AXAF
Science Center

MEMORANDUM

April 20, 2001

To: SS&AWG

From: David Morris

Subject: Effect of Radial Spoilers on Aspect Star Centroiding

1 Introduction

This memo details an analysis of the deviation in aspect star centroiding produced by the presence of radial spoiler stars within 50" of a guide or acquisition star. I have simulated the presence of a radial spoiler star during Aspect Camera on-board centroiding by superposing two Aspect Camera PSFs. I lay the first PSF at the center of a 6x6 Aspect Camera readout window while I vary the second PSF in relative intensity to the first and in relative position to the first. I calculate the centroid, using both the first moment and elliptical gaussian algorithms, of the center PSF alone, then of the superposition of center PSF and spoiler PSF. I retain the radial difference in these centroids as the expected deviation of the centroid reported by the Aspect Camera (AC) for a star with such a spoiler present. I also vary the position of the star (pair) on the AC focal plane to investigate the effect of the changing shape of the PSF on the centroid deviation. I use two existing libraries of PSFs for this analysis. One is a library of simulated PSFs generated using the raytrace software package MACOS and optical specifications from the Chandra Aspect Team and associated technical documentation. The other is a library of high resolution PSFs produced by centroid aligning and stacking many thousand actual AC star images (6x6 readout mode). Since the spacecraft dither slowly sweeps the stellar image across the focal plane, centroid aligning and stacking many slightly offset images in this manner effectively increases the resolution of the resultant PSF far beyond the AC's native 5" pixels. The true data library has the obvious advantage of being generated from real AC data but is limited in radial extent to approximately the 6x6 pixel (30"x30") readout of the AC. The raytraced library extends to 10x10 AC pixels.

2 Simulation Details

There are 5 degrees of freedom probed in this analysis - radial distance between star and spoiler, rotation angle between star and spoiler, magnitude difference between star and spoiler, x focal plane position of star-spoiler pair and y focal plane position of the star-spoiler pair.

Radial distance between star and spoiler is simply the radial distance between the individual centroids of the target star and spoiler star. This value is varied from 0 to 50 arcseconds (10 ACA pixels) in 1 arcsecond (0.2 pixel) steps. We are limited to about 50" distance in this variable by the finite size of the raytrace simulated PSF (we are limited to about 40" with the less extended stacked data PSFs).

The rotation angle between star and spoiler is the angle theta between the star and spoiler in a polar coordinate system with origin defined at the centroid of the unspoiled target star and theta=0 defined as the -Y Chandra axis (+row AC axis). This angle is varied through 360 degrees at 20 degree steps. The variation in this angle is to insure that we consider the worst possible centroid deviation due to a given spoiler at a given radial distance. Due to the presence of the ACA fiducial transfer mirror (FTM) in the optical path of the AC telescope, the AC PSF is not symmetric, but rather has a characteristic C shape, where the hole in the C is the shadow cast by the FTM. As a result, the centroid deviation caused by a given spoiler is heavily dependent on the angle theta.

