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STAR SELECTION ALGORITHM REQUIREMENTS

AXAF SCIENCE CENTER

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STAR SELECTION ALGORITHM REQUIREMENTS

Prepared for:

National Aeronautics and Space Administration
Marshall Space Flight Center
Alabama 35812

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

Preface

This document constitutes the requirements specification for the AXAF Star Selection Algorithm. It supersedes earlier versions, including the 8 Dec 1994 and 31 May 1995 versions. This specification is as complete as current (August 1996) knowledge of the AXAF hardware characteristics permits. Further revisions to this specification may occur as additional information and analysis results emerge. Updates from the 31 May 1995 version are indicated in sans serif font. These updates include additions and simplifications.

Contents

1 Introduction

1.1 Objectives

This document specifies the functional requirements for the AXAF star selection algorithm (SSA) that is to be implemented in the OCC for use in the mission planning activity for selecting acquisition stars and Guide stars from the AXAF star catalog for each AXAF science observation. The purpose of this document is to provide the requirements basis for star selection software design by the OCC OFLS development team. This specification defines the algorithm for the star selection process, together with an operational sequence diagram, a textual description of each step in the sequence, and a definition of inputs and outputs for each step. Because of algorithm dependencies on certain characteristics of the aspect camera assembly (ACA), other elements of the AXAF pointing control and aspect determination (PCAD) subsystem, and the information content in the final star catalog (scheduled for delivery in 1997), none of which are yet available, updates to the functional requirements specification are anticipated. To the extent possible we have attempted to anticipate possible changes by defining variable parameters in the ODB, and allowing for changes in the AGASC. We plan to review this specification as more information becomes available on the ACA, the PCAD and the star catalog and to issue revisions as necessary.

1.2 Scope

The scope of this document includes the complete OCC processing required to identify and select stars from the AXAF star catalog which meet the requirements of acquisition stars, guide stars, and aspect stars. Acquisition stars support real-time attitude updating of the PCAD after an extended spacecraft slew to a new pointing direction. Requirements for selection of these stars have been defined by TRW, and have been integrated into the star selection algorithm by the ASC. Guide stars support real-time attitude holding by the PCAD during an observation. Aspect stars support precision post-facto attitude history determination by the ASC as part of the observation data ground processing.

It has been determined by TRW that a set of stars that meet aspect-star criteria will also satisfy guide-star criteria, so that only a single set of (nominally) five stars need be selected by the algorithm to serve both functions. For simplicity, these stars will be referred to as "guide" stars in this document. It has further been determined by TRW that, at least for some observations, acquisition stars that are distinct from the guide stars will be required to assure reliable real-time attitude updating within the PCAD after an extended slew.

The star selection algorithm includes identification of candidate stars in the ACA field of view during an observation pointing together with potential column-spoiler stars, selection of candidate star sets from this group that meet specified criteria, and evaluation of candidate star sets against performance-related criteria. The algorithm selects acceptable sets of guide stars first, and then depending on a OR parameter, either applies acquisition-star selection criteria to determine whether a single set of five stars can be identified which satisfies both functions, or selects an independent set of acquisition stars. Contingency actions are specified which define further algorithmic functions, in the event that difficulties occur in selecting either guide stars or acquisition stars.

2 Applicable Documents

1. AMO-2000, AXAF Operations Ground System Requirements, 17 June 1994
2. AMO-2050, OCC/ASC Interface Control Document, 22 September 1995
3. SAO Internal Memo, "The HEAO-B Star Trackers", Steve Murray and Leon VanSpeybrock, 1973, 1976
4. AXAF Star Catalog V 1.0, June 1994
5. Detailed Information for AXAF Guide and Acquisition Star Catalog, AGASC V1.1, August 27 1996, Paul Green
6. TRW DR OP19, Operations Data Base User Guide, 6 September 1996
7. ASC TIM, Star Colors vs. Magnitude Range, 1 Feb 1995, M. Garcia
8. ASC TIM, Star Colors vs. Luminosity on Galactic Plane, 14 Feb 1995, M. Garcia
9. ASC TIM, Test Runs of GASSA v1.0, 24 Mar 1995, M. Garcia
10. ASC TIM, Tests of Acquisition Star Algorithm, v2.1, 3 May 1995, M. Garcia
11. SAO TIM, Constraints on selection of acquisition stars, 14 Feb 1995, Robert Cameron
12. SAO TIM, Error Array Definition in AXAF Guide Star Selection, 12 May 1995, Robert Cameron
13. ASC/MIT TIM, Computing the uncertainty in the centroid for a single star, 16 May 1995, Tom Markert
14. ASC Memo, Spoiler Codes for AGASC1.1 Stars, 27 June 1996, Paul J. Green
15. ASC Memo, Incorporating Roll into the SSA FOM, 7 Oct 1996, M. Garcia

3 General Description

3.1 Assumptions

The algorithm described in this document reflects the following assumptions:

1. The algorithm must be suitable for operational use in the OCC environment; in particular, it must be capable of automatic execution, without operator intervention

2. The algorithm must obtain its input data from standard sources, consisting of specific data elements in the Operations Data Base (ODB), without requiring FOT interpretation of unstructured scientific information to handle contingencies, or ad hoc requests to the ASC for supplemental input. (The ODB data elements that support star selection with the algorithm are: the AXAF Star Catalog, the Star Selection Algorithm (SSA) Parameters (see Appendix D), the Observation Request (OR) List, and the AXAF Characteristics (TBR).)

3. The algorithm must converge on an acceptable set of stars most of the time, with failure of the algorithm an unusual occurrence.

4. The algorithm must allow for occasional specification of one or more guide or acquisition stars or FIDs by the ASC, as part of the Observation Request (OR); *e.g.*, when it is scientifically desirable to obtain the optical signature of a target in the ACA field of view, as part of the observation data. If specified in the OR, the algorithm must allow the specified star(s) to be 'monitored' in order to telemeter the optical signature without using the on-board centroid to update the PCAD. Stars specified in the OR may not be in the current version of the AGASC, as they may be nova. In this case the position and magnitude must be taken directly from the OR.

5. The algorithm must allow for complete specification of all of the guide or acquisition stars or FIDs by the ASC as part of the OR, in unusual situations where either the scientific objectives of the observation require selection against more-stringent or otherwise different selection criteria than are used by the OCC algorithm, or when it is determined by either the ASC or the OCC that the algorithm does not produce scientifically adequate sets of stars (*e.g.*, near very dense star regions or regions with variable or diffuse background.)

6. The stars selected by the algorithm will be available to the ASC for examination for compatibility with the scientific objectives of the observation, as part of the mission schedule review and concurrence process. A possible but infrequent outcome of the review process may be specification of a different set of stars.

7. There will be a set of SSA parameters which the algorithm will obtain as input from the ODB. These parameters will nominally be fixed, but easy to update as needed as a result of ASC trends analysis.

3.2 Operational Sequence

An overview of the star selection process is shown in Figure 1. This overview shows the possible interaction between the guide star selection (GSSA) and the acquisition star selection (ASSA). The output of the guide selection is an ordered list of star sets. This list is ordered by FOM, so that the best set of stars is listed first. If so specified in the OR, star sets are taken from the top of this list, and each is tested by the ASSA (every acceptable set of candidate guide stars is tested up to a maximum number of sets) in order to see if it can also be used for acquisition stars. The algorithm ends as soon as a set of stars is found that serves both purposes. If none of the acceptable sets of guide stars can also serve as acquisition stars or if specified in the OR, the acquisition star algorithm attempts to find a different set of stars from the AGASC which can be used for acquisition.

The guide star selection algorithm is described in Figures 2,3 and 4, in the form of an operations sequence diagram. Data inputs to each step in the sequence are defined by the arrows at the left of the corresponding function. The individual steps in the sequence are as follows:

1. Using the pointing angles in celestial coordinates (RA, DEC) specified in the OR for the subject pointing, together with the Search Radius specified in the ODB, determine the nominal Star Search Region in celestial coordinates (the coordinates of the star catalog).

2. Identify stars from the star catalog that lie within the Star Search Region.

3. Check for FID lights which may be spoiled by stars.

4. Identify stars within the Star Search Region whose images will reliably lie on the ACA detector (CCD array), considering the geometry of the observation and the spacecraft pointing uncertainties. (These are the initial candidates for both aspect and acquisition stars.) Retain other stars that may lie on the ACA detector for later evaluation as potential column spoiler stars.

5. Identify, and eliminate from the list of candidates, non-stars and stars whose expected brightness as seen by the ACA detector is below a lower limit or above an upper limit. The expected brightness is either specified in the Star Catalog, or is determined by the brightnesses listed in the star catalog for one or more colors along with conversion factors that relate these to the expected brightness as seen by the ACA detector. The ACA apparent magnitude and the conversion factors are included as SSA Parameters in the ODB. Periodic updates will be provided to the OCC by the ASC as part of the trends analysis, as the ACA detector properties change.

   > Note: Eliminating insufficiently bright stars is necessary to achieve sufficiently accurate guide star centroids. Both internal detector noise and sensitivity of the ACA detectors to distortion of the point spread function (PSF) from other nearby stars render faint stars unacceptable. Eliminating stars that are overly bright is aimed at reducing detector saturation.

   This brightness screening is bypassed for stars specified for this observation by the ASC in the OR, or as part of the MS concurrence process. Such stars that are used that are outside the magnitude default limits should be prominently flagged in the MS.

6. Identify, and eliminate from the list of candidates, stars which fail to meet criteria associated with freedom of imaging interference from nearby stars and FID lights, or proximity to dead spots in the ACA, or whose Quality Code (QC) as listed in the star catalog does not fall within

a specified range. [The QC characterizes the accuracy with which the star image centroid position can be determined.] Check stars specified by the ASC in the OR for compatibility with these spatial filtering criteria (which are roll-angle sensitive, and therefore cannot be checked a priori by the ASC). If any ASC-specified star fails this filtering check, delete the star from the ASC-specified list, report the failure, and proceed.

