NAOMI Commissioning Procedures at the WHT **wht-naomi-33**

ATC Document number AOW/GEN/RAH/13.0/05/00 NAOMI commissioning
DRAFT (Version date: 25th May 2000)

1.0 Introduction.

The commissioning process will be also be a learning process and thus the test descriptions offer some options and flexibility. Minor modifications to the procedures are acceptable if made to improve efficiency and/or system performance without changing the test objective. All procedural modifications should be documented. Weather and schedule constraints may lead to the omission of some tests, e.g. recalibration checks. Any omissions shall be approved by the ING.

2.0 WHT Prerequisites for Commissioning

The following list is not intended to be fully inclusive. Its purpose is to draw attention to areas that require particular attention. Experience has shown that the failure to satisfy some conditions listed can create significant problems for adaptive-optics systems.

1. GHRIL bench vibration checked.
2. GHRIL bench surface aligned to optical axis; axis height 150.0± 0.5 mm.
3. Telescope optics and derotator in a clean condition.
4. Seal installed around derotator.
5. Derotator axis and pupil stability (≤ 0.036 pupil diameter) determined to be satisfactory.
6. Nasmyth focus location defined at GHRIL.
7. GHRIL electronics room cooling system operational.
8. Telescope altitude and azimuth drives functioning satisfactorily without oscillations or “jumps”.

3.0 Before Commissioning: Integration to the WHT, baseline calibration and performance confirmation.

Code	Objective(s)	Requirements	Description of Test	Date & Examiner	Pass/ Fail	Comments
1	Perform initial installation and alignment of NAOMI and INGRID.	??	**1.1 Installation and Alignment of the OMC** 1. The attached appendix gives the procedure for the optical alignment of the Opto-Mechanical Chassis (OMC). This must be completed successfully before the Nasmyth Calibration Unit (NCU) and then the wavefront sensor (WFS) are brought into alignment with it. **1.2 Installation and Alignment of the NCU** 2. 1.Install the NCU shelf on to the GHRIL bench.			

			3. Place the Nasmyth Calibration Unit (NCU) on the bench and shelf with the ball of the alignment aid (ATC drawing number 10a22a) in the chassis plate pivot hole. 4. Install the NFP mask at the Nasmyth focus. 5. Remove the Integrating Sphere Unit (ISU) if installed and replace with the f/11 alignment laser. 6. Turn on the f/11 laser.* 7. Ensure that f/11 NCU pupil mask is installed. 8. Install cross hairs on OAP1 (FSM) coincident with the optical axis. Check the centration with the MAT. 9. Adjust NCU jacking feet to bring the laser focus to the height of the central (on-axis) pinhole in the NFP mask. 10. Using the two grub screws on the alignment aid adjust the ball position until the pinhole is illuminated by the laser. Note that as the alignment proceeds the ball can be adjusted as required to keep the laser focus on axis. 11. Adjust the eccentric to bring the NCU optic axis (as defined by centre of laser beam relative to target cross hairs) into the x,z plane of the OMC. 12. Adjust the NCU feet into the x,z-plane of the OMC. 13. Iterate steps 10 to 13 if required until the NCU is aligned. 14. Lock the ball and remove alignment target. **1.3 Installation and Alignment of the WFS** 1. Install WFS on the bench in its nominal position using the approved handling procedure and make all connections. 2. Set WFS probe to the centre of its range in x, y and z and close WFS shutter. 3. Turn on f/11 He-Ne laser and verify that the beam is centred on the WFS pick-off mirrors and collimating lens. If not adjust the WFS centration and rotation as required. Turn off He-Ne laser. 4. Select WFS full-aperture doublet. 5. Select predetermined filters and set ADC to zero. 6. Turn on NCU white light source, WFS CCDs and insert NCU beamsplitter. 7. Manually install NFP mask. 8. Set WFS carriages to predetermined locations to view pinhole image.				

			9. Adjust WFS pick-off focus (z-axis) to give best focus of pinhole image. If motion is > 1mm readjust WFS position manually to bring refocusing within 1 mm. 10. Select pupil fiducial in WFS. 11. Move CCD carriage to view pupil fiducial and image of dummy-DM mask. Rotate WFS manually about pivot point to centre mask image in x-axis on the fiducial. Rotate WFS first pick-off fold mirror if required to centre in y axis. Observe CCD display during this operation. 12. View NCU on-axis point source image with CCD and recentre/refocus if required by moving WFS probe in x,y or z directions.* 13. Iterate to obtain correct pupil and image position simultaneously. 14. Turn off NCU white light source.			
2	Perform initial calibration and functional checkout of OMC, WFS and NCU.	??	**2.1 WFS Dark Counts** This simple procedure determines the number of dark counts, i.e. bias, for each pixel in the WFS CCDs. The variation with temperature and time will be explored. Note that the read noise may also be derived from this procedure. Assuming that the values are found stable and repeatable at all operational temperatures, dark-count correction will be performed with look-up tables. 1. Close WFS shutter. 2. Turn on WFS CCDs. 3. Record CCD dark counts over various intervals (TBD during system integration). 4. Record WFS temperature sensor readings. 5. Repeat at least hourly and over widest possible temperature range (as governed by GHRIL conditions) until bias variations can be reliably established. 6. Generate look-up tables to account for bias as a function of integration time and temperature. 7. Shutdown system power or reset to normal operation setup, as required. **2.2 WFS Flat Field** In this procedure the WFS calibration source is used to flat field the WFS CCDs but the NCU on-axis point source could			

