NAOMI WFS and OMC/NCU Acceptance Tests at the University of Durham wht-naomi-34

ATC Document number AOW/GEN/RAH/15.0/07/00 WFS and OMC/NCU acceptance tests
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This document combines two earlier draft documents that addressed the WFS and OMC/NCU separately. It also covers the system level acceptance tests that will be repeated at GHRIL to verify performance.

The ID numbers in the first column are those used in Dr. Andy Longmore's Microsoft Access database (see AJL file: integration_tests.mdb) which summarises the WPD requirements. The prefixes "WFS" and "OMC" before the ID number refer to the wavefront sensor and opto-mechanical chassis/Nasmyth calibration unit respectively. Most of the acceptance tests listed in the database have been included in this document; some selection of tests has been performed. Section 1 contains a grouping of tests with similar procedures. Elsewhere numbers in parentheses in the ID column identify tests that may be grouped together for efficient operation: note that there is no back referencing in the ID column. There is no requirement to perform the tests in the order given in this document.

Three levels of priority are shown, namely high, medium and low. These levels are indicated by the letters H , M and L in the ID column. In some instances a lower priority has been assigned where sufficient testing has been performed at the ATC or there is high confidence in the design.

A pre-requisite for the tests is the ability to observe a near diffraction-limited visible image with the SBIG camera at the IR science port. At least the first Airy ring should be observable in the image and the FWHM of the central peak should be consistent with diffraction theory after allowing for camera pixellation effects.

1. Grouped Tests

ID	Objective	Requirements	Description of Test	Date & Examiner	Pass/ Fail	Comments
OMC 15 M	Verify that the optics maintain the registration of the DM with the WFS lenslets independent of the guide star position.	?? OMC ?? WFS ?? NCU ?? Engineering level GUI	1. The integrated system is required for this test with the Nasmyth focal plane mask installed. 2. Flatten the DM and set the FSM to mid range. 3. Set up WFS in 4 x 4 pixel mode with lenslet array 1 and ADC set to zero dispersion. 4. Move the WFS pickoff to acquire the on-axis DL pinhole and centre the Hartmann spots. 5. Select the WFS fiducial mask and position the relay-lens/CCD carriage for the pupil-viewing mode. 6. Verify the DM registration with the fiducial mask. If not aligned adjust the DM x-y stage accordingly. (Note that the offset segment approach described in the next procedure may be used to obtain optimum alignment.) 7. Move the WFS pickoff to at least 4 other field points			

			and measure the DM/fiducial-mask registration. 8. 0.115 subaperture misregistration is predicted due to non telecentricity.			
WFS 7 H	Verify that the DM segments map onto the WFS subapertures.	?? WFS ?? OMC ?? NCU ?? Engineering level GUI	1. Flatten DM and set the FSM to midrange. Align WFS to on-axis NCU DL point source. 2. Set up WFS in 4 x 4 pixel mode with lenslet array 1 and ADC set to zero dispersion. 3. Adjust x-y position of the DM as required for the best overall registration of the DM image with the lenslet array in the pupil viewing mode. Return to Hartmann spot viewing. 4. Select a DM segment close to the DM centre and offset all adjacent segments so that their respective Hartmann spots move out of each subaperture's field of view. 5. Determine the light spillover into adjacent subapertures. Readjust DM in x and y if required to balance spillover. Spillover should not exceed 3.3% (2% is allowed for lenslet scattering and 1.3 % for misregistration. Note that in the next test 0.7% is allowed for angular misregistration.) 6. Repeat steps 4 and 5 for another segment close to the DM centre.			
WFS120 H	Lenslets shall be aligned in angle to better than 10 arcminutes relative to mapping of the DM segments.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	This test is a continuation of the preceding procedure. 1. Select a DM segment at edge of WFS subapertures and offset all adjacent segments so that their respective Hartmann spots move out of each subaperture's field of view. 2. Determine the light spillover into adjacent subapertures as a result of misregistration (angular or otherwise). 3. Repeat the measurement for three other subapertures so that all four lie at the extremes of a cross. Light spillover into an adjacent subaperture should not exceed 0.7 % due to rotation alone. Note allowance of 3.3% for other sources of error.			Requirement is achieved by shimming DM as required.
WFS 51	Spot displacements due to aberrations on-axis must be < 20% of pixel size.	?? WFS ?? NCU ?? OMC	Note: Although there is no off-axis specification the Hartmann spot offsets should be determined for other field positions as part of the system characterisation.			

H		?? Engineering level GUI	1. The integrated system is required for this test with the Nasmyth focal plane mask installed. 2. Flatten the DM and set the FSM to mid range. 3. Set up WFS in 4 x 4 pixel mode with lenslet array 1 and ADC set to zero dispersion. 4. Move pickoff to acquire on-axis source. 5. Adjust WFS pickoff to obtain best centration of Hartmann spots in array and record pick-off x-y position. 6. Adjust WFS integration time to give high photon rate without saturation. 7. Record spot centroid positions and determine displacement from centre of each pixel array. 8. Repeat steps 5-7 for lenslets 2 and 3. 9. Repeat steps 4-7 for other pinholes in grid of NFP mask (subject to time constraints).			
OMC 20 H	NCU provide capability to distortion map of AO optical train.	?? NCU ?? OMC ?? WFS ?? Engineering level GUI	Capability was demonstrated in preceding test.			
WFS 22 M	Verify that the acquisition accuracy is < 3.4 ?m.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	Acquisition accuracy will be ascertained as part of the astrometric mapping process in test WFS 51.			
WFS159 H	Combined motion of all carriages in response to pickoff motion shall produce no detectable focus error at WFS.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	Verified by observing WFS focus residuals during astrometric mapping in test WFS 22. Note that the WFS carriage drives are programmed to compensate for the OMC field curvature.			
WFS 29 L	Pickoff z-axis shall provide field curvature compensation.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	Verified by observing WFS focus residuals during astrometric mapping in test WFS 22. Note that the WFS carriage drives are programmed to compensate for the OMC field curvature.			
OMC186 H	Provision must be made to calibrate non-common path errors between science path and the WFS.	?? NCU ?? OMC ?? WFS ?? Engineering level GUI ?? SBIG camera	Procedure to be added later to cover methods developed by Durham.			