7. Form sets of five stars, consisting of guide stars specified by the ASC in the OR plus additional stars from the list of screened candidates, and calculate a figure-of-merit (FOM) for each set. Compare the FOM to a specified selection criterion (e.g., lowest achievable FOM or FOM below a threshold), and continue until either the selection criterion has been satisfied or it is determined that there is no set of stars from among the screened candidates which satisfies the criterion. Order the sets of stars which have acceptable FOMs according to increasing FOM. For each set compute three Group Quality Codes (GQC) which are the sums of the three QC values for the individual stars as listed in the Star Catalog.

8. If no set of stars is found that satisfies the (default) specified selection criterion, an expanded search is conducted, based on modified viewing geometry (roll angle, observation schedule), selection of an alternative set of FID lights, and allowing stars with higher QC. If the expanded search still does not satisfy the selection criterion, the best set of guide stars is selected and a flag is set in the Mission Schedule to indicate this.

9. The selected acquisition and guide stars are provided by the OFLS in the Mission Schedule, for review by the ASC against the science objectives of the observation as part of the Mission Schedule review. Under exceptional circumstances, based on the science objectives of the observation, the ASC might request a change in the selection of acquisition or guide stars as part of the MS concurrence process.

Selection of acquisition stars is based on the guide star algorithm, with a few differences. The "filtering" of stars proceeds identically, but there is an additional positional error term (due to the slew between targets) which must be considered when searching for column and radial spoilers. The AGASC quality codes for acquisition stars take this larger slew error into account, and are therefore different from the quality codes for guide stars. There is no need to determine a FOM for acquisition stars. Instead, the stars are ordered by magnitude (brightest stars first) and star sets are chosen from this ordered list. Therefore acquisition stars will on average be brighter than guide stars (if the sets are different).

4 Functional Requirements, Guide Stars

This section defines the functional requirements for the guide star selection algorithm. The requirements are organized to follow the flow chart presented in Figure A to A.

This section specifies functional requirements only. There are no performance or design requirements on the SSA algorithm that are governed by this specification.

4.1 General Requirements

1. If the OR (or MS concurrence process) specifies all stars, then flag, but do not disqualify stars based on brightness checks (4.5) and QC checks (4.6.1) but check to see that the stars fall on the ACA (4.4.1) and check for column (4.6.6) and shift register (4.7.2) spoilers, and check the ACA bad pixel map (4.6.5). Then bypass FOM-based checks (4.7) and contingency checks (4.9), but compute the FOM based on the ACA error array and predicted pointing direction and roll.

2. If the OR (or MS concurrence process) specifies one or more stars,then flag, but do not disqualify stars based on brightness checks (4.5) and QC checks (4.6.1) but check to see that the stars fall on the ACA (4.4.1) and check for column (4.6.6) and shift register (4.7.2) spoilers and check the ACA bad pixel map (4.6.5). Then proceed to optimize the FOM (4.7), given the constrained set.

3. When the OR specifies a complete set of fiducial lights for an observation, the software shall select those fiducial lights, irrespective of the results of applying the algorithm specified in the following sections.

4.2 Determine Nominal Field of View (Flow Chart Block 1)

The software shall determine a Star Search Region (SSR), in celestial coordinates (J2000 coordinates, as used in the Star Catalog), based on the following:

1. Right Ascension (RA) and Declination (DEC) for the specific pointing, as specified in the relevant Observation Request (OR)

2. A Search Radius, as specified in the SSA Parameters data element of the Operations Data Base (ODB).

The SSR is expressed as a center point and an angular radius, and defines the spatial region from which to select candidate acquisition/guide stars, and to identify potential interfering ("column spoiler") stars, from the star catalog. The SSR is larger than the ACA field of view, and includes margins for pointing offsets from the specified pointing coordinates and a roll angle that is (typically) determined during the mission scheduling process and is unknown prior to this time.

The pointing offsets include contributions from dither, attitude hold error, and boresight offset.

4.3 Determine Stars in Field of View (Flow Chart Block 2)

The software shall identify all stars whose celestial coordinates are within the spatial bounds defined by the SSR, using star identifications and star positions listed in the AXAF Star Catalog data element of the ODB.

4.4 Select Candidate Guide Stars (Flow Chart Block 3)

Stars whose images will reliably fall on the ACA detector, considering pointing errors and other factors, are retained for consideration as guide stars. All others within the SSR are eliminated from further consideration except those that might be potential column spoilers (see Section 4.6). These stars are stars which are sufficiently bright that may fall on the ACA CCD chip during the observation. To determine the set of stars that may fall on the chip, it is necessary to project the CCD on the SSR and consider the maximum excursion of the chip location, taking into account attitude hold error and programmed dither.

4.4.1 Determine Spatial Subregion of SSR That Is Subtended By the ACA Detector

The software shall calculate the spatial bounds of the subregion of the SSR which will be imaged on the ACA detector with high confidence, considering expected pointing errors (pitch, yaw)and pointing angle (roll) variations. Calculation of the spatial bounds of the subregion will be based on the following parameters:

1. The reference aperture of the ACA detector, as specified in the SSA Parameters data element of the ODB. The reference aperture is specified as a rectangular array of ACA pixels, plus a pixel size.

2. The roll angle for the observation. The roll angle is determined initially by the OFLS, using mechanisms not governed by this specification, unless specified in the OR. (The roll angle may be varied as part of this algorithm, under conditions described in Section 4.9)

3. The maximum pointing error that can occur during attitude hold, as specified in the SSA Parameters data element of the ODB.

4. The dither amplitude for the observation. The maximum dither amplitude that can occur is specified in the SSA Parameters data element of the ODB. The OR specifies whether dithering is to be implemented for the observation, and the amplitude of the dither.

5. The HRMA boresight correction, which defines the angular separation of the HRMA and ACA boresight axes, and is provided in the ODB.

6. The velocity aberration expected during the observation, based on the target co-ordinates and the heliocentric orbital velocity vector of the spacecraft. This should be computed based on the predicted spacecraft and earth orbit ephemerides, for the scheduled time(s) of the observation.

The calculation will be carried out by using the roll angle to orient the reference aperture on the sky, reducing both rectangular dimensions of the resulting subregion by the sum of the maximum pointing error and the dither amplitude, and using the boresight correction to shift the center of the reference aperture away from the specified pointing RA and DEC.

4.4.2 Identify Spatially-Filtered Candidate Stars

The software shall identify the stars within the SSR whose images will reliably fall on the ACA detector, by comparing each stellar position with the bounds of the spatial subregion defined in 4.4.1, and selecting those stars whose positions fall within these spatial bounds.

4.4.3 Retain IDs of Potential Column Spoiler Stars

The software shall retain, for examination as potential column spoilers, the identities of all stars within the SSR whose positions lie outside the bounds of the spatial subregion defined in 4.4.1, but which never-the-less may lie on the ACA.

4.4.4 Check FIDs for Stellar Column Spoilers

If a FID light is readout through a bright star, then the position of the FID light may be artificially distorted. Check to see if this will occur, and if so, attempt to avoid this by changing the roll angle as outlined in Section 4.9.1. If changing the roll angle does not avoid the condition, attempt the alternate FID light set as in Section 4.9.2. If this does not alleviate the condition, select the default set of FIDs and default roll, continue with the algorithm, and prominently indicate the FID and associated column spoiler star in the MS. In order to be a potential column spoiler the star must be "col_mag_diff_limit_gf" brighter than the FID light, and must be within "col_spoil_col_limit" columns of the FID light. The apparent magnitude of the FIDs is listed in the SSAPE/ODB as "fid_aca_mag". Note that FID positions are not shifted on the ACA due to velocity abberation, while star positions are. The column spoiler check must therefore allow for the range in position shifts expected due to velocity abberation during the observations.

4.5 Select Stars Based on Brightness (Flow Chart Block 4)

Identify stars from the list of candidate guide stars that may be too dim or too bright to use.

4.5.1 Get Instrumental Magnitudes

The software shall determine the instrumental magnitude of each star in the list. The instrumental magnitude is the stellar brightness as measured by the ACA. It is determined from the AGASC in the following way:

- if the "star_mag_conv_flag" (in the SSAPE/ODB[1]) has been set to 0, then the software will read the MAG_aca directly from the AGASC.
- if the "star_mag_conv_flag" (in the SSAPE/ODB) has been set to 1, then the software shall compute MAG_aca from the magnitudes in various colors as listed in the AGASC. The polynomial formula for computing MAG_aca is described below.

The coefficients of this polynomial are SSAPE/ODB input parameters with initial default values, the variables in the polynomial are the magnitude and colors in the AGASC, V1.1, ie, MAG, C1, C2, C3. The coefficients will vary with time as the star camera ages (periodic updates will be

[1]SSA Parameters data element of the Operations Data Base

provided by the ASC as part of the trends analysis). There will be a different set of coefficients for each of the (~ 10) "MAG_BAND" codes in the AGASC. For a single MAG_BAND, for example:

$$\begin{aligned} MAG\_aca \; = \; & aca\_mag\_00 + aca\_mag\_01(MAG) + \\ & aca\_mag\_01\_1(C1) + aca\_mag\_02\_1(C2) + \\ & aca\_mag\_01\_2(C1)^2 + aca\_mag\_02\_2(C2)^2 + \\ & aca\_mag\_01\_3(C1)^3 + aca\_mag\_02\_3(C2)^3 + \\ & aca\_mag\_01\_4(C1)^4 + aca\_mag\_02\_4(C2)^4 \end{aligned}$$

The coefficients aca_mag_00, aca_mag_01, aca_mag_01_1, etc., will be taken from the SSAPE/ODB and will be provided by the ASC.

