″ extent of the ACQ/SEARCH.

Acknowledgments

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References

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"Hubble Space Telescope Optical Telescope Assembly Handbook", version 1.0, Burrows, C., 1990

"Cosmic Origins Spectrograph Science Operations Requirements Document", OP-01, March 17, 2004, http://www.stsci.edu/hst/cos/documents/COS-01-0001_IR.pdf

"Cosmic Origins Spectrograph Instrument Handbook", version 1.0, Soderblom, D. R. et al. 2007, http://www.stsci.edu/hst/cos/documents/handbooks/current/cos_cover.html

Appendices

A1. Ground Systems Utilizing SIAF Data

Pre-observation

Aperture characteristics and POS TARG positions expressed in the V frame must be known by APT. Specifically the system must be aware of:

• the locations, orientations, and outlines of the available apertures in the V2,V3 frame.
• the alignment of the POS TARG frame with respect to the aperture.
• the size of any applicable Bright Object radius in arc-seconds from the aperture center.

Execution

The TRANS system and other front-end systems are involved in building the science mission schedule from the phase II proposal. These systems rely on a number of parameters from the SIAF tables, notably, the reference locations, shapes, sizes/corners in the ST frame. This is the fundamental data that determines guidestar and target placement. The SIAF transformation coefficients relating SIAS (pixels) to SICS (arc-seconds) are also utilized to determine the appropriate vehicle slews following an onboard target acquisition.

Post-observation & Science Processing

The HST science data pipeline, OPUS, uses the CGG5 file. This information is used to populate the WCS metadata that relates pixels in the science image to RA & Dec on the sky in an undrizzled image. This file contains the X & Y scales, the two angles relating SIAS to the ST frame, and the position in both the ST frame and the SIAS frame of the aperture reference point.

