Use of the Shutter Blade Side “A” for UVIS Short Exposures

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ABSTRACT

WFC3 UVIS uses a shutter blade with two sides, A and B, consecutively in exposures. Stellar PSFs in short-exposures taken with shutter B show larger FWHM and lower sharpness compared to those taken with shutter A. The difference in the FWHMs is most pronounced in the shortest (0.5 sec) exposures. The difference decreases as the exposure time increases and is negligible for exposure times of 30 seconds or larger. There are about 1000 to 2000 short-exposure images taken per year, which constitute about 10% of the total number of exposures. For about half of them, a good and stable PSF is crucial for the science. To facilitate the science, an option has now been added to APT to select the shutter side A, which will be particularly useful for exposure times of < 30 seconds. However, choosing the shutter side involves some additional mechanism movements and thus should only be done when required to achieve the science goals. Various tests were performed to confirm that these movements do not cause any unforeseen or undesirable behaviour in the science data.

WFC3 Shutter Mechanism

The WFC3 UVIS shutter is a rotating disk about 12 inches in diameter. It is divided into four 90° quadrants, with alternating quadrants providing the
blocking (i.e., there are two open and two closed positions). When the shutter is in the closed position initially, a commanded move of 90° places it into an open configuration. At the end of an exposure, another move of 90° places the shutter back into a closed position. Although the shutter can be operated in either a clockwise or counterclockwise direction, the current flight software always moves the blade in the same direction. Thus the two sides of the WFC3 UVIS shutter blades, A and B, are normally used alternately in consecutive exposures. (For a description of the shutter mechanism, see WFC3 Instrument Handbook, section 2.3.3, and Hartig 2008). These two sides of the shutter blade are referred to as SHUTRPOS A and SHUTRPOS B in the header of the science data.

**Image quality in UVIS short exposures**

Stellar PSFs in short-exposure images taken with side B of the blade show larger FWHM and lower sharpness compared to those taken with side A, due to shutter vibrations (Sabbi, 2009). The difference in the PSF widths in consecutive exposures taken with the two sides can be as much as ~20% for the shortest (0.5 sec) exposures. The difference decreases as the exposure time increases and is negligible for exposure times of 30 seconds or larger.

**Number distribution of short exposures**

The number distributions of all (science + calibration) WFC3 exposures in cycles 17 thru 20 are summarized in Table 1 and Figures 1 to 2. They show that short (< 10 sec) exposures constitute 21.7% of all exposures taken so far with WFC3. If we restrict ourselves to only the science exposures, short exposures constitute 11.2% of all the exposures. The total number of science exposures with exposure time < 10 sec is 4021 over the 4 cycles, and the total number of science exposures with exposure time less than 30 sec is 7687. Thus, there are typically more than 1000 science exposures per cycle with exposure time < 10 sec, and about 2000 science exposures per cycle with exposure time less than 30 sec.
### TABLE-1. Distribution of short exposure during cycle 17 thru 20

<table>
<thead>
<tr>
<th></th>
<th>No. of science exp</th>
<th>Percentage of science exp</th>
<th>No. of science + cal. exp</th>
<th>Percentage of science + cal. exp</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Exposures</td>
<td>35872</td>
<td>100</td>
<td>53368</td>
<td>100</td>
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<tr>
<td>Exposures with T(exp) &lt; 10 sec</td>
<td>4021</td>
<td>11.2</td>
<td>11595</td>
<td>21.7</td>
</tr>
<tr>
<td>Exposures with T(exp) &lt; 20 sec</td>
<td>6538</td>
<td>18.2</td>
<td>14943</td>
<td>28.0</td>
</tr>
<tr>
<td>Exposures with T(exp) &lt; 30 sec</td>
<td>7687</td>
<td>21.4</td>
<td>16399</td>
<td>30.7</td>
</tr>
</tbody>
</table>

**Image quality in science programs with short exposures**

We estimated that the shape of the PSF is important for about half of the science programs with short exposures. For these programs, it would be advantageous to take the short exposures with shutter A. But which shutter will be used is unknown *a priori*. So, until the fall of 2013, the only way to avoid PSF variation was to take 2 consecutive exposures in the same filter, so that one is guaranteed to be with the shutter blade A (which produces the sharper PSF). This was obviously a very inefficient use of telescope time since this strategy reduces the total number of exposures and the observing time. The measurement accuracy, which is often crucial for the science, could be improved if the short exposures could be taken exclusively with shutter A. Since there are typically >1000 short-exposures taken per year, for about half of which it is crucial to obtain a good PSF, it is impractical to allocate additional observing time for these programs in order to solve the problem.