2. OMC Tests (not addressed above)

ID	Objective	Requirements	Description of Test	Date & Examiner	Pass/ Fail	Comments
OMC 19 M	The NCU should provide a WHT pupil simulator (for on-axis use only)	?? NCU ?? OMC ?? WFS ?? Engineering level GUI.	1. Measure the f/ratio of the NCU output beam with the pupil mask in place. 2. If brightness is sufficient, verify that the pupil mask is imaged at the DM and its size is correct (56 mm). 3. If brightness inadequate for visual observation at DM the pupil viewing mode of the WFS may be used as follows. 4. Flatten DM and set FSM to midrange. 5. Set WFS ADC to zero dispersion and select doublet. 6. Acquire on-axis point source by moving WFS pickoff and centre in WFS FOV. 7. Switch to WFS pupil viewing mode. Verify pupil is in focus and record image for analysis. Confirm that pupil size is acceptable.			Test may be limited by source brightness.
OMC 21 (OMC 41) H	Average transmission from Nasmyth focus to WFS input must be >0.58 over 0.5 to 0.8 ?m (Mode 1).	?? NCU ?? OMC ?? Engineering level GUI. ?? ATC photometer (or equivalent, e.g. SBIG camera) ?? 0.5 -0.8?m filter	1. Flatten DM and set FSM to midrange. 2. With on-axis point source, pupil mask and spectral filter measure NCU output flux with photometer or SBIG camera. (Note that the latter can measure total flux). 3. Measure flux passing through centre of dichroic at WFS input and calculate transmission.			
OMC 51 (WFS 23, 24, 25) H	Show that loop closure can be maintained while dithering.	?? NCU ?? OMC ?? WFS ?? Engineering level GUI	1. Select NCU on-axis point source, i.e. no FP mask. 2. Flatten DM and set FSM to midrange. 3. Move WFS pickoff to acquire point source and centre in WFS FOV. 4. Close DM and FSM loops. 5. Setting the configuration to the dither mode, inject an increasing amplitude, low frequency tilt signal to the NCU tip/tilt mirror (maximum amplitude and frequency TBD). 6. Demonstrate that the system can maintain loop closure while dithering.			
OMC 55 (OMC 56, 57,	On-axis common/science path wavefront error shall be <30 nm rms within a	?? OMC ?? FISBA interferometer ?? Concave spherical	1. Install dummy DM with pupil stop. 2. Mount FISBA on axis at the OMC input (Nasmyth focus).			

58, 60) M	subaperture (note exceptions in WPD).	mirror and x, y & z mount (for use as retroreflector)	3. Install and align concave sphere so that its centre of curvature is coincident with the focused FISBA light at the WFS focus. 4. Measure and record the wavefront. Analyse for compliance. 5. Move the concave sphere to the science path and repeat the wavefront measurement. Analyse for compliance.			
OMC 56 M	Off-axis uncorrectable wavefront error over 1 arcmin field shall be <50 nm rms (note exceptions in WPD)	?? OMC ?? FISBA interferometer ?? Concave spherical mirror and x, y & z mount (for use as retroreflector)	1. Install dummy DM with pupil stop. 2. Mount FISBA at +0.5 arcmin off axis in x at OMC input (Nasmyth focus). 3. Install and align concave sphere so that its centre of curvature is coincident with the focused FISBA light at the WFS focus. 4. Measure and record the wavefront. Analyse for compliance. 5. Repeat steps 2-5 for –0.5 arcmin in x and ± 0.5 arcmin in y.			-0.5 arcmin in y may be omitted due to symmetry of the design.
OMC 57 M	The pupil wavefront error shall be <200 nm rms (goal < 170 nm) within 2 arcmin field. (Note exceptions in WPD).	?? OMC ?? FISBA interferometer ?? Concave spherical mirror and x, y & z mount (for use as retroreflector)	1. Follow same procedure as for ID 56 except that FISBA and sphere are located at ± 1 arcmin in x and y respectively. 2. Determine rms wavefront error over the pupil for each field position.			
OMC 58 M	The pupil wavefront error shall be <300 nm rms (goal < 265 nm) within 2.9 arcmin field. (Note exceptions in WPD).	?? OMC ?? FISBA interferometer ?? Concave spherical mirror and x, y & z mount (for use as retroreflector)	1. Follow same procedure as for ID 56 except that FISBA and sphere are located at ± 1.45 arcmin in x and y respectively. 2. Determine rms wavefront error over the pupil for each field position.			
OMC 60 M	Non-common path errors between science path and WFS shall be < 100 nm rms	?? OMC ?? WFS ?? FISBA interferometer ?? Concave spherical mirror and x, y & z mount (for use as retroreflector)	1. Calibrate wavefront quality of concave spherical mirror using the FISBA. Retain wavefront data for use in other tests that follow. 2. Set up the FISBA on axis at the input (Nasmyth focus) to the OMC. WFS should not be in position. 3. Flatten the DM or install the dummy DM. 4. Install and align the concave spherical mirror at the IR science port so that the IR science path can be measured in double pass with the FISBA. Measure			