A2. COS Pre-flight SIAF.dat file

```
C*******************************************************************GC
C  13-AUG-08 - COS APERTURES Update - Final COS pre-flight SIAF & CGG5 GC
C              STSCI/SCIOPSDB OPR #60444                             GC
C              Data from Matt Lallo ( pr.60444 07/18/08)             GC
C*******************************************************************GC
LFMAC      +231.66000     -236.21140    CIRC +42.000000    YY17.00LFMCCAJ
              +0.46165000E-01 +1385.4424     +45.000000    Y         CAJ
 11 +8192.0000     +512.00000     -185.13920     -48.281600          CAJ
COS LF                                                                AJ
        +0.            +0.            +0.            +0.             CAK
        +0.    +0.94300000E-01        +0.     +10.604450             CAK
+0.22600000E-01        +0.     +44.247790            +0.              AK
 +231.66000     -236.21140    +0.22600000E-01+0.94300000E-01          AM
 +135.00000     +45.000000     +8192.0000     +512.00000              AN
LFBOA      +231.66000     -236.21140    CIRC +2.5000000    NN     LFMCCAJ
              +0.46165000E-01 +4.9087000     +45.000000    Y         CAJ
 11 +8192.0000     +512.00000     -185.13920     -48.281600          CAJ
COS LF                                                                AJ
        +0.            +0.            +0.            +0.             CAK
        +0.    +0.94300000E-01        +0.     +10.604450             CAK
+0.22600000E-01        +0.     +44.247790            +0.              AK
 +231.66000     -236.21140    +0.22600000E-01+0.94300000E-01          AM
 +135.00000     +45.000000     +8192.0000     +512.00000              AN
LFPSA      +231.66000     -236.21140    CIRC +2.5000000    NN     LFMCCAJ
              +0.46165000E-01 +4.9087000     +45.000000    Y         CAJ
 11 +8192.0000     +512.00000     -185.13920     -48.281600          CAJ
COS LF                                                                AJ
        +0.            +0.            +0.            +0.             CAK
        +0.    +0.94300000E-01        +0.     +10.604450             CAK
+0.22600000E-01        +0.     +44.247790            +0.              AK
 +231.66000     -236.21140    +0.22600000E-01+0.94300000E-01          AM
 +135.00000     +45.000000     +8192.0000     +512.00000              AN
LNMAC      +231.66000     -236.21140    CIRC +42.000000    YY20.00LNMCCAJ
              +0.25800000E-01 +1385.4424     +45.000000    Y         CAJ
 11 +512.00000     +512.00000     -13.209600     -13.209600          CAJ
COS LN                                                                AJ
        +0.            +0.            +0.            +0.             CAK
        +0.    +0.25800000E-01        +0.     +38.759690             CAK
+0.25800000E-01        +0.     +38.759690            +0.              AK
 +231.66000     -236.21140    +0.25800000E-01+0.25800000E-01          AM
 +135.00000     +45.000000     +512.00000     +512.00000              AN
LNBOA      +231.66000     -236.21140    CIRC +2.5000000    NN     LNMCCAJ
              +0.25800000E-01 +4.9087000     +45.000000    Y         CAJ
 11 +512.00000     +512.00000     -13.209600     -13.209600          CAJ
COS LN                                                                AJ
        +0.            +0.            +0.            +0.             CAK
        +0.    +0.25800000E-01        +0.     +38.759690             CAK
+0.25800000E-01        +0.     +38.759690            +0.              AK
 +231.66000     -236.21140    +0.25800000E-01+0.25800000E-01          AM
 +135.00000     +45.000000     +512.00000     +512.00000              AN
LNPSA      +231.66000     -236.21140    CIRC +2.5000000    NN     LNMCCAJ
              +0.25800000E-01 +4.9087000     +45.000000    Y         CAJ
 11 +512.00000     +512.00000     -13.209600     -13.209600          CAJ
COS LN                                                                AJ
```

```
        +0.            +0.            +0.            +0.                CAK
        +0.    +0.25800000E-01        +0.     +38.759690                CAK
+0.25800000E-01        +0.     +38.759690            +0.                 AK
 +231.66000     -236.21140    +0.25800000E-01+0.25800000E-01             AM
 +135.00000     +45.000000     +512.00000     +512.00000                 AN
LAPTFPSAOF +241.03420     -226.83720    CIRC +2.5000000    NN     LFMCCAJ
              +0.46165000E-01 +4.9087000     +45.000000    Y            CAJ
 11 +8192.0000     +512.00000     -185.13920     -48.281600             CAJ
COS LF                                                                   AJ
        +0.            +0.            +0.            +0.                CAK
        +0.    +0.94300000E-01        +0.     +10.604450                CAK
+0.22600000E-01        +0.     +44.247790            +0.                 AK
 +241.03420     -226.83720    +0.22600000E-01+0.94300000E-01             AM
 +135.00000     +45.000000     +8192.0000     +512.00000                 AN
LAPTFBOAOF +222.28580     -245.58560    CIRC +2.5000000    NN     LFMCCAJ
              +0.46165000E-01 +4.9087000     +45.000000    Y            CAJ
 11 +8192.0000     +512.00000     -185.13920     -48.281600             CAJ
COS LF                                                                   AJ
        +0.            +0.            +0.            +0.                CAK
        +0.    +0.94300000E-01        +0.     +10.604450                CAK
+0.22600000E-01        +0.     +44.247790            +0.                 AK
 +222.28580     -245.58560    +0.22600000E-01+0.94300000E-01             AM
 +135.00000     +45.000000     +8192.0000     +512.00000                 AN
LAPTNPSAOF +241.03420     -226.83720    CIRC +2.5000000    NN     LNMCCAJ
              +0.25800000E-01 +4.9087000     +45.000000    Y            CAJ
 11 +512.00000     +512.00000     -13.209600     -13.209600             CAJ
COS LN                                                                   AJ
        +0.            +0.            +0.            +0.                CAK
        +0.    +0.25800000E-01        +0.     +38.759690                CAK
+0.25800000E-01        +0.     +38.759690            +0.                 AK
 +241.03420     -226.83720    +0.25800000E-01+0.25800000E-01             AM
 +135.00000     +45.000000     +512.00000     +512.00000                 AN
LAPTNBOAOF +222.28580     -245.58560    CIRC +2.5000000    NN     LNMCCAJ
              +0.25800000E-01 +4.9087000     +45.000000    Y            CAJ
 11 +512.00000     +512.00000     -13.209600     -13.209600             CAJ
COS LN                                                                   AJ
        +0.            +0.            +0.            +0.                CAK
        +0.    +0.25800000E-01        +0.     +38.759690                CAK
+0.25800000E-01        +0.     +38.759690            +0.                 AK
 +222.28580     -245.58560    +0.25800000E-01+0.25800000E-01             AM
 +135.00000     +45.000000     +512.00000     +512.00000                 AN
```