4.5.2 Filter Faint Stars

The software shall filter all stars dimmer than the instrumental magnitude "g_max_mag" (which is specified in the SSA parameter element of the ODB). "Filter" means to flag the star as being unacceptable as a potential guide star. Stars that have been specified by the ASC for inclusion in the guide star set should not fail this filter no matter what their magnitudes (*i.e.*, if these stars fail this test they should be so flagged, but not eliminated from consideration.)

4.5.3 Filter Bright Stars

The software shall filter all stars brighter than the instrumental magnitude "g_min_mag" (which is specified in the SSA parameter element of the ODB). "Filter" means to flag the star as being unacceptable as a potential guide star. Stars that have been specified by the ASC for inclusion in the guide star set should not fail this filter no matter what their magnitudes (*i.e.*, if these stars fail this test they should be so flagged, but not eliminated from consideration.)

4.6 Apply Spatial Filters on Stars (Flow Chart Block 5)

Identify all stars from the list of candidate stars that pass all of the tests defined in this section. We refer to this set of stars as the "filtered star list" below. Some of these tests check the value of the Quality Codes (QC) in the AGASC, in order to determine if they are within the ranges allowed or are suitably small (see below).

4.6.1 Filter on QC

The software shall identify the candidate stars for which the corresponding QCs listed in the AGASC fall between the limits specified in the SSA parameter fields of the ODB. As defined by the ASC, lower values of the QCs are "better", and therefore only stars which have QCs equal to the lower bound will be accepted for the first (and most likely only) pass through the SSA. Possible additional passes, and treatment of the QCs, are described in section 4.9.3. The three QCs listed in the AGASC (V1.1) are "ASPQ1", "ASPQ2", and "ASPQ3". The low and high bounds of the acceptable ranges are the ODB elements "guide_c1_code_min", "guide_c1_code_max", "guide_c2_code_min", "guide_c2_code_max", "guide_c3_code_min", "guide_c3_code_max".

The factors that go into the computation of the QCs are irrelevant to the OCC implementation of the SSA. For information purposes, however, they include such things as the presence of nearby stars ("spoilers" that can make the centroiding of a stellar position difficult), large positional uncertainties, known binary nature, known large proper motions, known excessive variability, and other factors.

4.6.2 Filter on Star CLASS

The software shall remove from the list of candidate stars all objects in the AGASC that have a CLASS parameter other than CLASS=0. These objects should be retained in the list of all stars, in order to check if they are possible column spoilers.

4.6.3 Filter on FID Spoilers

The software shall identify (and flag for exclusion) stars that may be too close to the fiducial lights. "Too close" is defined by the SSAPE/ODB parameter "fid_spoil_region". Note that because shifts in the pointing direction cause the stars to move across the ACA while the FIDS do not, the allowable errors due to attitude hold ("max_point_error" parameter in SSAPE/ODB) and dither ("max_dither" parameter in SSAPE/ODB) must also be included in the evaluation of proximity of the star with respect to the FIDs. The relative motion of the stars and FIDs due to velocity abberation must also be allowed for.

4.6.4 Filter on Exclusion Box Radius

The software shall identify (and flag for exclusion) stars that may have another bright star within the bounds of the ACA directed search region. Bright enough is defined as stars within 'exc_mag_diff_limit' (ODB entry) magnitudes of the candidate star. The region to be searched is a circle round the candidate star with a radius equal to $2 \times \sqrt{2} \times SBS$, where $SBS =$ guide_searchbox_size (ODB entry).

4.6.5 Filter on ACA Bad Pixel Map

The software shall identify (and flag for exclusion) stars that may fall in bad regions of ACA CCD. This region is defined in the SSA parameter field of the ODB as the entry called "ACA detector bad-region map". As above, note that attitude hold error, dither, and variations in velocity abberation must be considered in defining the size of the regions.

4.6.6 Filter Column Spoiler

The software shall identify (and flag for exclusion) stars that may have CCD "column spoilers" (*i.e.*, if a candidate star is read out through a column in which another bright star or FID light lies, it will be "spoiled" by the star or FID light). A star is considered bright, in this context, if it is "col_mag_diff_limit_gg" (SSAPE/ODB) magnitudes brighter than the star being considered. FIDS are always considered possible column spoilers. Stars (and FIDS) are considered to be in the same column, in this context, if they are within "col_spoil_col_limit" (from the SSAPE/ODB) columns.

4.6.7 Filter out Stars Spoiled by Planets

Check the position of the solar system planets to see if any fall in the FOV of the ACA during the planned observation. If any do, remove any candidate stars which may be column spoiled by the planets, using the same parameters as above (4.6.6). Also remove any candidate stars that are within a circle of radius "planet_rad_spoiler" arcseconds of a planet.

4.6.8 Collect Filtered Star List

The stars that have passed all of the above tests will then be suitable candidates for guide stars, and form the "filtered star list". If there are more than "max_filtered_list_len" (SSAPE/ODB) stars in this list, remove the fainter ones in order to get the list down to this size. From this list, a set of stars (five, unless otherwise specified in the OR) will be chosen as candidate guide stars. The technique for selecting this set of stars is described in the following sections.

4.7 Test for Performance Adequacy (Flow Chart Block 6)

Every set of N stars that can be drawn from the filtered star list should be checked for performance adequacy. N is typically 5; the default value is parameter num_guide_stars in ODB, but this can be overridden if the same parameter (num_guide_stars) appears in the OR. Calculate a figure of merit (FOM) for each set of N, related to the predicted uncertainty in the precision aspect solution. Determine three Group Quality Codes, which are the sum of the individual aspect QCs (ASPQ1, etc.) for each of the stars in each set. Decide when a set of N stars has been found that provides satisfactory performance as determined by the figure of merit. Sets of stars should have GQCs in an allowed range (as well as acceptably low FOMs) in order to be considered as acceptable guide star groups. The maximum allowed GQC is the sum of the maximum allowed values for the individual QCs.

4.7.1 Check for, and Remove, Row Spoilers

AS OF AUGUST 1996, IT IS NO LONGER NECESSARY TO REMOVE ROW SPOILERS, the ACA PEA CAN NOW ACCEPT STAR/FIDS WITH OVERLAPPING ROWS. THIS CHECK IS THEREFORE no longer NEEDED. DELETED TEXT:

> Check the row location of each of the stars in the sets of N, and remove from consideration the fainter star of any two that are within "row_spoiler_limit" rows of each other. Compute the FOM(4.7.4) on the remaining stars. Also remove from consideration any stars within "row_spoiler_limit" rows of a FID light.

4.7.2 Check for Readout Register Spoilers

Check for 'readout register spoilers'. Remove from consideration any candidate guide stars that are spoiled by possible readout register spoilers. Readout register spoilers are stars (or planets) which may fall on the ACA readout register and are "readout_reg_spoiler" magnitudes brighter than the candidate guide star. Only remove from consideration those candidate guide stars which are "downstream" of the spoiler, that is guide stars which are in columns closer to the center of the chip than the spoiler. If any of the FIDs are spoiled, switch to the alternate FIDs set and report the reason for the switch in the SSA output (Mission Schedule).

4.7.3 Position Uncertainty, Single Star

For each star in the list of accepted stars, the software shall compute the predicted uncertainty in the centroid of the stars on the ACA. This uncertainty is a function of the instrumental magnitude of the star (brighter stars provide more precise centroids) and systematic errors. The formula for the uncertainty (σ_i) in the centroid of an individual star is given and discussed in Appendix B.

4.7.4 Compute Figure of Merit

The software shall compute the FOM for all sets of N (=num_guide_stars) stars drawn from the filtered star list. Note that for every set of N stars, there is a separate FOM calculation. The FOM calculation is given in Appendix C. It shall flag those sets of stars that have an FOM lower than the maximum specified in the SSAPE/ODB ("max_acceptable_fom").

4.7.5 Compute Group Quality Codes

For the collection of star sets with acceptable FOMs, the software shall compute three Group Quality Codes (GQC). The GQC are the sums of the individual three QCs for the individual stars in the set.

4.7.6 Suspend FOM and GQC Checks for OR Specified Stars

The software shall permit constraints on the selection of stars; for example, the OR (or MS concurrence process) may pre-select one or more stars to be used as guide stars (such as the X-ray target). If all the guide stars are pre-selected, the FOM and GQC shall be computed for such sets, but no FOM/QC acceptability criteria will be applied. Such stars that are outside the normal brightness limits will be prominently flagged in the MS. If the OR specifies the star is to be 'monitored', and therefore not used as a guide star, then it should not be included in the FOM calculation.

4.7.7 Compute FOM, GQC if Less Than N Stars

The software shall compute an FOM and GQC if fewer than num_guide_stars stars are found in the filtered star list determined in Section 4.6.8. If at least one set of stars meeting the FOM and GQC criteria are found, then the algorithm proceeds to Section 4.10, and sets an aspect quality indicator in the MS to indicate GSSA goals have been met. Otherwise it proceeds to Section 4.9 (Flow Chart Block 7).

4.8 Collect Ordered List

The sets of stars having acceptable FOMs and GQC shall be ordered by FOM (smallest first). The length of the list shall be limited to "fom_list_length" (SSAPE/ODB) by dropping those sets with the larger FOMs.

4.9 Depart from Nominal Observation Parameters to Find Acceptable Set of Guide Stars (Flow Chart Block 7)

This section specifies how the algorithm should respond if it doesn't find a set of N stars (where N = num_guide_stars as set in ODB or overridden in OR) that satisfies the FOM/GQC criterion (Sections 4.6 and 4.7). The software is to attempt each of the fixes below in turn. If one of the fixes works, then the search should terminate, and the algorithm proceeds.

4.9.1 Try Off Nominal Roll

If the FOM/GQC are unsuitable, then the software should make small changes in the nominal roll angle (±1 degree, ±2 degrees, ... up to the nominal roll limit; as determined from the AXAF Characteristics data element in the ODB). If the roll has been specified in the OR, then small changes in the roll up to the delta_roll allowed in the OR may be made. The algorithm then branches back to Section 4.3 (Flow Chart Block 3) and determines a new set of candidate stars and new set of FOMs/GQCs. If this "fix" works, then the new set of stars is returned in the MS, along with an indication in the MS that it was necessary to use an off-nominal roll.