			and record the wavefront. 5. Move the concave sphere so that its centre of curvature lies at the WFS input focus. Measure and record the input wavefront to the WFS. Remove sphere. 6. Install the WFS and move its pickoff so that the FISBA light passes through to the optical science port (OSP). Reposition the sphere to allow a double-pass wavefront measurement to the OSP. Measure and record the wavefront. 7. Determine the non-common path errors from the measured wavefronts.			
OMC 67 M	General optical practice to avoid ghosting shall be followed.	?? OMC ?? NCU ?? Engineering level GUI ?? WFS ?? SBIG camera	The objective is to identify all ghost images within the optical train and quantify them in terms of relative intensity and location. 1. Set the NCU to maximum brightness, select the on-axis point source, flatten the DM and set the FSM to mid range. 2. Set up the SBIG camera at the IR science port to view the point source image. Demagnification to provide at least a 50 arcsecond field of view is suggested. Identify and quantify any ghost images. Note that an extended integration time may be needed to locate any ghosts. 3. Move the camera to the optical science port and repeat. Move the WFS pickoff to avoid obscuration of the SBIG camera. 4. Select the WFS doublet in the lenslet wheel and move the pickoff to acquire and centre the point source image. Set the ADC to zero dispersion. Identify and quantify any ghost images. Insert the lenslet arrays in turn and repeat the operation. Also insert the WFS filters in turn and rotate the ADC elements. 5. Similarly check for ghost images in the acquisition camera's field. 6. Install the NFP mask and search for ghosts at all ports for at least three field postions (TBD).			
OMC 77	Measures shall be taken to protect personnel from	?? OMC	Verify compliance with documented safety audit. Procedure to be established when document is made			

H	hazards.	?? NCU ?? Engineering level GUI	available to Durham.			
OMC 78 M	Handling procedures and lifting aids should be provided for heavy items.	?? NCU ?? OMC ?? Lifting aids (e.g. handles)	Verify availability and function of lifting aids when demonstrating installation and alignment (or disassembly on completion of tests).			
OMC 94 (WFS 4) H	SciOpReq Clauses 1 – 3 performance achievable for 1 hour integrations without recalibration	?? Turbulence simulator ?? OMC ?? WFS ?? Engineering level GUI ?? SBIG camera	This test should be performed as part of test ID WFS 4 which uses the turbulence simulator. The SBIG camera should be set up at the IR science port to view the compensated point source image. Observations of the image quality should be made for fixed test conditions over a 1 hour period.			
OMC 95 Priority TBD	The uncorrectable tip/tilt induced jitter shall be < 30 nrad (0.006 arcsec) in WHT object space. Note the inclusion of the WFS in the specification.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI ?? SBIG camera	Test is subject to review. 1. Flatten DM and set FSM to midrange. 2. Install SBIG camera at the optical science port to view DL pinhole in FP mask. 3. Align WFS to suitable pinhole in FP mask without obscuring image of the SBIG camera. 4. Measure PSF width at science port with WFS power sources off. 5. Turn on WFS power sources. Close FSM loop. Measure PSF width again. Determine change in width. Note: This test is similar to the WFS test ID 146 which also lacks a satisfactory procedure.			Test requires further thought. Difficult to distinguish uncorrectabl -e tilt from other sources of PSF degradation.
OMC 97 M	Cleaning procedures demonstrated on witness samples of all coatings.	?? Witness samples ?? Cleaning materials and procedures	1. If a suitable spectrophotometer is available the transmittance or reflectance of all witness samples should be measured before and after cleaning. 2. Perform cleaning in accordance with documentation. Verify that the cleaning does not leave residue or cause damage.			
OMC100 (OMC 101) M	Verify that the DM and its associated electronics on bench can be removed and re-installed safely in 1 hour or less.	?? OMC ?? NCU ?? WFS ?? Engineering level GUI	1. Flatten DM and set FSM to midrange. Select on-axis point source in NCU. 2. Select lenslet 1 and 4 x 4 pixel mode. Set ADC dispersion to zero. 3. Acquire and centre point source image in WFS by moving its pickoff. 4. In pupil viewing mode verify that DM segments are			