A3. COS Pre-flight SIAF.log file

```
LFMAC      SI: COS   SI  nme: L     Det: F            SHAPE: CIRC
         Mac Fl: Y  Mac ID : LFMC  Br Fl : Y  Br Th: 17.00
         MAJ:   42.000000      MIN:   42.000000      AREA:   1385.4424
         # X-PIX:     0            # Y-PIX:     0
         SICS Xso:  -185.13920     SICS Yso:  -48.281600
         SIAS Xao:   8192.0000     SIAS Yao:   512.00000
         X ref:   8192.0000        Y ref:   512.00000
         X inc:  0.22600000E-01    Y inc:  0.94300000E-01
         ASEC/PIX:  0.46165000E-01 THETA-V2V3:   45.000000
         Beta1:   135.00000        Beta2:   45.000000
         Ref V2:   231.66000       Ref V3:  -236.21140
         V2:    231.66000          V3:  -236.21140
         PARITY:  1 POLY DEG:  1   SIAS FL: Y
          1  A:          0.        B:          0.
          1A-1:          0.      B-1:          0.
          2  A:          0.        B:  0.94300000E-01
          2A-1:          0.      B-1:   10.604450
          3  A:  0.22600000E-01    B:          0.
          3A-1:   44.247790      B-1:          0.

LFBOA      SI: COS   SI  nme: L     Det: F            SHAPE: CIRC
         Mac Fl: N  Mac ID : LFMC  Br Fl : N  Br Th:  0.00
         MAJ:   2.5000000      MIN:   2.5000000      AREA:   4.9087000
         # X-PIX:     0            # Y-PIX:     0
         SICS Xso:  -185.13920     SICS Yso:  -48.281600
         SIAS Xao:   8192.0000     SIAS Yao:   512.00000
         X ref:   8192.0000        Y ref:   512.00000
         X inc:  0.22600000E-01    Y inc:  0.94300000E-01
         ASEC/PIX:  0.46165000E-01 THETA-V2V3:   45.000000
         Beta1:   135.00000        Beta2:   45.000000
         Ref V2:   231.66000       Ref V3:  -236.21140
         V2:    231.66000          V3:  -236.21140
         PARITY:  1 POLY DEG:  1   SIAS FL: Y
          1  A:          0.        B:          0.
          1A-1:          0.      B-1:          0.
          2  A:          0.        B:  0.94300000E-01
          2A-1:          0.      B-1:   10.604450
          3  A:  0.22600000E-01    B:          0.
          3A-1:   44.247790      B-1:          0.


LFPSA      SI: COS   SI  nme: L     Det: F            SHAPE: CIRC
         Mac Fl: N  Mac ID : LFMC  Br Fl : N  Br Th:  0.00
         MAJ:   2.5000000      MIN:   2.5000000      AREA:   4.9087000
         # X-PIX:     0            # Y-PIX:     0
         SICS Xso:  -185.13920     SICS Yso:  -48.281600
         SIAS Xao:   8192.0000     SIAS Yao:   512.00000
         X ref:   8192.0000        Y ref:   512.00000
         X inc:  0.22600000E-01    Y inc:  0.94300000E-01
         ASEC/PIX:  0.46165000E-01 THETA-V2V3:   45.000000
         Beta1:   135.00000        Beta2:   45.000000
         Ref V2:   231.66000       Ref V3:  -236.21140
         V2:    231.66000          V3:  -236.21140
         PARITY:  1 POLY DEG:  1   SIAS FL: Y
```

```
           1  A:           0.         B:           0.
           1A-1:           0.      B-1:            0.
           2  A:           0.         B:  0.94300000E-01
           2A-1:           0.      B-1:   10.604450
           3  A:  0.22600000E-01    B:           0.
           3A-1:   44.247790      B-1:           0.

LNMAC      SI: COS    SI  nme: L     Det: N            SHAPE: CIRC
          Mac Fl: Y  Mac ID : LNMC  Br Fl : Y  Br Th: 20.00
          MAJ:   42.000000      MIN:   42.000000      AREA:   1385.4424
          # X-PIX:      0            # Y-PIX:      0
          SICS Xso:  -13.209600     SICS Yso:  -13.209600
          SIAS Xao:   512.00000     SIAS Yao:   512.00000
          X ref:   512.00000        Y ref:   512.00000
          X inc:  0.25800000E-01    Y inc:  0.25800000E-01
          ASEC/PIX:  0.25800000E-01 THETA-V2V3:   45.000000
          Beta1:   135.00000        Beta2:   45.000000
          Ref V2:   231.66000       Ref V3:  -236.21140
          V2:    231.66000          V3:  -236.21140
          PARITY:  1 POLY DEG:  1   SIAS FL: Y
           1  A:           0.         B:           0.
           1A-1:           0.      B-1:            0.
           2  A:           0.         B:  0.25800000E-01
           2A-1:           0.      B-1:   38.759690
           3  A:  0.25800000E-01    B:           0.
           3A-1:   38.759690      B-1:           0.

LNBOA      SI: COS    SI  nme: L     Det: N            SHAPE: CIRC
          Mac Fl: N  Mac ID : LNMC  Br Fl : N  Br Th:  0.00
          MAJ:   2.5000000      MIN:   2.5000000      AREA:   4.9087000
          # X-PIX:      0            # Y-PIX:      0
          SICS Xso:  -13.209600     SICS Yso:  -13.209600
          SIAS Xao:   512.00000     SIAS Yao:   512.00000
          X ref:   512.00000        Y ref:   512.00000
          X inc:  0.25800000E-01    Y inc:  0.25800000E-01
          ASEC/PIX:  0.25800000E-01 THETA-V2V3:   45.000000
          Beta1:   135.00000        Beta2:   45.000000
          Ref V2:   231.66000       Ref V3:  -236.21140
          V2:    231.66000          V3:  -236.21140
          PARITY:  1 POLY DEG:  1   SIAS FL: Y
           1  A:           0.         B:           0.
           1A-1:           0.      B-1:            0.
           2  A:           0.         B:  0.25800000E-01
           2A-1:           0.      B-1:   38.759690
           3  A:  0.25800000E-01    B:           0.
           3A-1:   38.759690      B-1:           0.