4.9.2 Try Alternate FID Lights

If the "fix" in Section 4.9.1 fails, then the software should try using the alternate FID light set. This should first be attempted at the nominal roll, and then at off-nominal rolls as in 4.9.1. If using the alternate FID light set works, then there should be an indication in the MS that the alternate set was used, and the names (numbers) of the alternate FIDS should be listed in the MS.

4.9.3 Accept Higher QCs

If the alternatives in sections 4.9.1 and 4.9.2 fail to find acceptable FOM/GQC, then the software should branch back to the QC filtering section (4.6.1) and allow stars with the next highest integer value of the ASP-QCs. This should continue until an acceptable set of stars is found, or the maximum allowable value of the ASP-QC is reached ("guide_c1_code_max", etc., in SSAPE/ODB) for each of the three QCs. A non-zero value of the GQC is then reported in the MS. The use of higher QCs should first be attempted at the nominal roll, then at off-nominal roll, then at nominal roll, alternate FID lights, then at off-nominal roll with alternate FID lights.

If no set of stars is found after the extended search process described in Section 4.9 is completed, the MS shall halt further processing of the OR and report the results of Section 4.9 processing in the free-text files of the MS. An aspect quality indicator will also be set in the MS to indicate that the GSSA goals have not been met.

4.10 Report Results (Flow Chart Block 8)

The results of the SSA shall be reported to the ASC in the MS. The report shall include (but need not be limited to)

- A histogram of the FOM for the sets in this final list, and the FOM for the chosen set of guide stars.

- The characteristics of the selected set of stars, including AGASC identification, RA/DEC, ACA Z,Y pixel position, positional uncertainty in arcsec as defined in Section 4.7.3, instrumental magnitude, spectral type, and quality codes. Stars that have been pre-selected in the OR should be labeled as such. In addition, pre-selected stars that fail the magnitude range and QC checks shall be highlighted in the report.

- If OR selected stars are found to fail spatial filters, it should be reported in the MS which spatial filter was failed by the star.

5 Functional Requirements, Acquisition Stars

This section defines the functional requirements on the acquisition star selection algorithm. The requirements are organized to follow the flow chart presented in Figures A to A, which is specifically for guide stars, but also largely applies to acquisition stars.

This section specifies functional requirements only. There are no performance or design requirements on the SSA algorithm that are governed by this specification.

5.1 General Requirements

1. If the OR specifies one or all of the stars, then flag, but do not disqualify stars based on brightness checks (5.5) and QC checks (5.6.1) but check to see that the stars fall on the ACA (5.4.1) and check for column spoilers (5.6.5), readout register spoilers (5.7.1) and check the ACA bad pixel map (5.6.4).

2. When the Guide Star Selection Algorithm specifies a complete set of trial acquisition stars for an observation, the software shall determine if those stars pass all of the filters outlined below.

3. When the OR specifies a complete set of fiducial lights for an observation, the software shall select those fiducial lights, irrespective of the results of applying the algorithm specified in the following sections.

5.2 Determine Nominal Field of View (Flow Chart Block 1)

The software shall determine a Star Search Region (SSR), in celestial coordinates (J2000 coordinates, as used in the Star Catalog), based on the following:

1. Right Ascension (RA) and Declination (DEC) for the specific pointing, as specified in the relevant Observation Request (OR)

2. A Search Radius, as specified in the SSA Parameters data element of the Operations Data Base (ODB) parameter "search_radius".

The SSR is expressed as a center point and an angular radius, and defines the spatial region from which to select candidate acquisition/guide stars, and to identify potential interfering ("spoiler") stars, from the star catalog. The SSR is larger than the ACA field of view, and includes margins for pointing offsets from the specified pointing coordinates and a roll angle that is (typically) determined during the mission scheduling process and is unknown prior to this time. The pointing offsets include contributions from mispointing errors after a slew, attitude hold errors, and boresight mis-alignment, but not programmed dither.

5.3 Determine Stars in Field of View (Flow Chart Block 2)

The software shall identify all stars whose celestial coordinates are within the spatial bounds defined by the SSR, using star identifications and star positions listed in the AXAF Star Catalog data element of the ODB.

5.4 Select Candidate Acquisition Stars (Flow Chart Block 3)

Stars whose images will reliably fall on the ACA detector, considering pointing errors and other factors, are retained for consideration as acquisition stars. All others within the SSR are eliminated from further consideration, but are held for examination in Section 5.6 as potential "column spoilers."

5.4.1 Determine Spatial Subregion of SSR That Is Subtended By the ACA Detector

The software shall calculate the spatial bounds of the subregion of the SSR which will be imaged on the ACA detector with high confidence, considering expected pointing errors (pitch,yaw) and pointing angle (roll) variations. Calculation of the spatial bounds of the subregion will be based on the following parameters:

1. The reference aperture of the ACA detector, as specified in the SSA Parameters data element of the ODB. The reference aperture is specified as a rectangular array of ACA pixels, plus a pixel size (arcsec).

2. The roll angle for the observation. The roll angle is determined initially by the OFLS, using mechanisms not governed by this specification, unless defined in the OR. (The roll angle may be varied as part of this algorithm, under conditions described in Section 5.8.)

3. The maximum pointing error that can occur during attitude hold, as specified in the SSAPE/ODB.

4. The maximum pointing error (radius in arcsec) that can occur after a slew, as specified in the SSA Parameters data element of the ODB. This value increases with the length of the slew. We quantize this error in six steps, using the following prescription

$$\begin{aligned}
\text{Slew_Error} &= M_1 \times \Theta_{slew} + \beta_1;\ \text{for } \Theta_0 < \Theta_{slew} < \Theta_1 \\
&= M_2 \times \Theta_{slew} + \beta_2;\ \text{for } \Theta_1 < \Theta_{slew} < \Theta_2 \\
&= M_3 \times \Theta_{slew} + \beta_3;\ \text{for } \Theta_2 < \Theta_{slew} < \Theta_3 \\
&= M_4 \times \Theta_{slew} + \beta_4;\ \text{for } \Theta_3 < \Theta_{slew} < \Theta_4 \\
&= M_5 \times \Theta_{slew} + \beta_5;\ \text{for } \Theta_4 < \Theta_{slew} < \Theta_5 \\
&= M_6 \times \Theta_{slew} + \beta_6;\ \text{for } \Theta_5 < \Theta_{slew} < \Theta_6
\end{aligned}$$

   where Θ_{slew} is the slew distance (in degrees) computed by the OFLS system, and Θ_x set the applicable ranges in slew angles. Nominal value of the slew error for a 180 degree slew is $133''$, the slew error for smaller slews will be smaller. The values of the parameters above depend on the TBD specifics of the AXAF Gyro set, but will be contained in the SSAPE/ODB.

5. DITHER will routinely be disabled during acquisition, so there is no need to add the dither amplitude to the SSR errors.

6. The HRMA boresight correction, which defines the angular separation of the HRMA and ACA boresight axes, and is provided in the ODB.

7. The velocity aberration expected during the observation, based on the target co-ordinates and the heliocentric orbital velocity vector of the spacecraft. This should be computed based on the predicted spacecraft and earth orbit ephemeris, for the scheduled time(s) of the observation.

The calculation will be carried out by using the roll angle to orient the reference aperture on the sky, reducing both rectangular dimensions of the resulting subregion by the sum of the maximum pointing error and the dither amplitude, and using the boresight correction to shift the center of the reference aperture away from the specified pointing RA and DEC.

5.4.2 Identify Spatially-Filtered Candidate Stars

As for Guide Stars, Section 4.4.2

5.4.3 Retain IDs of Potential Spoiler Stars

As for Guide Stars, Section 4.4.3

5.5 Select stars based on brightness (Flow Chart Block 4)

As for Guide Stars, Section 4.5

5.5.1 Get Instrumental Magnitudes

As for Guide Stars, Section 4.5.1

5.5.2 Exclude Faint Stars

As for Guide Stars, Section 4.5.2, except:
Replace "g_max_mag" with "a_max_mag" from the SSAPE/ODB.

5.5.3 Exclude Bright Stars

As for Guide Stars, Section 4.5.3, except:
Replace "g_min_mag" with "a_min_mag" from the SSAPE/ODB.

5.5.4 Rank Order by Brightness

Order the list of stars passing the filters by brightness (instrumental magnitude), with the brightest stars first.

5.6 Apply Spatial Filters on Stars (Flow Chart Block 5)

As for Guide Stars, Section 4.6.

5.6.1 QC Filters

There are six acquisition star quality filters, ACQQx, with $1 \leq x \leq 6$. Each filter corresponds to one of the six maneuver ranges as specified in Section 5.4.1, item 4. The filter is a real number defined at $100 \times (M_{spoofer} - M_{acqstar})$, the difference in magnitude between the candidate and the brightest star within the candidates exclusion box radius. After determining which of the six filters to use, only allow stars with a code GREATER than the lower limit set by the ODB parameter "acq_qual_code_min"; filter out all other stars.

5.6.2 Filter on Star CLASS

The software shall remove from the list of candidate stars all objects in the AGASC that have a CLASS parameter other than CLASS=0. These objects should be retained in the list of all stars, in order to check if they are possible column spoilers.

5.6.3 Filter FID Spoilers

The software shall identify stars that may be too close to the fiducial lights. "Too close" is defined by the SSAPE/ODB parameter "fid_spoil_region". Note that because changes in the pointing direction and velocity abberation cause the stars move across the ACA while the FIDS do not, the allowable errors due to slew and attitude hold ("max_slew_error", "max_point_error" parameters in SSAPE/ODB) must also be allowed for. It is not necessary to allow for dither during the acquisition phase.