The short exposures constitute about 10% of the total, so using only shutter A for them is unlikely to cause shutter lifetime issues. The overhead time required to select the shutter as needed is not large (~2 sec). But the effective
overhead in repeating the short-exposures is large since in most proposals with short exposures, the number of exposures is large, resulting in large overheads due to extra buffer dumps. Thus, an option to choose the shutter side A for <60 sec exposures is a practical solution which will result in improved accuracy in many of the important WFC3 science programs.

Fig. 1. Number distribution of all (science + calibration) WFC3 exposures (black) and only science observations (red) from 0 to 500 seconds in cycles 17 thru 20. Short (<10sec) exposures constitute 21.7% of all (science + cal) exposures, and 11.2% of all science observations. On average, there are more than 1000 science exposures with <10sec exposures per year.
Fig. 2. Number distribution of all (science + calibration) WFC3 exposures (black) and only science exposures (red) from 0 to 100 seconds in cycles 17 thru 20.

**Implementation of blade A for short exposures**

Before implementing an option to choose the shutter side, it was necessary to:

i. Verify the functionality of blade A option itself,
ii. Verify that there is indeed no PSF degradation due to shutter vibrations after choosing blade A,
iii. Verify that there are no unforeseen effects caused by the mechanism movements in order to choose blade A.

The risk of testing the blade A option directly on existing HST programs was considered low, thus we used existing GO and calibration programs as
test cases to verify the implementation of this option. The programs used were:

1. GO-13457, PI: Sahu, “Microlensing by the nearby white dwarf Stein 2051-B”, and
2. Contamination proposal (13088, PI: Baggett)

For GO-13457, the science observations with commanded blade A were taken on 1st October 2013, where the bright (V ~12) target Stein 2051b was imaged with an exposure time of 0.5 sec. For the calibration proposal 13088, observations were taken on 2nd October 013, where the bright (V~12.8) spectrophotometric standard star GRW+70D5824 was imaged with exposure times of 3.1 to 6 sec. There were no problems with the data acquisition or the associated buffer dumps.

**GO 13457 and CAL-13088 observations**

For GO-13457, there were a total of four short (0.5 sec) exposures, out of which two (esq and euq) could not be processed through the calibration pipeline due to errors in the reference file selection step. Similarly for CAL-13088, two exposures (ozq and p1q) could not be processed through the pipeline due to errors in the reference file selection step. On further investigation, it was found that no SHUTRPOS keyword was present in the headers of the raw data which prevented the pipeline from selecting appropriate reference files. The shutter positions, as recorded in the corresponding spt files of these exposures are given in Table 2. We note that if the engineering keyword ISHRBPOS (shutter readback position) is between 800 and 2100, or 33600 and 34900 resolver counts, then the shutter blade SHUTRPOS keyword is set to B, and if ISHRBPOS is between 17200 and 18500 or 50000 and 51300 resolver counts, then SHUTRPOS is set to A. The readback positions in the above four cases were thus slightly beyond the nominal values.
TABLE-2. Shutter positions in exposures that failed pipeline processing

<table>
<thead>
<tr>
<th>Program</th>
<th>Rootname</th>
<th>ISHRBPOS*</th>
<th>ISHCMPOS*</th>
</tr>
</thead>
<tbody>
<tr>
<td>GO-13457</td>
<td>icdl01esq</td>
<td>18512</td>
<td>18384</td>
</tr>
<tr>
<td>GO-13457</td>
<td>icdl01euq</td>
<td>18528</td>
<td>18384</td>
</tr>
<tr>
<td>CAL-13088</td>
<td>ic5za0ozq</td>
<td>18544</td>
<td>18384</td>
</tr>
<tr>
<td>CAL-13088</td>
<td>ic5za0p1q</td>
<td>18512</td>
<td>18384</td>
</tr>
</tbody>
</table>

*ISHRBPOS refers to Shutter Readback Position, and ISHCMPOS refers to Shutter Commanded Position.