			aligned to lenslets. If not adjust DM x-y position as required. 5. Turn off all power to system. 6. Remove and re-install DM and bench-mounted electronics, noting time required for complete operation.			
OMC101 L	Verify that only further minor alignment is needed on re-installation of DM.	?? OMC ?? NCU ?? WFS ?? Engineering level GUI	This test is a continuation of the procedure for test ID 100. 1. Power up the system and check for the image of the point source and pupil alignment in the WFS. 2. If re-alignment is required, verify that it is minor, i.e. within limits of adjustments provided.			
OMC103 (OMC 104) L	Verify that there is at least ± 4mm of travel on the DM motorized stages.	?? OMC ?? Engineering level GUI. ?? Travelling microscope or equivalent	1. Set up travelling microscope to view a reference point on the DM, e.g. segment boundary. Take care not to touch the DM surface. 2. Command the DM x-y stage drive to each limit of travel and measure distance moved with the travelling microscope. Verify travel is acceptable.			
OMC104 L	Verify that DM motorized stage motions are repeatable to < 0.2 mm.	?? OMC ?? Engineering level GUI. ?? Travelling microscope or equivalent	This test should be combined with test ID 103. 1. Set up travelling microscope to view a reference point on the DM, e.g. segment boundary. Take care not to touch the DM surface. 2. Command the x-y stage to drive set distances (TBD) repeatedly and measure position after each command with the travelling microscope. Verify that the repeatability is acceptable.			
OMC110 H	Verify that the FSM is protected against being driven to limits of its safe operational range.	?? OMC ?? Engineering level GUI	Drive the FSM in incremental steps (TBD) towards its limits noting the point at which the offload to the TCS occurs. Verify that FSM does not exceed safe operating limits. Note: A means of independently monitoring the FSM surface tip/tilt is desirable for this test.			
OMC111 H	Verify that FSM offsets are off-loadable to the TCS.	?? OMC ?? Engineering level GUI	This test should be combined with test ID 110.			
OMC112 M	Characterise the FSM frequency response to 200 Hz.	?? OMC ?? Engineering level GUI ?? Collimator and position-sensing detector to measure	1. Set up collimator and position-sensing detector (PSD) to measure FSM surface tilt. 2. Apply small amplitude (≤ 50?rad surface tilt) sinusoidal oscillation to FSM progressing from low to higher frequencies. Record FSM tip/tilt amplitude			Repeat of tests performed at the ATC. Test subject

		FSM surface tilt.	as measured with PSD. Exercise caution if resonance starts to occur. 3. Determine –3 dB frequency.			to equipment availability.
OMC113 Priority TBD	Verify that the FSM open-loop jitter is < 48 nrad (0.01 arcsec) rms in WHT object space for either axis.	?? OMC ?? SBIG camera ?? NCU ?? Engineering level GUI	Test is subject to review. 1. Install and align the NCU and OMC. 2. Flatten the DM or install the dummy DM. 3. Install the SBIG camera at the IR science port to view the NCU on-axis DL point source. 4. With the FSM power off, measure the point spread function (PSF) using the SBIG. 5. Measure the PSF again with the FSM power on in open loop. 6. Determine the increase (if any) in the PSF width in both axes with the power on and convert to angle in WHT object space using the plate scale.			
OMC131 (WFS 39) M	OMC and WFS must register repeatably to each other with < 50 ?m accuracy in all 3 axes.	?? OMC ?? NCU ?? WFS ?? Engineering level GUI.	This test is identical to WFS test ID 39 and it should not be repeated.			
OMC147 M	NCU provides on-axis point source which is full-aperture diffraction limited (DL) at visible wavelengths.	?? NCU ?? SBIG camera	1. Set up the SBIG camera to view the NCU on-axis point source. 2. Record and analyse the PSF.			
OMC150 H	Verify that the NCU point source radiant intensity conforms to OMC WPD Table 2.	?? OMC ?? NCU ?? WFS ?? Engineering level GUI.	1. Flatten DM and set FSM to midrange. 2. Select WFS lenslet 1, 4 x 4 pixel mode and ADC to zero dispersion. 3. Move WFS pickoff to acquire and centre NCU on-axis point source image in WFS field of view. 4. Determine photons received per subaparture in 5 msec integration time and convert to radiant intensity from source. 5. Extrapolate to infrared from these test results.			More detailed information to be provided.
OMC202 L	Measure the open-loop transfer function of the NCU tip/tilt mirror.	?? OMC ?? NCU ?? SBIG camera ?? Engineering level GUI.	The approach assumes that a sufficiently sensitive, high bandwidth position-sensing detector is not available. 1. Flatten DM and set the FSM to midrange. Set up the SBIG on axis at the science port. 2. Turn on the on-axis point source with the tip/tilt mirror stationary. Record the image and determine the PSF width (baseline).			Test approach is subject to review. Phase information is not

			3. Turn on the tip/tilt mirror (amplitude TBD) at 1 Hz. 4. Integrate with SBIG for > 30 sec. Determine width of blurred PSF and subtract baseline width to arrive at measured amplitude of oscillation. 5. Repeat at 10 Hz intervals to 150 Hz. Shorter integration times may be used at the higher frequencies. 6. Derive transfer function from ratio of commanded motion to measured motion as a function of mirror frequency.			obtained.
OMC154 M	Verify that the NCU point source tip/tilt injection frequency is controllable from 0.1 to 150 Hz.	?? OMC ?? NCU ?? WFS ?? Engineering level GUI.	This requirement should be verified as part of the preceding test.			
OMC153 (OMC 154) H	Verify that the NCU point source tip/tilt injection amplitude is variable up to 2.6 arcsec	?? OMC ?? NCU ?? WFS ?? Engineering level GUI.	This procedure may be performed as part of test OMC 202 provided the SBIG camera is set up with sufficient FOV to accept the image motion with a 2.6 arcsecond amplitude. An alternative procedure using the WFS is given below. 1. Select NCU on-axis point source, i.e. no FP mask. 2. Flatten DM and set FSM to midrange. 3. Select WFS doublet and set ADC dispersion to zero. Select lenslet array 2. 4. Move WFS pickoff to acquire point source and centre in WFS FOV. 5. Set NCU tip/tilt mirror to 2.6 arcsec amplitude at < 10Hz and determine amplitude seen by WFS.			
OMC157 M	NCU point source spectral distribution shall correspond to G0 to K0 spectral type.	?? NCU ?? ATC photometer or equivalent calibrated detector. ?? Spectral filters (ideally 0.1 ?m bandwidth over 0.5 to 1.0 ?m)	Measure the spectrum of the direct output of the NCU using the photometer and filters. If suitable equipment is not available, calculate spectral type from lamp colour temperature and data on any colour-balancing filter in the NCU.			Test subject to availability of suitable filters and detector.
OMC165 M	Verify that the extended source radiance conforms to Table 3 of OMC WPD.	?? NCU ?? Engineering level GUI ?? ATC photometer	Note that the solid angle of the extended source must be determined (or assumed from the optical design). The photometer measures irradiance and the solid angle is needed to determine radiance, i.e. $W/cm^2/ster$. As the			Test subject to equipment availability.