5.6.4 Filter on ACA Bad Pixel Map

The software shall identify stars that may fall in bad regions of ACA CCD. This region is defined in the SSA parameter field of the ODB as the entry called "ACA detector bad-region map". As above, note that slew errors, velocity abberation, and attitude hold errors must be allowed for.

5.6.5 Filter Column Spoilers

The software shall identify stars that may have CCD "column spoilers" (*i.e.*, if a candidate star is read out through a column in which another bright star or FID light lies, it will be "spoiled" by the star or FID light). A star is considered bright, in this context, if it is "col_mag_diff_limit_a" magnitudes brighter (SSAPE/ODB) than the star being considered. FIDS are always considered possible column spoilers. Stars (and FIDS) are considered to be in the same column, in this context, if they are readout within "col_spoil_col_limit" (SSAPE/ODB) columns.

5.6.6 Filter out Stars Spoiled by Planets

Check the position of the solar system planets to see if any fall in the FOV of the ACA during the planned observation. If any do, remove any candidate stars which may be column spoiled by the planets, using the same parameters as above (4.6.6). Also remove any candidate stars that are within a circle of radius "planet_rad_spoiler" arcseconds of a planet.

5.6.7 Collect Filtered Star List

The stars that have passed all of the above tests will then be suitable candidates for acquisition stars, and form the "filtered star list". From this list a set of stars (typically 3, but specified in the ODB as "num_acq_stars" or overridden in the OR) will be chosen as candidate acquisition stars. The technique for selecting these sets of stars is described in the following sections.

5.7 Select Brightest Acquisition Stars (Flow Chart Block 6)

Rather than computing a FOM as for guide stars, the algorithm simply chooses the brightest N stars (typically N=3, but as specified in the ODB as "num_acq_stars" or overridden in the OR) to use as acquisition stars. If less than this minimum number can be found, then take the remedial steps outlined in Section 5.8.

5.7.1 Check for Readout Register Spoilers

Check for 'readout register spoilers'. Remove from consideration any candidate acquisition stars that are spoiled by possible readout register spoilers. Readout register spoilers are stars (or planets) which may fall on the ACA readout register and are "readout_reg_spoiler" magnitudes brighter than the candidate acquisition star. Only remove from consideration those candidate acquisition stars which are "downstream" of the spoiler, that is acquisition stars which are in columns closer to the center of the chip than the spoiler. If any of the FIDs are spoiled, switch to the alternate FIDs set and report the reason for the switch in the SSA output (Mission Schedule).

5.7.2 OR/GSSA Selected Stars

The software shall permit constraints on the selection of stars; for example, the OR or the Guide Star Selection Algorithm (GSSA) may pre-select one or more stars to be used as acquisition stars. In this case the algorithm shall test the pre-selected set to see if it passes the brightness (Section 5.5) and spatial (Section 5.6) filters, and REJECT any stars that fail. The reasons for rejection should be reported in the MS. If specified in the OR by the flag "select_acq_from_guide" being "yes", then all acceptable sets of guide stars are to be searched for candidate sets of acquisition stars; if at least "min_num_acq_stars" out of the pre-selected set pass, the algorithm has successfully chosen a single set of stars to serve as both guide and acquisition stars.

5.8 Depart from Nominal Observation Parameters to Find Acceptable Set of Acquisition Stars (Flow Chart Block 7)

This section specifies what we want the algorithm to do if it doesn't find a set of N stars (where N is "min_num_acq_stars") that pass all the filters above. The software is to attempt each of the fixes below in turn. If one of the fixes works, then the software is required NOT to attempt further fixes.

5.8.1 Use Less Than N Acquisition Stars

Incrementally lower the number of acquisition stars being searched for, until the number reaches "min_num_acq_stars". The algorithm shall be considered successful if at least "min_num_acq_stars" (typically 3, but specified in the SSAPE/ODB) stars can be found.

5.8.2 Try Off Nominal Roll

If the FOM/GQC are unsuitable, then the software should make small changes in the nominal roll angle (± 1 degree, ± 2 degrees, ... up to the nominal roll limit; as determined from the AXAF characteristics). The algorithm then branches back to (Flow Chart Block 3) and determines a new set of candidate stars. If this "fix" works, then the new set of stars is returned in the MS, along with an indication in the MS that it was necessary to use an off-nominal roll.

5.8.3 Try Alternate FID Lights

If the "fix" in Section 5.8.2 fails, then the software should try using the alternate FID light set. This should first be attempted at the nominal roll, and then at off-nominal rolls as in 5.8.2. If using the alternate FID light set works, then there should be an indication in the MS that the alternate set was used, and the names (numbers) of the alternate FIDS should be listed in the MS. However, only one set of FID lights is allowed per observation interval. That is, the SSA may use the alternate FID light either to find guide or acquisition stars, but both sets of stars must use the same FID light set.

5.8.4 Accept Higher QCs

Given the new definition of the Acquisition Quality Codes (ACQQx), this section is no longer applicable.

5.9 Report Results (Flow Chart Block 8)

The Mission Schedule (sub-element of scheduled OR/ER Data in ODB) should include the stars, fiducial lights, and roll angle which are selected, the quality codes for the selected stars, and any flags resulting from pre-selected stars failing spatial checks. When the quality code is non-zero, additional information on the outcome of the star selection process may be required as well (TBS).