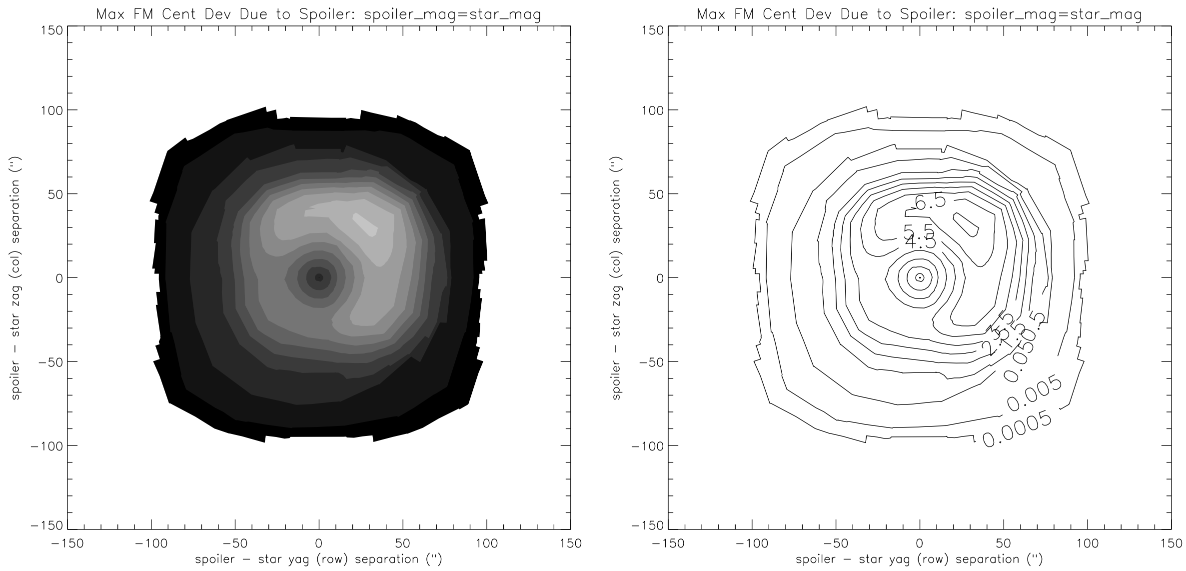

Figure 1: Rotation angle dependency of spoiler induced centroid deviation. Both plots illustrate the case in which the target star and spoiler star are of equal magnitude. The left, shaded, plot shows the characteristic C-shape of the PSF which is born out in this dependency. The right, hollow, plot shows the magnitude of the contour levels in arcseconds.

Rather than concern ourselves with exactly what angle theta gives the worst deviation, I have sampled the rotation angle as indicated and will select the worst deviation at all rotation angles to be that which I consider.

The magnitude difference between star and spoiler is simply mag_spoiler-mag_star so that negative values indicate the region where the spoiler is brighter than the star and positive values where the spoiler is dimmer than the star. I vary this parameter from -6 mags to 6 mags in steps of 0.125 mags (steps of roughly 10% increases in flux).

The x and y focal plane focal plane position of the star-spoiler pair is the AC row and column position at which the AC PSF used in the analysis was generated. The AC PSF is not uniform over the entire AC focal plane, mostly due to astigmatism in the optics. The result is that the PSF is elongated along a radial axis from the PSF position to the center of the focal plane. To investigate this effect, I have used PSFs drawn from 5 positions on the ACA focal plane: row=0,col=0 and the 4 extreme corners of the focal plane +/+, +/-, -/- and -/+. In the raytrace PSF library, the corners are at row=+/-520, col=+/-520 while in the stacked data library the corners are at row=+/-390, col=+/-390. The difference in positioning is due to the extrapolation effects of the stacking technique at the extreme edges of the focal plane. There was little data available for use in the stacking technique near the extreme edges of the focal plane, and thus the model of the PSF generated with this technique at those extreme corners breaks down. In either case, using these 5 positions insures that I consider the most minimally perturbed AC PSF (at 0,0) as well as the 4 most badly perturbed PSFs (in the 4 corners of the focal plane). As with the star-spoiler rotation angle, I sample the AC x-y focal plane position as described and will select the worst deviation at all 5 positions as that which I consider.

Thus, I am left with a data array covering the dimensions of star-spoiler radial separation and star-spoiler magnitude separation, indicating the worst possible centroid deviation due to the presence of such a spoiler. I have produced 4 such data arrays. The first indicates the centroid deviation produced with first moment centroiding of the raytrace library, the second shows first moment centroiding of the stacked data library, the third shows elliptical gaussian centroiding of the raytrace library, and the fourth shows elliptical gaussian centroiding of the stacked data library.

3 Results

The plots below show the centroid deviation induced by a spoiler star of the given relative magnitude to the target star and within the given radial distance from the target star. The left plot is the mean deviation seen at all 18 rotation angles and all 5 positions on the AC focal plane. The right plot shows the maximum deviation seen at all 18 rotation angles and all 5 positions on the focal plane. Four sets of plots follow, the first pair of plots is built using first moment centroiding of the raytrace PSF library data.

