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WFC3 Optical Alignment Characterization in Thermal-Vacuum Test #3

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ABSTRACT

We have performed an assessment of the optical alignment of the WFC3 instrument in its final flight configuration, including the UVIS-1' and IR-4 detectors, during the 3rd thermal-vac test in March 2008. Both detectors are found to be aligned to well within tolerance in all degrees of freedom. The corrector settings, after adjustment to optimize image quality, are within the budgeted range for ground alignment, leaving ample range for on-orbit alignment optimization. The UVIS and IR fields of view are concentric to within ~1 arcsec and their respective AXIS-2 orientations are aligned to <0.1 deg at field center.

Introduction

The WFC3 design includes corrector mechanisms for both UVIS and IR channels that enable the alignment of each channel to the HST OTA. Because of the large spherical aberration present in the OTA, each WFC3 channel has a corrective element located at a pupil and the OTA exit pupil must be very well aligned (to within a fraction of a percent of the pupil diameter) to this element to avoid the introduction of significant coma. The corrector mechanisms also permit optimization of focus. Although WFC3 was constructed with careful metrology of the optical system with respect to the instrument latches by which it will be mechanically mounted into the HST, there are uncertainties in the latch positions and launch vibration and gravity release effects, so sufficient range in the corrector mechanisms must be allocated for on-orbit alignment.

The primary tool for assessing the instrument alignment is the WFC3 Optical Stimulus (OS), more commonly referred to as the CASTLE (which may be an acronym for CAlibrated STimulus from Leftover Equipment, since it was adapted at GSFC from the stimulus built by JPL to test WF/PC and WFPC-2, or may just be a description of its appearance).

This apparatus was repeatedly, and with multiple techniques, verified to be an accurate opto-mechanical match to the OTA by the GSFC optical test section (Greeley, et al) and the HST Independent Verification Team at GSFC, headed by W. Eichhorn.
In addition to permitting global alignment of the instrument using the corrector mechanisms, the CASTLE also provides point source illumination with full field coverage matched to the OTA focal surface that facilitates assessment of the detector alignment in 6 degrees of freedom to the instrument focal surface for each channel. Previous measurements of the detector alignment in ambient and thermal vacuum tests were reported by Hartig (2005) and demonstrated the inadequacy of the detector alignment transfer techniques used at the time. Since then, a more direct technique, involving focus measurement of the (packaged) detector surfaces through the window(s) has been developed for both IR and UVIS detectors. This enabled successful alignment of the final flight detectors, as currently installed in WFC3 and measured in TV3, as reported below.

The WFC3 alignment process with CASTLE is subject to two constraints: 1.The CASTLE metrology of its optical system to latches can be performed well in the SSDIF cleanroom, but accuracy is degraded in the SES vacuum chamber due to inability to use standard measurement techniques (space limitations, lack of stable platform for measurement systems). 2. Imaging with the IR channel requires that WFC3 be in a thermal-vacuum environment, since the detector must be operated cold to avoid dark current saturation. The adopted approach is to measure and align the UVIS channel with respect to the well-characterized CASTLE in the SSDIF, then, after transfer to the SES chamber, align the CASTLE to the UVIS channel (with its corrector left in the previously aligned state) and then the IR channel to this CASTLE alignment while operating in thermal-vacuum conditions. Good repeatability of UVIS/CASTLE alignment after return to the SSDIF following TV1 and TV2 validates this approach.

Measurement chronology

The flight UVIS1' detector was installed in the instrument in Dec. 2007 and alignment measurements made with the CASTLE (previously aligned to RIAF latches; OS config. "ZE") in the SSDIF on 08 Jan 2008 (ref log 200808a, exposure entries 45171:45749). After the corrector was adjusted in tip/tilt and focus to optimize image quality, focus scans at 16 field points distributed uniformly over the field, performed with two iterations of the SMS set UVAL1S1,2,3, were used to assess the detector alignment, as described by Hartig (2005). The resultant corrector settings were very close to those previously determined and the detector was found (for the first time!) to be within spec in all degrees of freedom (Table 1.), although, based on previous experience, changes were expected when the instrument is operated in a flight-like environment. The table displays results of both encircled energy (EE) through-focus scans and phase retrieval (PR) analyses of images obtained far from focus. We adopt the EE results as the most directly representative of science performance.