			ATC photometer only operates over 0.5 to 1.0 ?m one may have to use an IR camera to complete the measurement.			
OMC167 M	Verify that NCU extended source uniformity is < 0.5 % over 10 mm diameter.	?? NCU ?? Engineering level GUI ?? ATC photometer with 1mm dia mask or SBIG camera. ?? x-y stage with >10 mm travel for photometer head	1. Install mask on photometer head (or at SBIG focus) and mount assembly at NCU output. 2. Set up NCU to provide extended source. 3. Measure uniformity of illumination across at least two diameters moving in ≤ 1 mm increments. Alternative procedure with SBIG camera. 1. Install lens on camera to give 5:1 demagnification. 2. Set up SBIG to view extended source. 3. Analyse uniformity of image. 4. Rotate camera 90 degrees about axis and repeat. Analyse data for camera rotational variations in response. 5. Displace camera by +/- half the FOV. Analyse data for lateral variations in camera response. Separate camera non-uniformities from source non-uniformity.			Difficult to make reliable measuremen-ts to 0.5 %.
OMC168 L	Verify that a NCU He-Ne laser source is available for on-axis alignment.	?? NCU ?? OMC ?? Engineering level GUI	1. Install He-Ne laser in NCU 2. Turn on the laser and verify that beam properly illuminates the DM.			
OMC199 M	Verify fit and function of spare components, if any.	?? Spare components	Any components to be identified by the ATC.			
200 H	Verify the mechanical fit of the OMC/NCU components in their shipping containers.	?? OMC ?? NCU ?? Shipping containers	Pack and inspect.			

3. WFS Tests (not addressed above)

ID	Objective	Requirements	Description of Test	Date & Examiner	Pass/ Fail	Comments
WFS 4	Verify that the WFS will operate with atmospheric	?? WFS	1. Set up WFS to view point source through turbulence simulator with DM flattened and FSM at midrange.			

H	coherence lengths > 8 cm at 0.55 ?m.	?? OMC ?? Engineering level GUI ?? Liquid crystal turbulence simulator	2. Demonstrate that satisfactory Hartmann spot data can be obtained over required range of turbulence conditions, changing between lenslets 1 and 2 in accordance with turbulence strength.			
WFS 10 (WFS 11, 12) H	Verify that CCDs operate with 6 x 6 and 4 x 4 pixels (unbinned)	?? WFS ?? OMC ?? NCU ?? Engineering level GUI	1. Flatten DM or install dummy DM. Set FSM to midrange. Align WFS to on-axis NCU DL point source. 2. Set up WFS in 4 x 4 pixel mode with lenslet array 1 and ADC set to zero dispersion. 3. Adjust WFS pickoff to centre Hartmann spots in array. 3. Adjust NCU brightness and WFS integration time to give high photon rate without saturation. 4. Operate in required readout modes and show that the data streams can be reconstructed into the appropriate images.			
WFS 11 H	Verify that the CCDs operate in a quad cell mode (2 x 2 binned pixels).	?? WFS ?? OMC ?? NCU ?? Engineering level GUI	1. Flatten DM or install dummy DM. Set FSM to midrange. Align WFS to on-axis NCU DL point source. 2. Set up WFS in quad cell mode with lenslet array 1 and ADC set to zero dispersion. 3. Adjust WFS pickoff to centre Hartmann spots in array. 4. Adjust NCU brightness and WFS integration time to give high photon rate without saturation. 5. Verify that the data stream can be reconstructed into the appropriate image.			
WFS 12 H	Verify that the CCD configuration is changeable without loosing lock.	?? WFS ?? OMC ?? Engineering level GUI ?? Liquid crystal turbulence simulator	1. This test should be performed on completion of test ID 4. 2. With lenslet 1 and 4 x 4 pixels close the DM and FSM loops for simulated r_o TBD (>15 cm suggested). 3. Demonstrate that one can change to quad cell mode and 6 x 6 pixels without loosing lock.			
WFS 20 M	Pickoff must allow acquisition of WFS source	?? WFS ?? Engineering level GUI	1. Acquire WFS calibration source by moving pickoff. 2. Verify that images of source can be centred in CCDs field of view.			
WFS 23	Dithering range of 1.7 mm (5 arcsecond) with $\pm$ 3.4 ?m	?? WFS ?? NCU	1. Flatten DM or install dummy DM. Set FSM to midrange. Install NCU FP mask.			