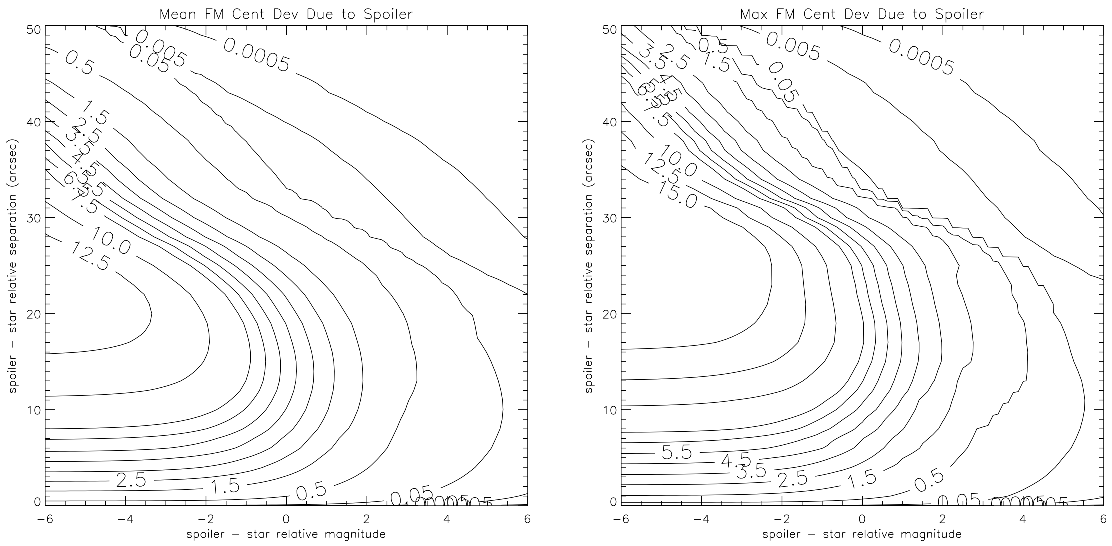

Figure 2: Magnitude-separation dependency of the spoiler induced first moment centroid deviation of the raytrace PSF library. The left plot is the mean deviation seen in the analysis, the right plot is the maximum deviation. Deviation contours are in units of arcseconds.

The second pair of plots is built using first moment centroiding of the stacked AC data PSF library.

Once again the left plot shows the mean deviation induced by all 18 rotation angles investigated and all 5 positions on the AC focal plane. The right plot shows the maximum deviation induced.