First look at the science and calibration data

Despite the somewhat out-of-range shutter readback positions, the images were perfectly normal in all cases: the PSFs of the affected short exposures are as expected from blade A, and not consistent with blade B (see Fig. 3-5). Further investigation revealed that the tolerance on the moves is +/- 364 resolver counts. All of the out-of-range positions are well within tolerance, which implies that the shutter is moving correctly, and the hardware is working as expected. In fact, if the shutter were to ever NOT achieve the proper position within tolerance, the onboard action would be to suspend the instrument.

![Image](image-url)

Fig. 3. The subarray image of Stein 2051A+B as observed with commanded blade A exposure that failed pipeline processing due to off-nominal shutter readback position. The PSF shape is nominal.
Fig. 4. Two standard star subarray images in F336W taken with commanded A shutter (left) and nominal A shutter (right), radial profiles of which are shown in the next figure.

Fig. 5. Radial profile of GRW+70D5824 for the commanded shutter A exposure (ozq, left) and nominal shutter A exposure (i3q, right). There is no discernible difference between the two profiles.

**Shutter position anomaly**

To further investigate the larger-than-expected shutter position difference, we examined the recorded shutter positions all the WFC3 UVIS images. In
Fig. 6. The shutter position difference for all the WFC3 exposures vs. commanded blade A exposures.

Fig. 7. The shutter position difference for all the blade A WFC3 exposures vs. commanded blade A exposures.
Fig. 8. Shutter position difference in a sequence of exposures where the blade was commanded to be in position A.

Fig. 6 we plot the shutter position difference (for both A and B blades) in all the WFC3 exposures (top) and the shutter position difference in all the commanded blade A exposures (bottom). Fig. 7 shows the shutter position difference in all the WFC3 exposures taken with blade A (top) and the shutter position difference in all the commanded blade A exposures (bottom). Clearly, the commanded blade A exposures have outliers (>100) which are completely absent in any of the other ~40,000 WFC3 exposures taken so far! To investigate whether this anomalous shutter position behavior happens only in the first exposure in a sequence, we looked at a sequence of exposures, all taken with commanded blade A position (GO-13469, PI: Bond). This is plotted in Figure 8; there is no correlation between the exposure’s location in a sequence and the difference between the measured and commanded shutter positions.
Effect of shutter position on post-flash levels and illumination pattern

We investigated whether the shutter position was slightly out-of-range only when the shutter blade was commanded to move to position A and whether this out-of-range position affects the illumination pattern in any part of the detector due to effects such as vigneting.

The data to check for this possible effect consisted of all high signal-to-noise post-flash (PF) images available in the MAST archive: 88 images of medium current, 100 sec PF, 0.5 sec exposures, half of which were taken with blade A, the other half were taken with blade B. The images were acquired between Aug 2012 and Dec 2013 and standard calwf3 processing (bias level, bias file, and dark correction) was performed. The average PF illumination level was ~7200 e-/pix. The commanded and actual (readback) shutter positions were extracted from the associated engineering files (ISHCMPOS, ISHRBPOS spt keywords). Fig 9 shows histograms of the actual minus commanded positions for the A and B shutter PF images. The maximum shutter difference in the PF images was +/-96 and +/-112 resolver counts for shutters A and B respectively; the external images included shutter differences ranging beyond 120 resolver counts.

The calibrated PF images were combined to generate a median stack for shutter A and a median stack for shutter B. Each individual PF image was then ratio’d to the appropriate median stack and statistics of the good pixels measured and plotted as a function of observation date (MJD) and shutter position difference (actual minus commanded). Fig 10 shows the result for chip 2, blade A; results for chip 1 were similar. While the average PF level fluctuates within an envelope of about +/-1% (standard deviation ~0.5%), there is no apparent correlation of PF illumination level with time or with shutter position difference. Two outliers exceed the envelope: acquired MJD 56472 (June 29, 2013), their PF level is ~1.5% above the average. Each outlier image was acquired during a separate visit, there is nothing unusual about the observing sequence, there are no obvious problems evident in the images, and the shutter differences for these two images (-16, -64) are not extreme.
Fig 9: Histograms of the actual minus commanded positions for the A (left) and B (right) shutter for the PF images.