(WFS 24, 25) H	repeatability is required.	?? OMC ?? Engineering level GUI	2. Set up WFS with doublet and ADC set to zero dispersion. 3. Select pair of pinholes in FP mask with separation closest to 1.7 mm. 4. Establish pickoff positions that centre each pinhole in CCDs' FOV. 5. Dither between these pinholes and determine repeatability from Hartmann spot positions at ends of each dither cycle.			
WFS 24 H	Dithering range of 6 mm (18 arcsecond) with ± 8.5 ?m repeatability is required.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	This test is similar to the previous test (ID 23) except that the dither range is increased accordingly.			
WFS 25 H	Dithering amplitude accuracy shall be ± 17 ?m (± 0.05 arcsecond) or better.	??	This test should be combined with tests ID 23 and 24. These tests establish repeatability. To establish accuracy one compares the commanded pickoff positions with the actual as determined by the spot positions as seen by the CCDs.			
WFS 30 L	Maximum z-axis speed shall be > 1.9 mm/sec.	?? WFS ?? Engineering level GUI	Measure time for z-axis motion of 19 mm.			
WFS 39 (WFS 163) M	WFS must register with OMC with a 3-axis repeatability < 50 ?m.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	1. Install dummy DM with fiducial. Set FSM to midrange. Align WFS to on-axis NCU DL point source. Set NCU to high brightness. 2. Set up WFS in 4 x 4 pixel mode with lenslet array 1 and ADC set to zero dispersion. 3. Adjust WFS pickoff to centre Hartmann spots in array. Adjust integration time to give go best signal to noise ratio without saturation. 4. Measure spot positions, mean separation, pupil image of fiducial in front of dummy DM. 5. After taking all precautions, lift the WFS using the handling gear provided and carefully replace. 6. Repeat step 4 and calculate replacement accuracy from spot position and pupil changes.			
WFS 40 M	WFS must pivot about f/16.8 focus in both axes.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	This capability is verified as part of the OMC/WFS initial installation and alignment.			
WFS 41	Phase-gradient measurement	?? WFS	1. Flatten DM or install dummy DM. Set FSM to			

(WFS 42) H	accuracy of 0.018 wave (?=2.2 ?m) rms required with 1500 photons/subaperture .	?? NCU ?? OMC ?? Engineering level GUI	midrange. Align WFS to on-axis NCU DL point source. 2. Set up WFS in 4 x 4 pixel mode with lenslet array 1 and ADC set to zero dispersion. 3. Adjust WFS pickoff to centre Hartmann spots in array. 4. Adjust NCU brightness and WFS integration time to give photon rate. Record spot centroid positions. 5. Tilt FSM angle* 20.8 ?rad (4.3 arcsec) and measure spot centroid positions. Repeat several times and determine the dispersion. (* Mirror surface tilt corresponding to required phase gradient accuracy.)			
WFS 42 H	Phase-gradient measurement accuracy of 0.14 wave (?=2.2 ?m) rms required with 40 photons/subaperture.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	1. Flatten DM or use dummy DM. Set FSM to midrange. Align WFS to on-axis NCU DL point source. 1. Set up WFS in quad cell mode with lenslet array 1 and ADC set to zero dispersion. 2. Adjust WFS pickoff to centre Hartmann spots in array. 3. Adjust NCU brightness and WFS integration time to give photon rate. Record spot centroid positions. 4. Tilt FSM angle TBD and measure spot centroid positions. Repeat several times and determine the dispersion.			
WFS 43 H	Verify phase gradient range is at least <u>+</u> 1.5 waves/subaperture (?=2.2 ?m) with 4 x 4 pixels for r_o=8 cm and 8 x 8 pixels for r_o >13 cm.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	1. Flatten DM or use dummy DM. Set FSM to midrange. Align WFS to large NCU source which simulates time-averaged source degraded by strong turbulence. 2. Set up WFS in 4 x 4 pixel mode with lenslet array _ and ADC set to zero dispersion. 3. Move WFS pickoff along x-axis until edge of pixel array is reached in each direction. Note that <u>+</u> 1.5 waves/subaperture corresponds to a pickoff motion of <u>+</u> 0.41 mm. Record pickoff positions at array edges. 4. Repeat for y-axis. 5. Align WFS pickoff to NCU DL point source and select lenslet 1 and 8 x 8 pixel mode. 6. Repeat steps 3 and 4 for this configuration.			