Table 1. Pre-TV3 Ambient UVIS-1' Alignment Test Results

	8-Jan-08 -50C "ZE" a		9-Jan-08 -50C "ZE" b	
	EE	PR	EE	PR
Θ_X (^{o})	-0.09	-0.18	-0.10	-0.19
Θ_y (^{o})	0.21	0.27	0.18	0.29
Z (mm)	-0.026	0.136	0.035	0.174
X(mm)	-0.132		-0.124	
Y(mm)	-0.129		-0.117	
Θ_z (^{o})	0.040		0.038	

Mean 8-9 Jan '08	
EE only	
Θ_X (^{o})	-0.094
Θ_y (^{o})	0.192
Z (mm)	0.005
X(mm)	-0.128
Y(mm)	-0.123
Θ_z (^{o})	0.039

The TV3 program commenced with the WFC3 installed in the RIAF in CASTLE in the SES thermal-vacuum chamber at GSFC, in a configuration similar to that used for the Jan '08 ambient testing in the SSDIF, but with thermal shrouds surrounding the RIAF and instrument. Because complete optical metrology of the apparatus could not be performed due to restricted space in the SES chamber, the CASTLE image position and chief ray direction were aligned to the UVIS channel of WFC3 (by adjusting the two CASTLE fold flats), so that the image location and coma content at the UV01 field point were the same as in the Jan '08 ambient measurements (for which the CASTLE alignment was independently set, to best simulate the OTA beam relative to the instrument latches). This resulted in definition of a new 'ZH' series of CASTLE pointings to the standard 16 image positions covering the field of each channel (Hartig, 2003). After a single iteration of the alignment measurement SMSs, executed in ambient on 22-23 Feb '08 (ref. log 2008053c, exposure entries 48808-49063) demonstrated reasonable alignment (Table 2.), the chamber was evacuated.

Table 2. Pre- and Post-TV3 SES Ambient UVIS-1' Alignment Test Results

	23-Feb-08 -50C "ZH" c		20-Apr-08 -50C "ZM" b	
	EE	PR	EE	PR
Θ_X (^{o})	-0.10	-0.22	0.02	-0.09
Θ_y (^{o})	0.12	0.23	0.13	0.28
Z (mm)	-0.198	-0.069	-0.155	-0.033
X(mm)	-0.147		-0.121	
Y(mm)	-0.143		-0.138	
Θ_z (^{o})	0.057		0.049	

Mean	
EE only	
Θ_X (^{o})	-0.039
Θ_y (^{o})	0.125
Z (mm)	-0.177
X(mm)	-0.134
Y(mm)	-0.141
Θ_z (^{o})	0.053

With the thermal environment set to "Cold Operate", the UVIS alignment was again measured on 7 Mar '08 (log 2008068b) and CASTLE alignment adjusted to optimize image quality and match location at the UV01 field point, resulting in CASTLE alignment "ZJ". As seen in previous TV tests, the CASTLE alignment responded to the temperature change, requiring pupil and image position offsets of (-0.412,-0.082) and (1.285,-1.285) mm in (V2,V3), respectively. A focus offset of ~360 um was measured at the detector and corrected with the UVIS corrector focus drive. Then the UVAL1S1-3 alignment SMS suite was run twice (entries 49619:50132) to evaluate the UVIS alignment and wavefront error. The mean coma over the field was found to be ~1nm RMS, indicating excellent alignment of the CASTLE and UVIS pupils and mean focus error was < 50 um. The detector alignment was found to be well in spec in all degrees of freedom (Table 3).

Table 3. TV3 UVIS-1' Alignment Test Results

	8-Mar-08 -83C "ZJ" a		9-Mar-08 -83C "ZJ" b		24-Mar-08 -83C "ZL" b		Mean Mar '08	
	EE	PR	EE	PR	EE	PR	EE only	
Θ_X (°)	-0.10	-0.21	-0.09	-0.21	-0.04	-0.15	Θ_X (°)	-0.077
Θ_y (°)	0.05	0.18	0.04	0.17	0.04	0.19	Θ_y (°)	0.044
Z (mm)	-0.612	-0.484	-0.626	-0.500	-0.609	-0.489	Z (mm)	-0.616
X(mm)	-0.115		-0.132		-0.156		X(mm)	-0.134
Y(mm)	-0.113		-0.118		-0.122		Y(mm)	-0.118
Θ_z (°)	0.050		0.049		0.051		Θ_z (°)	0.050

With CASTLE well aligned to the instrument, we proceeded to align the IR channel, making substantial adjustments of the cylinders to minimize coma and defocus (log 2008069b). Because of the significant coupling of focus and pupil adjustment (Hartig, 2005), several iterations were required and IDL tool *wfc3_ir_corr* was used (and refined) to determine the corrections from the phase retrieval and focus scan results. The alignment was then assessed with the IRAL1S4,5,6 SMS suite (entries 50202:50406) , and further corrections were made before repeating the SMS suite (entries 50485:50740). The resultant mean coma over the 16 field points was ~3nm RMS and the mean focus error ~3 um. The detector alignment was found to be in spec in all 6 degrees of freedom (Table 4).