A Figures

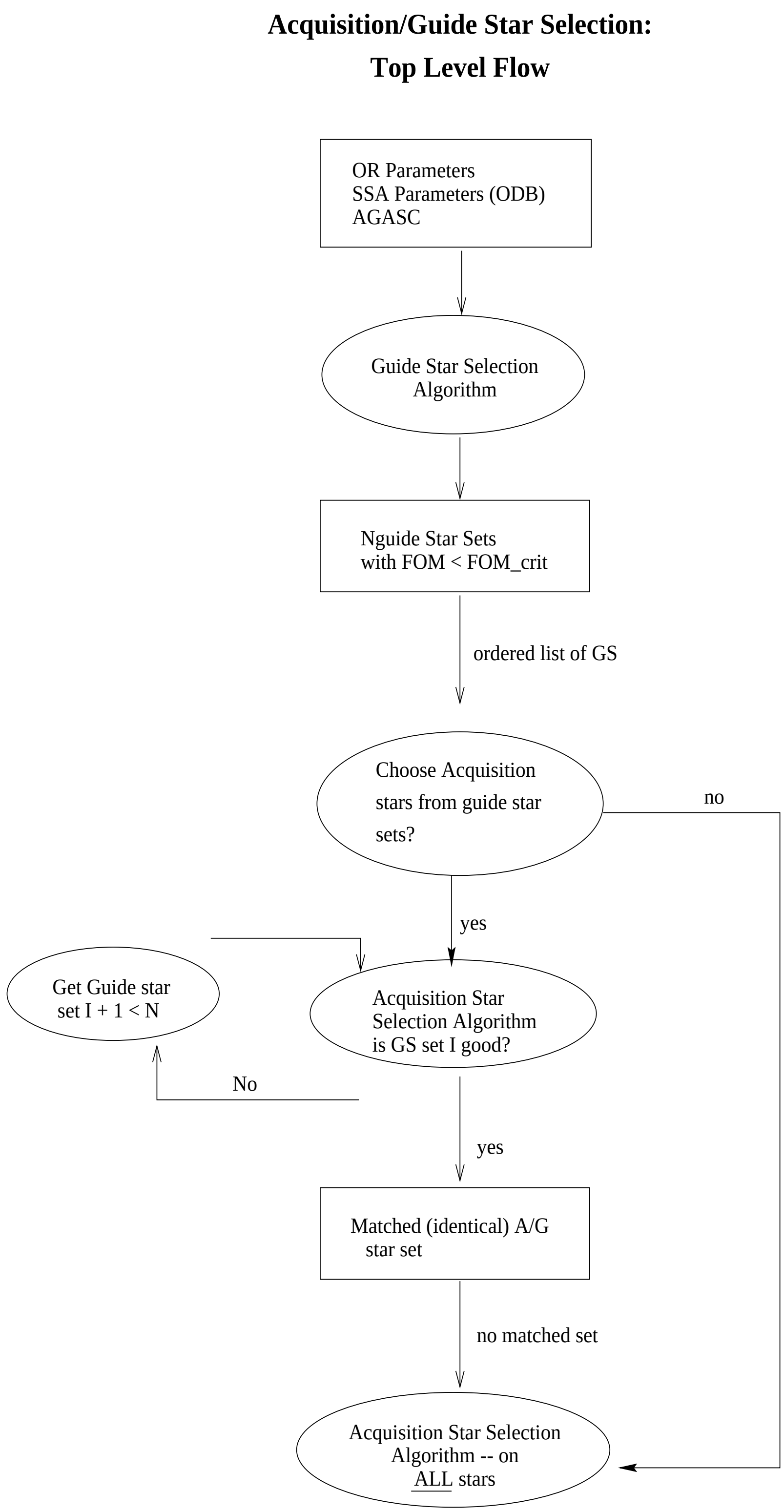

Figure 1: SSA Overview

Operational Sequence Diagram

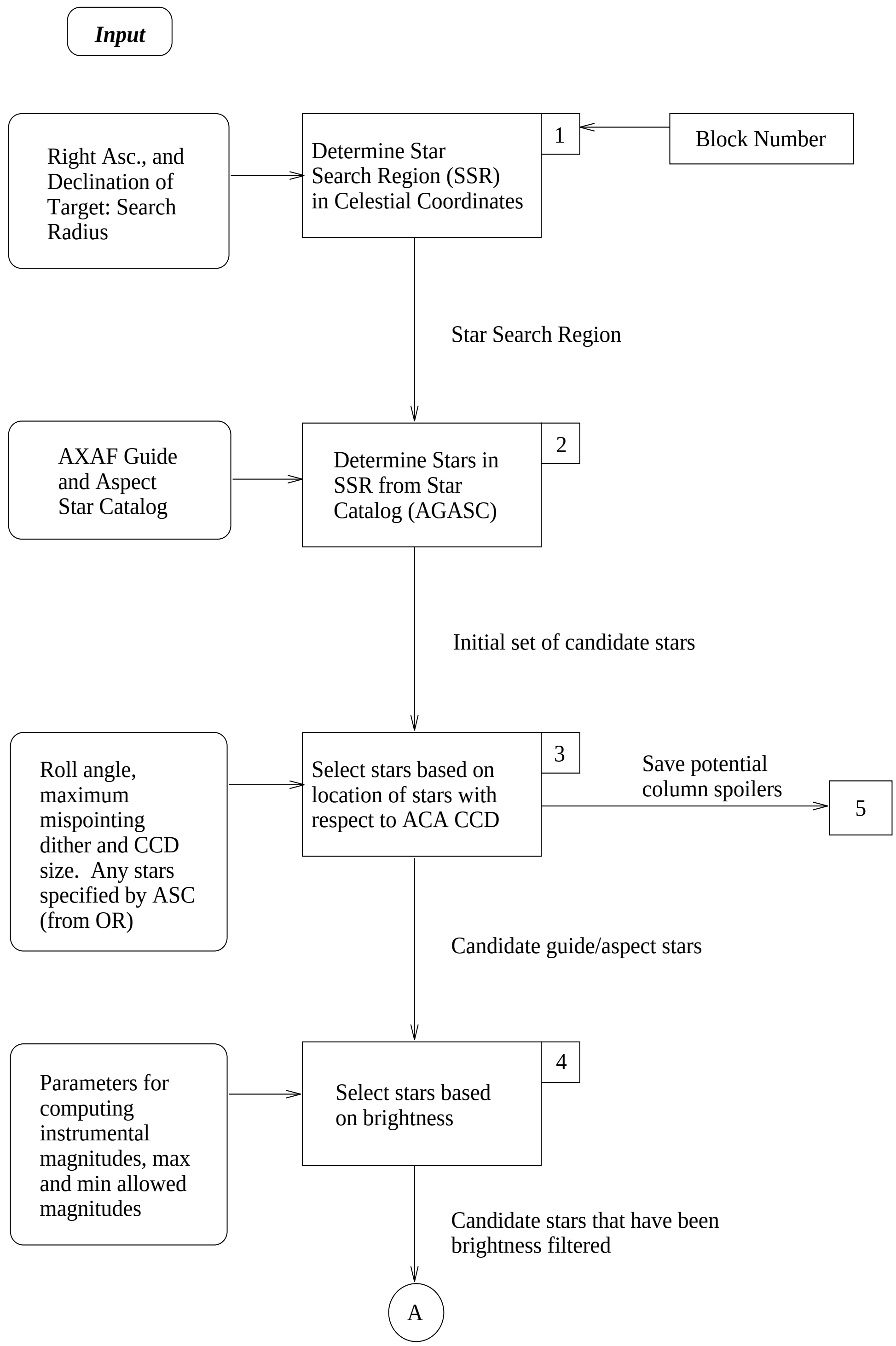

Figure 2: Operational Sequence Diagram, Part 1

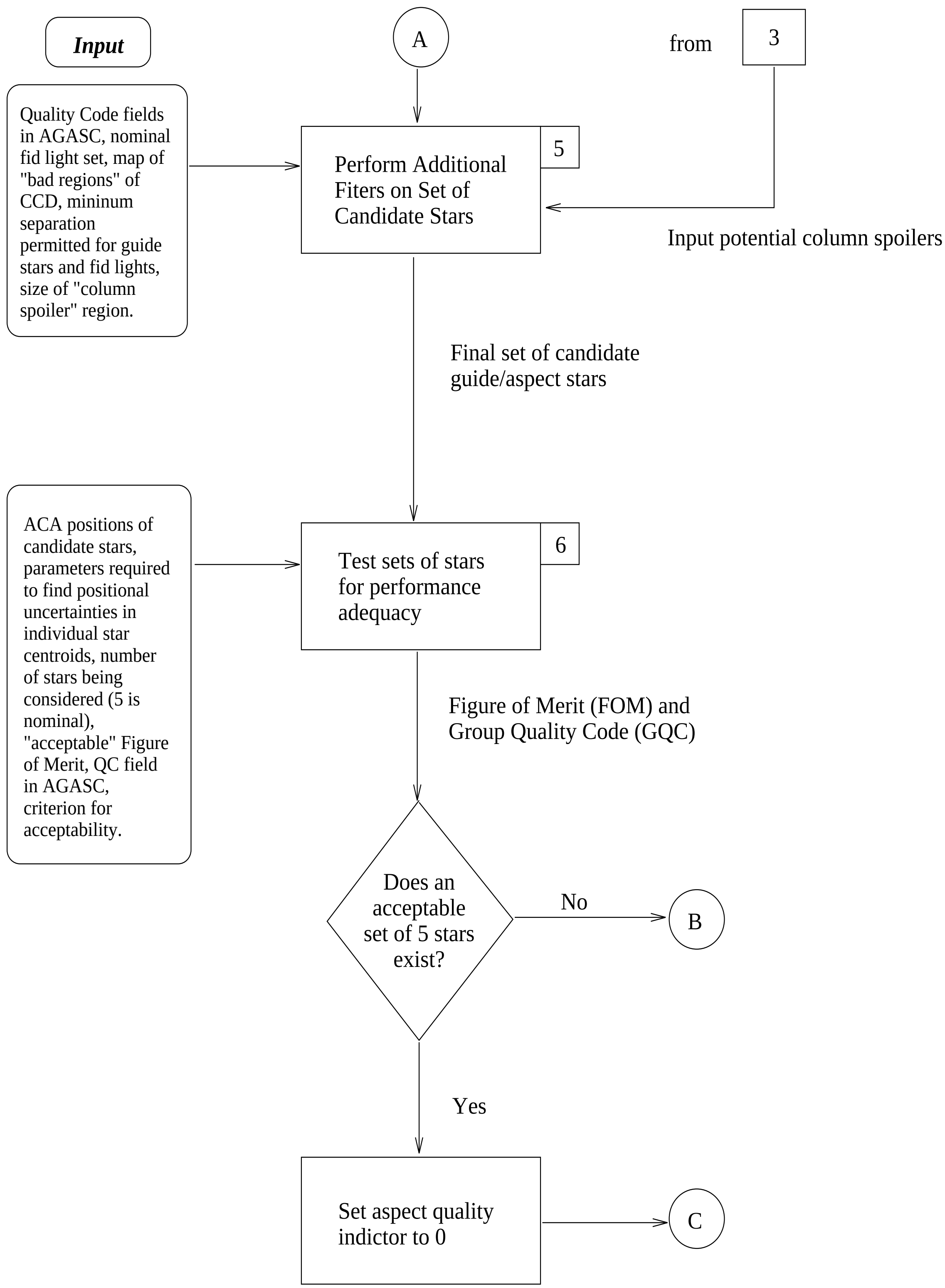

Figure 3: Operational Sequence Diagram, Part 2

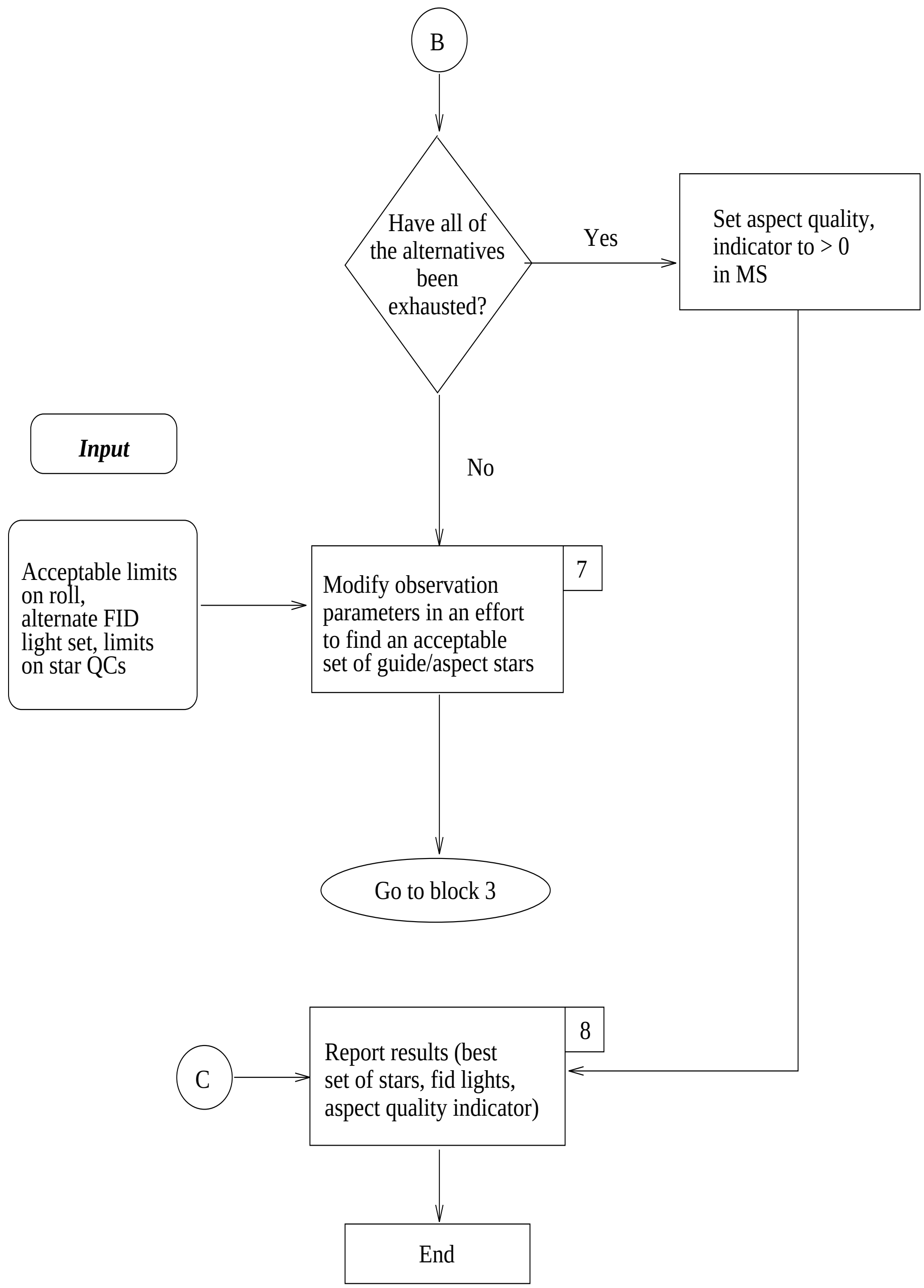

Figure 4: Operational Sequence Diagram, Part 3

B Computing Positional Uncertainty for Single Stars

The Star Selection Algorithm finds a Figure of Merit (FOM) for sets of candidate guide stars (typically there are 5 such stars) according to the formula in Appendix B. This formula is a function of the the uncertainties in the centroid positions of the n (n typically = 5) stars. Here we show how the uncertainties in the centroid positions (the σ_{is}) may be computed.