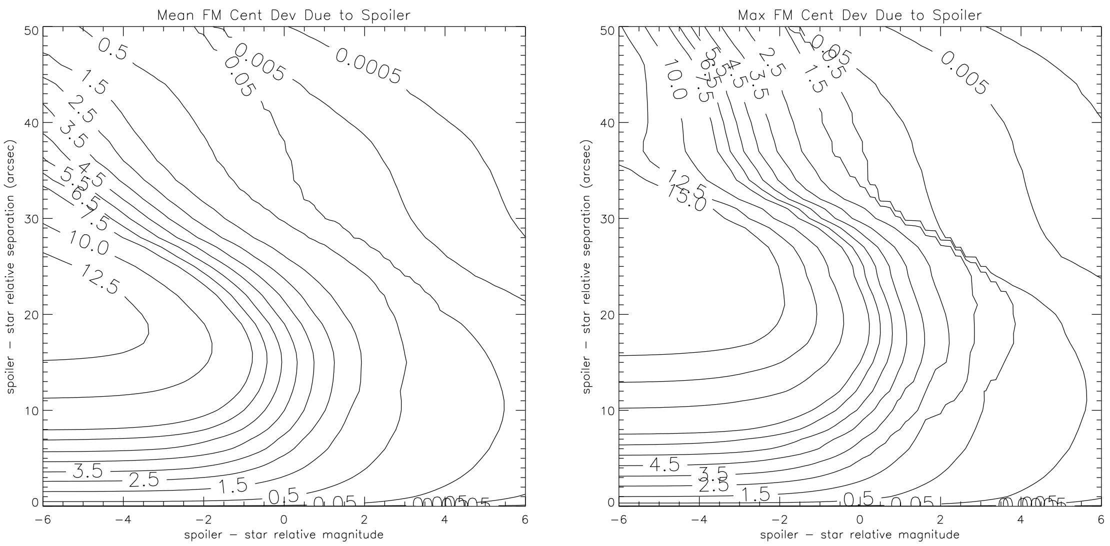

Figure 3: Magnitude-separation dependency of the spoiler induced first moment centroid deviation of the stacked ACA PSF library. The left plot is the mean deviation seen in the analysis, the right plot is the maximum deviation. Deviation contours are in units of arcseconds.

The third pair of plots is built using elliptical gaussian centroiding of the raytrace AC PSF library.

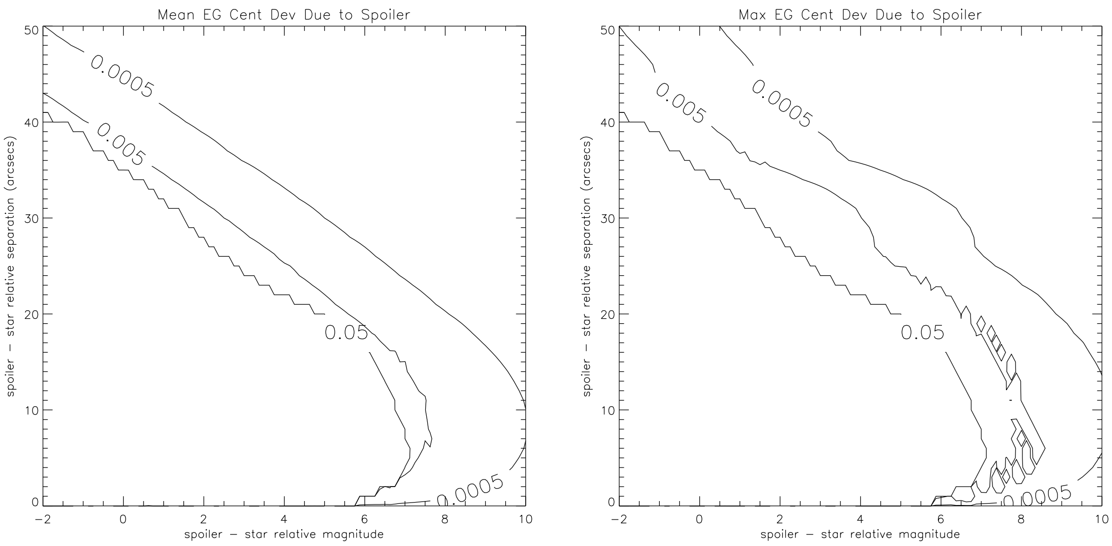

Figure 4: Magnitude-separation dependency of the spoiler induced elliptical gaussian centroid deviation of the raytrace ACA PSF library. The left plot is the mean deviation seen in the analysis, the right plot is the maximum deviation. Deviation contours are in units of arcseconds. Only contours where the elliptical gaussian algorithm converges to a solution are plotted.

The elliptical gaussian centroiding algorithm has difficulty converging to a solution as the amount of spoiler flux in the centroiding window increases and distorts the PSF radically from an elliptical gaussian profile. This limitation prevents us from examining the regions of higher centroid deviation in these plots (centroid deviations greater than 0.05"). Note that the x-axis range (spoiler-star relative magnitude) is shifted to dimmer spoilers in these plots. The elliptical gaussian centroiding method also has difficulty converging to a solution when the PSF shape is highly distorted (as it is in the corners of the AC focal plane) and thus here I plot the deviation for only a star-spoiler pair at AC focal plane position x=0,y=0. This should not be considered a limitation of the Post Facto Aspect processing pipeline but rather a limitation of this analysis only. This simulation is only a crude approximation of the Post Facto Aspect Pipeline and does not prescreen the data used in performing centroiding, as is done in the Post Facto Pipeline. A more rigorous simulation could be performed to investigate the true effect of the changing shape of the PSF on Post Facto processing as well as on OBC first moment centroiding, but such a study is beyond the scope of this memo. The left plot shows the mean deviation induced by all 18 rotation angles investigated at the focal plane position x=0,y=0. The right plot shows the maximum deviation induced at all 18 rotation angles.