Table 4. TV3 IR-4 Alignment Test Results

	9-Mar-08 -128C "ZJ" a		10-Mar-08 -128C "ZJ" c		25-Mar-08 -128C "ZL" c		Mean Mar 08	
	EE	PR	EE	PR	EE	PR	EE only	
Θ_X (°)	0.11	0.15	0.07	0.10	0.06	0.14	Θ_X (°)	0.088
Θ_y (°)	0.03	0.04	0.09	0.06	0.06	0.00	Θ_y (°)	0.062
Z (mm)	-0.141	-0.146	-0.164	-0.205	-0.13	-0.147	Z (mm)	-0.153
X(mm)	0.046		0.175		0.039		X(mm)	0.111
Y(mm)	0.022		0.062		0.06		Y(mm)	0.042
Θ_z (°)	-0.029		-0.027		-0.030		Θ_z (°)	-0.028

After execution of many calibration measurements the chamber environment was transitioned to "Hot Operate" and the CASTLE alignment was again adjusted to match the UVIS channel image and pupil locations on 24 Mar '08. Only small offsets (~100 um and 300 um in image and pupil location, respectively) were required, and the new OS configuration "ZL" was established. A single run of the UVAL1S1,2,3 SMS suite was performed (entries 53225:53480), again confirming that the detector was well aligned (Table 3) and that the coma and focus were optimized. This was followed by adjustment of the IR corrector and a single run of the IRAL1S4,5,6 SMS suite (entries 53545:53817), which again demonstrated near optimal coma and focus over the field and good detector alignment (Table 4).

After the thermal vacuum test program completed, the WFC3 was warmed and the SES chamber was vented to ambient. After again aligning CASTLE to the UVIS channel (OS config "ZM"), a follow-up (single) set of the UVIS alignment SMSs was run on 20 Apr '08 (log 2008110c, entries 58852-59107), with detector temperature set to –50 C. These measurements were reasonably consistent with the pre-thermal-vacuum measurements, as seen in Table 2.

Discussion

Prior to installation of the flight detectors a set of alignment tolerances in all 6 degrees of freedom was adopted, the rationale for which was discussed by Hartig (2005). The measurements presented herein demonstrate that the WFC3, with flight detectors installed, meets those specifications, as shown in Tables 5 and 6. Furthermore, the instrument alignment to the CASTLE stimulus, which (with the RIAF latching fixture) is taken as a high fidelity representation of the OTA, is optimized with both UVIS and IR corrector settings that are within the ground alignment budget. There was initially some concern that the IR channel INNER cylinder, which required an offset of ~90 steps (>5000 resolver counts) from the nominal position, may have placed the working location outside of the budget, but a study of the mechanism test data at Ball concluded that ample range remains (Delker, 2008). The final corrector settings determined in TV3 are displayed in Table 7; these should be the settings with which WFC3 flies, as they represent our best estimate of the optimal positions for use on orbit.

Tables 5 and 6. TV3 UVIS1' and IR-4 Detector Alignment Test Results Summary

UVIS-1' TV3 Alignment Summary			
	ColdOp	HotOp	Spec
X(mm)	-0.124	-0.156	0.3
Y(mm)	-0.116	-0.122	0.3
Z (mm)	-0.619	-0.609	0.85
Θ_x (°)	-0.096	-0.038	0.2
Θ_y (°)	0.046	0.041	0.2
Θ_z (°)	0.050	0.051	0.5

IR-4 TV3 Alignment Summary			
	ColdOp	HotOp	Spec
X(mm)	0.111	0.039	0.18
Y(mm)	0.042	0.060	0.18
Z (mm)	-0.153	-0.130	0.2
Θ_x (°)	0.088	0.057	0.3
Θ_y (°)	0.062	0.055	0.3
Θ_z (°)	-0.028	-0.030	1

Table 7. Final Flight UVIS and IR Channel Corrector Settings

		UVIS		IR	
Adjust	Range	Nominal	Gnd Test	Nominal	Gnd Test
Focus	±3600	2408	2525	2240	2287
Inner Cyl	±10700	10322	8608	58601	53193
Outer Cyl	±10700	53791	53311	44523	43069

Using the image location (X and Y) data from Tables 5 and 6, which represent offsets in the respective detector axes for the UVIS and IR channels from their common nominal field center points, and converting to arcsec using the appropriate plate scales, the offset between the two field centers is ~1.3 arcsec (cold op) and 1.0 arcsec (hot op). Each field is oriented (Θ_z) within ~0.05 degrees of nominal, but with offsets in opposite directions, so the Y axes of the two channels are aligned within ~0.08 degrees.

Conclusion

We have performed an assessment of the optical alignment of the WFC3 instrument in its final flight configuration, including the UVIS-1' and IR-4 detectors, during the 3rd thermal-vac test in March-April 2008. Both detectors are found to be aligned to well within tolerance in all degrees of freedom. The corrector settings, after adjustment to optimize image quality, are within the budgeted range for ground alignment, leaving ample range for on-orbit alignment optimization. The UVIS and IR fields of view are concentric to within ~1 arcsec and their respective AXIS-2 orientations are aligned to <0.1 deg at field center.

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