There are several effects that must be considered:

(a) Contribution due to the brightness of the star. The basic idea here is that the brighter the star is, the better the centroid position. (Of course, systematic uncertainties, discussed below, limit the accuracy to which the centroid may be computed).

Let m_{aca} be the magnitude of the star in Aspect Camera Assembly (ACA) magnitudes. The number of counts accumulated by the ACA from this star is then approximately

$$S = \text{cts\_mag10 x t x } 10^{-0.4(m_{aca}-10)} \qquad \text{counts} \qquad [1]$$

where S = number of counts
t = accumulation time (nominally 1 second)
m_{aca} = instrumental magnitude
cts_mag10 = the number of counts accumulated by the ACA (in one second) for a star of instrumental magnitude 10. Nominally cts-mag10 is 4096.

and

$$\sigma_{mag} = \sigma_{p1} \text{ x} S^{-0.75} + \sigma_{p2} \text{ x } S^{-0.5} \qquad \text{pixels} \qquad [2]$$

where σ_{mag} = uncertainty in stellar centroid position due to instrumental magnitude
σ_{p1} and σ_{p2} are parameters defined in the SSAPE/ODB; current values are:

$$\sigma_{p1} = 16.2 \text{ and } \sigma_{p2} = 0.5$$

(b) Contributions due to location in the telescope FOV.

There is a little additional blurring as you move away from the ACA telescope optical axis. The contribution to the centroiding uncertainty is $off\_axis\_blur\_factor$. This value is computed at the ASC and is input to OFLS as indicated below.

(c) Contributions due to charge-transfer effects in the ACA CCD

If the star in question is located, nominally, near the edges of the CCD, it does not take as many charge transfers to read out the detected photoelectrons. For every charge transfer there is a potential loss of information due to the charge transfer inefficiency (CTI) of the CCD. Therefore, the centroiding process is more accurate for stars located near the edge of the CCD and less accurate for stars near the center.

The charge-transfer effect depends on the magnitude of the star being observed. The factor (call it, say, CTI_blur_factor) is computed by the ASC and stored in a 1024^2 array in the SSAPE/ODB. Its effect on the σ_i is given below.

(d) Finally we must account for other systematic uncertainties which limit the ultimate accuracy of the star centroiding process. We choose to do this by assigning a residual systematic uncertainty to each pixel in the ACA CCD (call it σ_{CCD}). These uncertainties arise from such things as position calibration residuals, non-uniformity of the CCD responsivity and dark current. The entries in three 1024^2 uncertainty arrays will be computed by the ASC and stored in the SSAPE/OBD.

(e) Averaging the CCD effects

Uncertainty contributions (b), (c) and (d) depend on the nominal location of the star in CCD chip. Since the star wanders around the chip due to initial mispointing, jitter and programmed dither, it is incorrect to use a value based on a precise location in the ACA CCD. Rather we must do an average over the CCD pixels where the star might fall during an observation. The size of this region is approximately

$(d_1 + \delta)$ x $(d_2 + \delta)$ $pixel^2$ where d_1 and d_2 are the dither amplitudes in the (y,z) direction and δ is the pointing uncertainty due to initial mispointing and attitude jitter.

To average the effects in (b), (c) and (d), the OFLS shall take the values of the effects for each pixel in the region and average them (all pixels equally weighted, TBR).

(f) Computation of σ_i

The formula for the uncertainty in the centroid of a single star is, therefore:

$$\sigma_i^2 = (\sigma_{mag} \text{ x } < CTI\_blur\_factor > \text{ x } < off\_axis\_blur\_factor >)^2 + < \sigma_{CCD} >^2$$

where <> indicates the appropriate average as described in (e) above.

(g) Implementation at the OFLS

The OFLS must contain software to compute the σ_i. The ASC will supply the required parameters to make the computations. These are:

1. The parameters needed to compute σ_{mag}, i.e., σ_{p1}, σ_{p2}, and t. m_{aca} will be available from the Star Catalog, either directly or by computation from the listed magnitudes.
2. A multiplicative array of dimension 1024 x 1024 giving the CTI_blur_factor for every CCD pixel.

3. Three additive arrays of dimension 1024 x 1024 giving the effects of the remaining CCD uncertainties (σ_{CCD}).

4. A multiplicative array of dimension 1024 x 1024 giving the PSF degradation in percent due to the telescope optics.

5. The pointing uncertainty due to initial mispointing and attitude jitter. The OFLS must find the dither magnitude(s) in the Observation Request.

C Figure of Merit (FOM) Formula

The FOM is a measure of the expected attitude reconstruction error. As such, smaller values of the FOM are better. Let σ_i be the one-dimensional uncertainty in the position of star i. We simplify this formula somewhat by insisting that the $\sigma_{yi} = \sigma_{zi}$, (*i.e.*, the uncertainties for a given star are the same in both the y and z directions) although the σ_i need not be the same as σ_j. The resulting equation for the variance in the location of the pointing (X) axis is:

$$\sigma_x^2 = \frac{2}{\sum_i 1/\sigma_i^2} + \frac{(\bar{\xi})^2 + (\bar{\eta})^2}{\sum_i \frac{(\xi_i - \bar{\xi})^2 + (\eta_i - \bar{\eta})^2}{\sigma_i^2}}$$

where (ξ_i, η_i) is the position of star i in CCD coordinates, with the convention that (ξ_i, η_i) are aligned with the AXAF (Y,Z) axis, respectively, (reference Fig 1, ACA Equipment Spec, EQ7-278, 22 Mar 96, TRW). Here the $\bar{\xi}$ and $\bar{\eta}$ are the weighted means (weighted by the uncertainty σ_i^2)

$$\bar{\xi} = \sum_i \frac{\xi_i}{s_i^2}$$

$$\bar{\eta} = \sum_i \frac{\eta_i}{s_i^2}$$

and where $s_i^2 = \sigma_i^2 \sum_j (1/\sigma_j^2)$.

This formula may be somewhat simplified:

$$\sigma_x^2 = \frac{1}{\sum_i (1/\sigma_i^2)} \left\{ 2 + \frac{(\bar{\xi})^2 + (\bar{\eta})^2}{((\bar{\xi^2} + \bar{\eta^2}) - ((\bar{\xi})^2 + (\bar{\eta})^2))} \right\}$$

where the $\bar{\xi}$ and $\bar{\eta}$ are as defined above and the $\bar{\xi^2}$ and $\bar{\eta^2}$ are defined similarly, *i.e.*,

$$\bar{\xi^2} = \sum_i \frac{\xi_i^2}{s_i^2}$$

$$\bar{\eta^2} = \sum_i \frac{\eta_i^2}{s_i^2}$$

Note that the equations in the 31 May 95 use the nomenclature $\bar{\xi}^2$ and $\bar{\xi}^2$, which was somewhat unclear. We clarify this by using the nomenclature of $\bar{\xi^2}$ and $(\bar{\xi})^2$, respectively. The first is the quantity squared, then averaged, and the second is the quantity averaged, then squared.

The corresponding term for the variance in the roll about the X-axis is:

$$\sigma_{roll}^2 = \frac{1}{\sum_i (1/\sigma_i^2)} \left\{ \frac{1}{((\bar{\xi^2} + \bar{\eta^2}) - ((\bar{\xi})^2 + (\bar{\eta})^2))} \right\}$$

Errors in the location of the X-axis (motions in pitch and yaw) translate directly into errors in the ACA (and SI) focal plane, ie, a $5''$ motion in pitch moves a star 1 pixel on the ACA. Errors in roll do not; a $5''$ roll motion about the X-axis moves a star at the edge of the ACA (1^o off axis) only 0.02 pixel. In order to add the X-axis and roll errors, the roll error must be scaled by some appropriate lever arm. This will be based on the SSA/ODB parameter "ssa.roll.lever.arm" (units arcmin). The default value will be set to $5'$. Note also that the units of the roll variance σ^2_{roll} are radians^2 (length/length)^2, while the X-axis variance has units of length^2. We must convert the units of the roll variance appropriately in order to add it to the X-axis variance. We therefore define

$$\sigma_{roll.x} = units.scale * (ssa.roll.lever.arm/5') * \sigma_{roll}$$

and we define the FOM to be a measure of the total attitude error

$$FOM = \sigma_t^2 = \sigma_x^2 + \sigma_{roll.x}^2$$

and we require that the units of $\sigma_{roll.x}$ and σ_x match.