WFS 54 H	Transmission shall be >90% over 0.5 to 1.0 ?m spectral range.	?? WFS ?? OMC ?? NCU or suitable bright source at Nasmyth focus ?? ATC photometer	1. A "point" source of sufficient brightness is required at the input to the OMC, i.e. the Nasmyth focus. "Sufficient brightness" is defined as a good signal to noise level with the ATC photometer when its head is placed at the f/16.8 focus, i.e. the WFS input. 2. Measure the signal at the f/16.8 focus with the photometer head. 3. Move the CCD carriage to the rear limit of its travel. 4. Select the WFS doublet in the lenslet wheel. 5. Mount the photometer head to collect all light from the doublet. 6. The ratio of the second reading to the first is a measure of the transmission (excluding relay optics). 7. Perform this operation with different filters (subject to availability) to assess transmission variation with 0.5 to 1.0 ?m spectral region.			Measurement excludes relay optics.
WFS 67 H	Lenslets shall not scatter >2% into adjacent subapertures.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	1. Flatten DM and set FSM to midrange. 2. Set up WFS in 4 x 4 pixel mode with lenslet array 1 and ADC set to zero dispersion. 3. Align WFS to on-axis NCU point source. 4. In pupil-viewing mode verify correct registration of DM segments to lenslets. 5. Select a subaperture and tilt segments around this subaperture to limit away from subaperture. 6. Measure flux in adjacent subapertures and compare with flux in selected subaperture.			Difficult to distinguish between lenslet scattering and DM mis-registration.
WFS 80 M	ADC Pupil shift and residual dispersion shall be <5% subap. and <0.04 arcsec at 45deg zenith: <8% subap, 0.06 arcsec at 60 deg zenith.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	Satisfactory procedure not yet defined.			Difficult to perform a credible test.
WFS 85 H	Remotely-controlled shutter with EPICS interface is required.	?? WFS ?? Engineering level GUI	Verify remote operation of shutter.			
WFS 88 H	Verify that two electronically switchable readout modes have been provided.	?? WFS ?? Engineering level GUI	Demonstrate synchronized mode switch (by inspection of output data stream?) while observing WFS calibration source.			

WFS 90 H	At 100 kilopixel/sec the readout noise shall be 3 e-/pixel or less.	?? WFS ?? Engineering level GUI	With the WFS shutter closed, set the readout rate, determine the dark field and readout noise level.			
WFS 91 H	At maximum rate, the readout noise shall be 7 e-/pixel or less.	?? WFS ?? Engineering level GUI	Similar to previous test (ID90) but at maximum readout rate.			
WFS103 M	Reference wavefront tilt accuracy must be a factor of two better than WFS can detect.	?? WFS ?? Engineering level GUI	Confirm by calculation. Compare pickoff resolution to Hartmann spot centroid accuracy as determined in ID 41.			
WFS105 H	WFS calibration source intensity must be $\geq$ 3 x 10^-8 W/steradian.	?? WFS ?? Engineering level GUI	1. With lenslet 1 and 4 x 4 pixel mode, acquire the calibration source and centre Hartmann spots in CCD FOV. 2. Measure number of photons /subaperture in 5 msec through broadest spectral filter with no ND. Number of photons should exceed 2500.			
WFS107 M	WFS calibration source intensity must be uniform.	?? WFS ?? Engineering level GUI	1. With lenslet 1 and 4 x 4 pixel mode, acquire the calibration source and centre Hartmann spots in CCD FOV. 2. Switch to the pupil-viewing mode, increasing the integration time if required to obtain sufficient signal. 3. Record the pupil image and assess the uniformity.			
WFS108 M	WFS calibration source must simulate G0-K0 star.	?? WFS	Determine by analysis from lamp colour temperature and the spectral characteristics of any filters installed in the calibration source.			Difficult to devise and perform suitable test.
WFS111 L	Verify that WFS transfer curve linearity is <15% (except in quad cell mode).	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	1. Flatten DM or use dummy DM. Align WFS to on-axis NCU DL point source. 2. Set up WFS in 4 x 4 pixel mode with lenslet array 1 and ADC set to zero dispersion. 3. Move WFS pickoff along x-axis in 5 ?m increments until edge of pixel array is reached in each direction. 4. Record WFS mean centroid position for each increment. 5. Plot mean centroid position against pickoff position. 6. Repeat steps 3-5 for y-axis. 7. Determine linearity of transfer curves.			
WFS121	Lenslet accuracy shall be	?? WFS	1. With lenslet 1 and 4 x 4 pixel mode acquire the WFS			

M	maintained when lenslets are changed.	?? Engineering level GUI	calibration source. Centre the source image by adjusting the pickoff position as required. 2. Record spot positions. 3. Rotate lenslet wheel and reselect lenslet 1. 4. Re-measure spot positions. 5. Repeat for other lenslets.			
WFS132 M	WFS shall perform to specification with a temperature change of 1 deg C/hour.	?? WFS ?? NCU ?? OMC ?? Engineering level GUI	This test could be a continuation of ID 121 by monitoring the spot position, deviation and size with temperature.			
WFS146 Priority TBD	WFS vibration sources must contribute < 0.0035 arcsec rms uncorrectable tip/tilt jitter	?? WFS ?? NCU ?? OMC ?? Engineering level GUI ?? SBIG camera	This test is subject to review. 1. Flatten DM and set FSM to midrange. 2. Install SBIG camera at the optical science port to view DL pinhole in FP mask. 3. Align WFS to suitable pinhole in FP mask without obscuring image of the SBIG camera. 4. Measure PSF width at science port with WFS power sources off. 5. Turn on WFS power sources. Close FSM loop. Measure PSF width again. Determine change in width.			Extremely difficult to detect.
WFS147 H	Cleaning procedures for all optical components must be developed and demonstrated.	?? WFS	Cleaning procedures should first be demonstrated on witness samples wherever possible to reduce the risk of damage. An area of particular concern is the WFS pickoff mirror as no spare is available. Advise waiting until cleaning is required.			
WFS162 M	Verify proper function of encoder readout and use in any feedback.	?? WFS ?? Engineering level GUI	A separate test is not essential in that other tests should adequately demonstrate the encoder functions. Tests already performed at the ATC indicate satisfactory operation.			
WFS163 M	Lifting frame and attachments must be provided for the WFS.	?? WFS ?? Lifting equipment	Demonstrated as part of ID 39.			
WFS164 H	Verify fit of components in shipping containers and adequacy of protection.	?? WFS ?? Shipping containers	Pack and inspect.			
WFS165 H	Verify fit and functionality of any spares.	?? WFS ?? Engineering level GUI ?? WFS spares	Verify fit and functionality of any spares (to be provided by the ATC).			