LNPSA      SI: COS    SI  nme: L     Det: N            SHAPE: CIRC
          Mac Fl: N  Mac ID : LNMC  Br Fl : N  Br Th:  0.00
          MAJ:   2.5000000      MIN:   2.5000000      AREA:   4.9087000
          # X-PIX:      0            # Y-PIX:      0
          SICS Xso:  -13.209600     SICS Yso:  -13.209600
          SIAS Xao:   512.00000     SIAS Yao:   512.00000
          X ref:   512.00000        Y ref:   512.00000
          X inc:  0.25800000E-01    Y inc:  0.25800000E-01
          ASEC/PIX:  0.25800000E-01 THETA-V2V3:   45.000000
```

```
          Beta1:   135.00000        Beta2:   45.000000
          Ref V2:   231.66000       Ref V3:  -236.21140
          V2:    231.66000          V3:  -236.21140
          PARITY:  1 POLY DEG:  1   SIAS FL: Y
           1  A:          0.        B:          0.
           1A-1:          0.      B-1:          0.
           2  A:          0.        B:  0.25800000E-01
           2A-1:          0.      B-1:   38.759690
           3  A:  0.25800000E-01    B:          0.
           3A-1:   38.759690      B-1:          0.

 LAPTFPSAOFSI: COS   SI  nme: L     Det: F            SHAPE: CIRC
          Mac Fl: N  Mac ID : LFMC  Br Fl : N  Br Th: 17.00
          MAJ:   2.5000000      MIN:   2.5000000      AREA:   4.9087000
          # X-PIX:      0           # Y-PIX:      0
          SICS Xso:  -185.13920     SICS Yso:  -48.281600
          SIAS Xao:   8192.0000     SIAS Yao:   512.00000
          X ref:   8192.0000        Y ref:   512.00000
          X inc:  0.22600000E-01    Y inc:  0.94300000E-01
          ASEC/PIX:  0.46165000E-01 THETA-V2V3:   45.000000
          Beta1:   135.00000        Beta2:   45.000000
          Ref V2:   241.03420       Ref V3:  -226.83720
          V2:    241.03420          V3:  -226.83720
          PARITY:  1 POLY DEG:  1   SIAS FL: Y
           1  A:          0.        B:          0.
           1A-1:          0.      B-1:          0.
           2  A:          0.        B:  0.94300000E-01
           2A-1:          0.      B-1:   10.604450
           3  A:  0.22600000E-01    B:          0.
           3A-1:   44.247790      B-1:          0.

 LAPTFBOAOFSI: COS   SI  nme: L     Det: F            SHAPE: CIRC
          Mac Fl: N  Mac ID : LFMC  Br Fl : N  Br Th: 11.43
          MAJ:   2.5000000      MIN:   2.5000000      AREA:   4.9087000
          # X-PIX:      0           # Y-PIX:      0
          SICS Xso:  -185.13920     SICS Yso:  -48.281600
          SIAS Xao:   8192.0000     SIAS Yao:   512.00000
          X ref:   8192.0000        Y ref:   512.00000
          X inc:  0.22600000E-01    Y inc:  0.94300000E-01
          ASEC/PIX:  0.46165000E-01 THETA-V2V3:   45.000000
          Beta1:   135.00000        Beta2:   45.000000
          Ref V2:   222.28580       Ref V3:  -245.58560
          V2:    222.28580          V3:  -245.58560
          PARITY:  1 POLY DEG:  1   SIAS FL: Y
           1  A:          0.        B:          0.
           1A-1:          0.      B-1:          0.
           2  A:          0.        B:  0.94300000E-01
           2A-1:          0.      B-1:   10.604450
           3  A:  0.22600000E-01    B:          0.
           3A-1:   44.247790      B-1:          0.

 LAPTNPSAOFSI: COS   SI  nme: L     Det: N            SHAPE: CIRC
          Mac Fl: N  Mac ID : LNMC  Br Fl : N  Br Th: 20.00
          MAJ:   2.5000000      MIN:   2.5000000      AREA:   4.9087000
          # X-PIX:      0           # Y-PIX:      0
          SICS Xso:  -13.209600     SICS Yso:  -13.209600
          SIAS Xao:   512.00000     SIAS Yao:   512.00000
```

```
          X ref:   512.00000        Y ref:   512.00000
          X inc:  0.25800000E-01    Y inc:  0.25800000E-01
          ASEC/PIX:  0.25800000E-01 THETA-V2V3:   45.000000
          Beta1:   135.00000        Beta2:   45.000000
          Ref V2:   241.03420       Ref V3:  -226.83720
          V2:    241.03420          V3:  -226.83720
          PARITY:  1 POLY DEG:  1   SIAS FL: Y
           1  A:          0.        B:          0.
           1A-1:          0.      B-1:          0.
           2  A:          0.        B:  0.25800000E-01
           2A-1:          0.      B-1:   38.759690
           3  A:  0.25800000E-01    B:          0.
           3A-1:   38.759690      B-1:          0.

 LAPTNBOAOFSI: COS   SI  nme: L     Det: N            SHAPE: CIRC
          Mac Fl: N  Mac ID : LNMC  Br Fl : N  Br Th: 14.43
          MAJ:   2.5000000      MIN:   2.5000000      AREA:   4.9087000
          # X-PIX:     0            # Y-PIX:     0
          SICS Xso:  -13.209600     SICS Yso:  -13.209600
          SIAS Xao:   512.00000     SIAS Yao:   512.00000
          X ref:   512.00000        Y ref:   512.00000
          X inc:  0.25800000E-01    Y inc:  0.25800000E-01
          ASEC/PIX:  0.25800000E-01 THETA-V2V3:   45.000000
          Beta1:   135.00000        Beta2:   45.000000
          Ref V2:   222.28580       Ref V3:  -245.58560
          V2:    222.28580          V3:  -245.58560
          PARITY:  1 POLY DEG:  1   SIAS FL: Y
           1  A:          0.        B:          0.
           1A-1:          0.      B-1:          0.
           2  A:          0.        B:  0.25800000E-01
           2A-1:          0.      B-1:   38.759690
           3  A:  0.25800000E-01    B:          0.
           3A-1:   38.759690      B-1:          0.
```