If σ_x is in units of pixels, then $units.scale = 60\ pix$ for the $5'$ lever arm, and

$$\sigma_{roll.x}(pix) = 60(pix) * (ssa.roll.lever.arm(arcmin)/5') * \sigma_{roll}$$

If the X-axis error σ_x and the roll error σ_{roll} are both measured in radians, then the units.scale factor would be 0.00145 for the $5'$ lever arm, or

$$\sigma_{roll.x}(rad) = 0.00145 * (ssa.roll.lever.arm(arcmin)/5') * \sigma_{roll}$$

D Star Selection Algorithm Parameter Element, Operations Data Base (SSAPE/ODB)

This appendix contains the specification for the SSA Parameters data element of the AXAF Operations Data Base (ODB), and constitutes an update of the specification contained in TRW DR OP19, ODB Users' Guide, dated 6 Sept 1996. This data element specification is provided for reference in interpreting the SSA specification contained in the main body of this document.

The SSA Parameters data element contains a file of parameters used with the star selection algorithm in the OFLS to select acquisition stars and guide stars from the AXAF-I Star Catalog to support AXAF on-orbit operations. The parameter file contains the following information:

- ACA and other PCAD-related parameters, used in defining star search and selection regions within the overall star field as represented in the AXAF Star Catalog
- Star brightness prediction and related star selection parameters
- Star filtering parameters supporting image position prediction on the ACA detector, and screening of candidate stars based on predicted detector position coordinates
- Candidate-star-set evaluation and selection parameters
- Additional parameters controlling the selection of a single set of stars that satisfy both guide star and acquisition star criteria.

The SSA Parameters data element is provided as a flat file, consisting of the following fields:

- Search-radius about pointing direction, for initial star identification

search_radius	Real	Radius of search region (deg), centered at observation RA and dec, within which to read initial set of stars from star catalog
num_guide_stars	Int	Number of guide stars to search for

- ACA reference aperture

max_aca_row	Int	Maximum ACA pixel row number
max_aca_col	Int	Maximum ACA pixel column number
min_aca_row	Int	Minimum ACA pixel row number
min_aca_col	Int	Minimum ACA pixel column number
Pixel_size	Real	ACA pixel width (arcsec)

- Pointing error bounds

max_point_error	Real	Maximum pointing error during attitude hold (arcsec)
max_dither	Real	Maximum dither amplitude (arcsec)
max_slew_error	Real	Maximum pointing error at end of slew (arcsec)

- Star selection brightness thresholds, used in selecting candidate guide and acquisition stars from among those in the ACA reference field of view. (Thresholds are specified for the apparent brightness as seen by the ACA, considering the spectral response characteristics of the ACA detector.)

g_max_mag	Real	Maximum instrument magnitude, for guide stars
g_min_mag	Real	Minimum instrument magnitude, for guide stars
a_max_mag	Real	Maximum instrument magnitude, for acquisition stars
a_min_mag	Real	Minimum instrument magnitude, for acquisition stars

- Star brightness conversion coefficients (11 coefficients); used to estimate the apparent brightness of a star as seen by the ACA detector (= MAG_aca)

aca_mag_00	Real	ACA magnitude 0th order offset
aca_mag_01	Real	ACA magnitude scale factor coefficient
aca_mag_01_1	Real	ACA magnitude 1st order coefficient of color 1 (c1, in AXAF Star Catalog)
aca_mag_01_2	Real	ACA magnitude 2nd order coefficient, c1
aca_mag_01_3	Real	ACA magnitude 3rd order coefficient, c1
aca_mag_01_4	Real	ACA magnitude 4th order coefficient, c1
aca_mag_02_1	Real	ACA magnitude 1st order coefficient of color 2 (c2)
aca_mag_02_2	Real	ACA magnitude 2nd order coefficient, c2
aca_mag_02_3	Real	ACA magnitude 3rd order coefficient, c2
aca_mag_02_4	Real	ACA magnitude 4th order coefficient, c2

- Star magnitude conversion method flag; specifies whether to compute apparent star brightness as seen by the ACA (MAG_I, instrument magnitude) from color intensity (c1-c3) star data records in the AXAF Star Catalog, or read instrument magnitude directly from star data records

star_mag_conv_flag	Int	1=compute, 0=read directly

- ACA detector scale factors

  The SSA should use the canonical $5''/pixel$ scale factor for the ACA in order to convert between off-axis angles and pixels. The SSA should use the BORESIGHT, as defined elsewhere in the OBD, in order to determine the alignment between the ACA aimpoint and the AXAF spacecraft (HRMA) aimpoint.

- ACA detector centroid position uncertainty coefficients, for position uncertainty calculations from star magnitude and centroid coordinates

n_params_epos	Int	No. of parameters for computation of star positional uncertainty (sigma)
count_threshold	Real	Flux level above which sigma doesn't improve
sigma_p1	Real	First coefficient of positional uncertainty eqn
sigma_p2	Real	Second coefficient of positional uncertainty eqn

- Fid light keepout distance (angular radius); used to specify the minimum distance between an acceptable star image and a fidlight image on the ACA detector, and apparent FID magnitude

fid_spoil_region	Int	Keepout distance, in pixels (stars within ± X pixels of fids are spoiled)
fid_aca_mag	Real	Apparent magnitude of FID lights in ACA

- Fid light selection index that selects candidate fiducial lights, can be over-ridden by value set in OR

i_fid_select	Int	Key to fid light look-up table, to be overridden by OR value, if supplied. Both i_fid_select and the SI designation are needed to fine the appropriate entry point into the look-up table.

- Keepout parameters for ACA detector column spoilers check; the allowable upper limit on spoiler star brightness, plus other parameters

rad_mag_diff_limit	Real	This many mags brighter to be radial spoilers
col_mag_diff_limit_gf	Real	Guide stars this many mags brighter than FIDs may be column spoilers
col_mag_diff_limit_gg	Real	Guide stars this many mags brighter may be column spoilers for other guide stars
col_mag_diff_limit_a	Real	This many mags brighter to be column spoilers for acquisition stars
exc_mag_diff_limit	Real	Within this many mags to be exclusion box spoofer
guide_searchbox_size	Real	Within radial distance of $2\sqrt{2}$ this many pixels to be possible exclusion box spoofer
col_spoil_col_limit	Int	Within this many columns to be column spoiler
planet_rad_spoiler	Real	Stars within this many arcsec of a planet are spoiled
readout_reg_spoiler	Real	Stars this many magnitudes brighter than candidate cause it to be spoiled

- ACA detector centroid position uncertainty index array, and scale factors, three 1024^2 arrays and scale factors to be rss combined to form the σ_{CCD} array of Appendix B.

aca_err_array_coef	Real	Coefficient for aca error array
aca_t_err_array_coef	Real	Coefficient for temp dependent additive aca error array
aca_a_err_array_coef	Real	Coefficient for sun angle dependent additive aca error array
aca_err_array	Real	File name for aca error array
aca_t_err_array,	Real	File name for temp dependent additive aca error array
aca_a_err_array,	Real	File name for sun angle dependent additive aca error array

- Two 1024^2 arrays representing the point spread function (PSF) off-axis blur ($off\_axis\_blur\_factor$) and charge transfer inefficiency (CTI_blur_factor) terms in Appendix B

max_off_axis_PSF	Real	Percent star sigma increase from off-axis effect
CTI_blur_factor	Real	CTI-induced transfer blur factor

- ACA detector bad-region map, a 1024^2 array of 0, 1, and 2, where 0 indicates a good pixel, 1 indicates a single bad (ie, no response or erratic response) pixel, and 2 indicates a 'short to ground', all pixels in the column farther away from the readout register will also have the value 2.

- Limit on number of stars to consider as candidate guide stars

max_filtered_list_len	Int	Maximum number of stars to accept in the filtered star list

- Expanded-search parameter secondary limits; used in an expanded search for aspect and acquisition stars when the primary search and selection criteria fail to converge on a set of stars meeting default criteria.

max_acceptable_fom	Real	FOM less than this meet error tree requirements, in arcsec, provided by ASC NB - was "min_acceptable_fom" previously

- Acceptable ranges on quality codes; six pairs of integers indicating high and low limits for guide/acq star quality codes

acq_qual_code_min	Int	Min allowable acq c1 code
guide_c1_code_min	Int	Min allowable guide c1 code
guide_c1_code_max	Int	Max allowable guide c1 code
guide_c2_code_min	Int	Min allowable guide c2 code
guide_c2_code_max	Int	Max allowable guide c2 code
guide_c3_code_min	Int	Min allowable guide c3 code
guide_c3_code_max	Int	Max allowable guide c3 code

- Number pertaining to selection of acquisition stars

FOM_list_len	Int	Number of FOMs to retain, in ordered list of guide star candidate sets
min_num_acq_stars	Int	Minimum number of acquisition stars required for successful star search
num_acq_stars	Int	number of acquisition stars to attempt to find

- Factors for slew errors due to IRU scale uncertainties

slew_error_m1	real	coefficient for slew error, slew between 0 and 30 degrees
slew_error_m2	real	coefficient for slew error, slew between 30 and 60 degrees
slew_error_m3	real	coefficient for slew error, slew between 60 and 90 degrees
slew_error_m4	real	coefficient for slew error, slew between 90 and 120 degrees
slew_error_m5	real	coefficient for slew error, slew between 120 and 150 degrees
slew_error_m6	real	coefficient for slew error, slew between 150 and 180 degrees
slew_error_b1	real	intercept for slew error, slew between 0 and 30 degrees
slew_error_b2	real	intercept for slew error, slew between 30 and 60 degrees
slew_error_b3	real	intercept for slew error, slew between 60 and 90 degrees
slew_error_b4	real	intercept for slew error, slew between 90 and 120 degrees
slew_error_b5	real	intercept for slew error, slew between 120 and 150 degrees
slew_error_b6	real	intercept for slew error, slew between 150 and 180 degrees
slew_error_t0	real	slew angle rand limits for error equations
slew_error_t1	real	slew angle rand limits for error equations
slew_error_t2	real	slew angle rand limits for error equations
slew_error_t3	real	slew angle rand limits for error equations
slew_error_t4	real	slew angle rand limits for error equations
slew_error_t5	real	slew angle rand limits for error equations
slew_error_t6	real	slew angle rand limits for error equations