WFS168 L	Temperature sensors will be provided to allow correction to unavoidable alignment changes caused by contraction or expansion.	?? WFS ?? Engineering level GUI	Test and monitor temperature sensors over a couple of 24 –hour periods. Confirm that readings are consistent with those from an independent thermometer.			

4. System Level Acceptance Tests

ID	Objective	Requirements	Description of Test	Date & Examiner	Pass/ Fail	Comments
N/A	Verify that a Strehl of $\geq$0.48 is obtained using NCU tilt injector with FSM-only correction. ?? Measured at IR science port with SBIG ST-5 camera. ?? Wavelength: 850 nm ?? Inject frequency: 10 Hz; Amplitude: +/- 0.1 arcsec. ?? Inject frequency: 20 Hz; Amplitude: +/- 0.0.05 arcsec.	?? NCU ?? WFS ?? OMC ?? Engineering level GUI	1. Flatten DM and set the FSM to midrange. Align WFS pick-off to on-axis NCU DL point source. 2. Install and align SBIG camera with 850 nm filter at IR science port. 3. Set up WFS in 4 x 4 pixel mode with lenslet array 1 and ADC set to zero dispersion. 4. Adjust x-y position of the DM as required for the best overall registration of the DM image with the lenslet array. 5. Adjust NCU point source intensity to obtain maximum signal with saturation at maximum (TBD) WFS frame rate. 6. Optimise the SBIG camera image using the "Nathanising" procedure. Fix the DM. 7. Set the NCU tilt injector to 10Hz and an amplitude of +/- 0.1 arcsecond. 8. Close the tilt loop. 9. Record the PSF seen by the SBIG camera. 10. Set the NCU tilt injector to 20Hz and an amplitude of +/- 0.05 arcsecond. 11. Close the tilt loop. 12. Record the PSF seen by the SBIG camera. 13. Determine the Strehl ratio for the two measurement conditions.			Test subject to availability of software to allow closure of tilt loop only.

N/A	As above using reconstructed DM-only correction.	?? NCU ?? WFS ?? OMC ?? Engineering level GUI	1. Flatten DM and set the FSM to midrange. Align WFS pick-off to on-axis NCU DL point source. 2. Install and align SBIG camera with 850 nm filter at IR science port (if not already in place). 3. Set up WFS in 4 x 4 pixel mode with lenslet array 1 and ADC set to zero dispersion. 4. Adjust x-y position of the DM as required for the best overall registration of the DM image with the lenslet array. 5. Adjust NCU point source intensity to obtain maximum signal with saturation at maximum (TBD) WFS frame rate. 6. Set the NCU tilt injector to 10Hz and an amplitude of +/- 0.1 arcsecond. 7. Close the DM loop. 8. Record the PSF seen by the SBIG camera. 9. Set the NCU tilt injector to 20Hz and an amplitude of +/- 0.05 arcsecond. 10. Close the tilt loop. 11. Record the PSF seen by the SBIG camera. 12. Determine the Strehl ratio for the two measurement conditions.			
N/A	Verify maximum WFS offsets below with hill-climbed on-axis DL spot at 850 nm on SBIG and DM fixed. ?? <30" off axis: no spot >0.1" from box centre ?? <90" off axis: no spot >0.2" from box centre	?? NCU ?? WFS ?? OMC ?? Engineering level GUI	1. Install the NFP mask. 2. Flatten DM and set the FSM to midrange. Align WFS pick-off to on-axis NCU DL point source. 3. Install and align SBIG camera with 850 nm filter at IR science port (if not already in place). **4.** Set up WFS in 4 x 4 pixel mode with lenslet array 1 and ADC set to zero dispersion. **5.** Adjust x-y position of the DM as required for the best overall registration of the DM image with the lenslet array. 6. Adjust NCU point source intensity to obtain maximum signal with saturation at maximum (TBD) WFS frame rate. 7. Close the DM loop and follow the "Nathanising" procedure to obtain the optimum image at the SBIG camera. Fix the DM. 8. Move the WFS pick-off to acquire and centre the			

			closest (6.5 mm in NCU grid space) point source image in the +x direction. 9. Measure and record the Hartmann spot positions relative to each "box" centre. 10. Repeat steps 8 and 9 for the –x and +/- y positions. 11. Repeat steps 8 to 10 but for NFP point sources that are 19.5 mm (NCU grid space) off axis. 12. Verify that the test objectives have been satisfied.			
N/A	Low light level specification: With 100 detected photons/ms/subaperture and inject/measurement conditions as for first test, verify Strehl $\geq$ 0.23.	?? NCU ?? WFS ?? OMC ?? Engineering level GUI	Follow the procedure for the first test but with the following exceptions: Before setting the tilt injector (step 7) switch the WFS to quad cell operation and adjust the NCU source brightness to give the specified photon rate in the objectives column. Continue with step 7.			