The fourth and final pair of plots is built using elliptical gaussian centroiding of the stacked data PSF library. Once again, because of difficulty in converging to a solution using the elliptical gaussian centroiding method, I only plot deviations of lower magnitude produced by a star-spoiler pair centered at AC focal plane position x=0,y=0. The left plot shows the mean deviation at all 18 rotation angles while the right plot shows the maximum deviation.

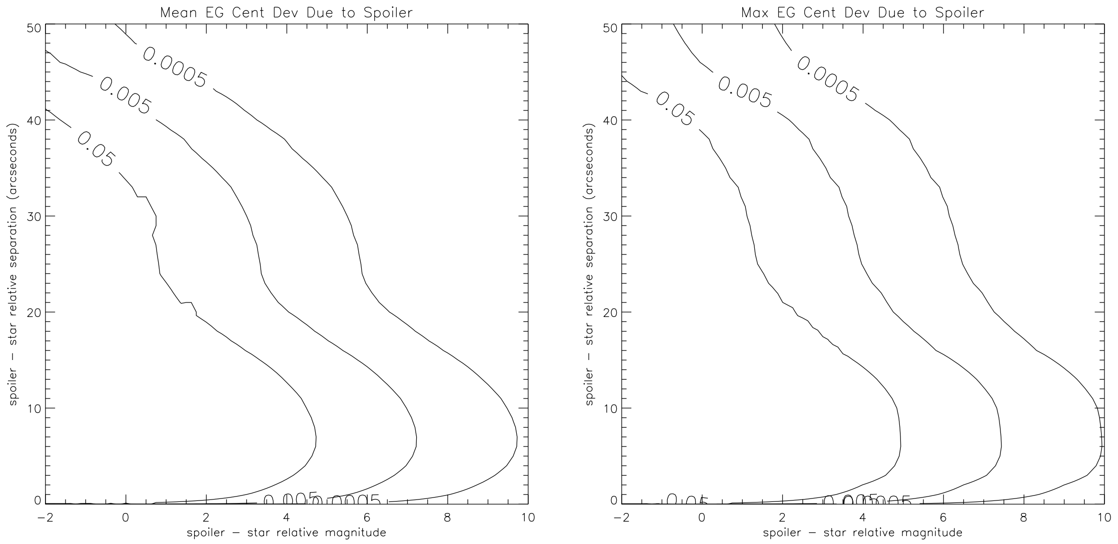

Figure 5: Magnitude-separation dependency of the spoiler induced elliptical gaussian centroid deviation of the raytrace ACA PSF library. The left plot is the mean deviation seen in the analysis, the right plot is the maximum deviation. Deviation contours are in units of arcseconds. Only contours where the elliptical gaussian algorithm converges to a solution are plotted.

4 Conclusions

In the regions of validity common to all sets of plots shown, the shape and magnitude of the induced centroid deviations seems consistent. It is important to note that we have not intimately simulated the centroiding process either onboard Chandra or in the Post Facto Aspect Pipeline. We have not considered effects such as the enhancement of the ACA background due to the presence of a spoiler in one of the 4 pixels used for background estimation, an issue known to be of importance to the Post Facto Aspect Pipeline. Nor have we considered the effect of warm or hot pixels dithering into and out of the centroiding window. Rather, we have considered a low fidelity model of a spoiler-aspect star interaction and have examined the gross centroid deviation expected based on two separate algorithms and using two separate but similar models of the ACA PSF. While it is undoubtably prudent not to consider this analysis a complete study of the centroid deviation induced by radial spoilers, the agreement noted between the several algorithm-PSF combinations investigated seems to suggest that we have determined a robust lower limit for the radial spoiler induced centroid deviation as a function of magnitude and position separation.