Fig 10: The average normalized PF level for chip 2, shutter blade A, as a function of MJD (left) and shutter position difference (right).
Fig 11 shows the average PF level for chip 2, shutter blade B, as a function of MJD (left plot) and shutter position difference (right plot); results are similar to those for blade A. The two outliers with PF level ~1.5% above average were taken as part of the same two visits which resulted in the two blade A outliers. For unknown reasons, the shutter B data lack images with shutter position differences between +50 to +100 steps.

The intensity ratio in each image (i.e., individual image ratio’d to either shutter A or B median stack) is plotted as a function of column in Fig 12, and appears featureless. However, cuts through the ratios reveal slight slopes across the FOV though only for the B shutter ratios. Cuts through the A shutter image ratios are flat to better than 0.05%. The figure below shows an average of 2030 lines from a typical shutter A ratio image (left) and a shutter B ratio (right, shutter diff of -112 resolver counts).
Fig. 12. Intensity ratio in each image (i.e., individual image ratio’d to either shutter A or B median stack) as a function of column appears featureless.

Finally, Fig. 13 shows the measured slopes as a function of shutter difference (actual position – commanded) for shutter A (left) and shutter B (right). The slope changes in B appear to be symmetrical about shutter position difference of 0, with a maximum of ~0.2% at the largest shutter position differences (+/-112 resolver counts). There are a few outliers in the A plot at ~0.1% off-nominal, but these were not investigated further.

In summary, there are small changes (up to ~0.2% across the full FOV) in the B shutter illumination pattern as a function of the difference between the actual and the commanded shutter position. No such effect is present in shutter A images. Average absolute levels of the PF fluctuate by about +/-1% but the level does not correlate with either observation date or shutter position difference.
Fig. 13. The measured slopes as a function of shutter difference (actual position – commanded) for shutter A (left) and shutter B (right).

**Implementation**

The shutter behavior under commanded shutter A conditions was found to be normal, so adjusting the resolver limits in OPUS was a natural fix to the pipeline issue and was implemented in Fall 2013. The availability of the blade A selection option in APT has been announced through a STAN (http://www.stsci.edu/hst/wfc3/documents/newsletters/STAN_10_11_2013).

There are GO programs with short exposures where it is critical to the science goals to have a sharp PSF. Such programs may now take short exposures (<30 sec, but up to <60 sec) with less shutter-induced vibration using the exposure-level option BLADE=A in APT. Note, however, that since this option causes additional motions of the shutter mechanism, its use will be allowed only when scientifically justified.

As noted earlier, specifically choosing the option to use shutter blade A adds a small amount of overhead (~ 2 sec) and causes additional movement of the shutter mechanism. This extra overhead and shutter movement can sometimes be avoided by taking into account the natural sequence of the shutter movement. For example, if there is a series of exposures which are alternately short and long (such as: 1 sec +100 sec +1 sec +100 sec +1 sec +100 sec….), then if the shutter blade side A is is chosen for the first (1 sec) exposure, then all the 100 sec exposures should automatically be taken with shutter blade B, and all the short exposures should automatically be taken
with shutter blade A. However, this need not be always true since there is a small possibility that the exposures may be interrupted by earth occultation, during which some internal calibration observations may be taken. Placing the exposures in a “sequence” in APT will guarantee that the observations will be sequential and will not be interrupted by occultation, in which case the method described above can be used to avoid extra overheads and shutter movements (for more details on the use of “sequence,” refer to APT help/users’ manual).

It is worth noting here that if we ever have to switch WFC3 over to the Side 1 electronics, the resolver count positions for the shutter will change. The Side 1 resolver positions are approximately 900 counts less than the resolver positions for side 2, a significant difference which will need to be taken into account.

References

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