A4. Pre-flight cgg5_COS.dat file

```
LFMAC       2000.001:00:00:00  1  231.6600   -236.2114    0.022600    0.094300    135.0000     45.0000   8192.0000     512.0000
LFBOA       2000.001:00:00:00  1  231.6600   -236.2114    0.022600    0.094300    135.0000     45.0000   8192.0000     512.0000
LFPSA       2000.001:00:00:00  1  231.6600   -236.2114    0.022600    0.094300    135.0000     45.0000   8192.0000     512.0000
LNMAC       2000.001:00:00:00  1  231.6600   -236.2114    0.025800    0.025800    135.0000     45.0000    512.0000     512.0000
LNBOA       2000.001:00:00:00  1  231.6600   -236.2114    0.025800    0.025800    135.0000     45.0000    512.0000     512.0000
LNPSA       2000.001:00:00:00  1  231.6600   -236.2114    0.025800    0.025800    135.0000     45.0000    512.0000     512.0000
LAPTFPSAOF2000.001:00:00:00  1  241.0342   -226.8372    0.022600    0.094300    135.0000     45.0000   8192.0000     512.0000
LAPTFBOAOF2000.001:00:00:00  1  222.2858   -245.5856    0.022600    0.094300    135.0000     45.0000   8192.0000     512.0000
LAPTNPSAOF2000.001:00:00:00  1  241.0342   -226.8372    0.025800    0.025800    135.0000     45.0000    512.0000     512.0000
LAPTNBOAOF2000.001:00:00:00  1  222.2858   -245.5856    0.025800    0.025800    135.0000     45.0000    512.0000     512.0000
```