			also be used for this purpose. 1. Turn on WFS power, WFS calibration source and control system. 2. Select predetermined WFS spectral and ND filters. 3. Set WFS ADC to zero deviation. 4. Select lenslet 1 in lenslet wheel. 5. Set WFS camera focus position for lenslet 1 focus. 6. Move WFS probe to acquire WFS calibration source. 7. Verify Hartmann spot positions are satisfactory; if not adjust probe position. 8. Select clear aperture in lenslet wheel. 9. Move camera focus to view clear aperture. 10. Record CCD pixel intensities over a pre-determined integration period. 11. Shutdown system power or reset to normal operation setup, as required. **2.3 WFS internal collimation** This procedure serves as a check that the light leaving the WFS collimating lens is properly collimated and that the WFS carriage positions repeat from those established in Durham. . If the light is not collimated the Hartmann spot spacing will increase or decrease as one moves to the edges of the Hartmann spot array as seen by the CCDs. The spot pattern will appear to exhibit either pincushion or barrel distortion depending on whether the beam is divergent or convergent. If a problem exists the distance between WFS pick-off and the collimating lens must be adjusted until a uniform spot spacing is obtained. The reconstructor should, of course, be used to provide a quantitative measure of defocus. 1. Turn on WFS power, WFS calibration source and control system. 2. Select predetermined WFS spectral and ND filters. 3. Set WFS ADC to zero deviation. 4. Select lenslet 1 in lenslet wheel. 5. Set WFS camera focus position for lenslet 1 focus. 6. Move WFS probe to acquire WFS calibration source using x,y and z co-ordinates established in Durham. 7. Verify Hartmann spot separations are uniform and determine defocus using the reconstructor. If not adjust			

spacing between pick-off and collimating lens until defocus is zero within the limits set by system noise, i.e. change fore-optics focus position. Note that the camera focus must also be adjusted to follow this focus change.

8. Shutdown system power or reset to normal operation setup, as required.

2.4 WFS transfer curve with WFS calibration source

This procedure describes the procedure for generating a WFS transfer curve for a selected lenslet array and CCD pixel binning configuration using the WFS calibration source. By moving the WFS probe relative to the WFS calibration source in the x-y plane one produces a tilt of the input wavefront. From the Hartmann spot shifts and the focal length of the lenslet one can determine the measured tilt (or phase gradient). A plot of the commanded tilt vs measured tilt (ordinate axis) gives the transfer curve. The procedure may also be employed in an iterative manner to set the WFS camera focus as described in the next section.

1. Turn on WFS power, WFS calibration source and control system.
2. Select predetermined WFS spectral and ND filters.
3. Set WFS ADC to zero deviation.
4. Select specified lenslet in lenslet wheel.
5. Select specified WFS CCD camera pixel binning configuration.
6. Set WFS camera focus position to pre-determined (look up) focus.
7. Move WFS probe to acquire WFS calibration source.
8. Move WFS probe in pre-determined increments along x-axis and record spot positions for each incremental step.
9. Generate transfer curve using measured spot positions for each incremental step.
10. Repeat steps 7 and 8 but for y axis if desired.
11. Shutdown system power or select the next lenslet array and/or binning configuration as required.

2.5 **WFS camera focus**

This procedure is used to check the focus of a selected lenslet array. As the CCD relay lens relay lens is telecentric the effect of a focus change is a change in spot size but without a centroid shift. Uniform illumination of the each

			lenslet is assumed for this statement to hold true. Probably the best measure of focus is to determine the slope of the WFS transfer curve, i.e. the steepest slope is given at best focus. Thus the procedure is functionally the same as that given in the preceding section.. 1. Turn on WFS power, WFS calibration source and control system. 2. Select predetermined WFS spectral and ND filters. 3. Set WFS ADC to zero deviation. 4. Select specified lenslet in lenslet wheel. 5. Select specified WFS CCD camera binning conifiguration. 6. Set WFS camera focus position to pre-determined (look up) focus. 7. Move WFS probe to acquire WFS calibration source. 8. Move WFS probe in pre-determined increments along x-axis and record spot positions for each incremental step. 9. Generate transfer curve using measured spot positions for each incremental step. 10. Compare transfer curve with previously determined curve in look-up table. 11. If curve differs from look-up table, i.e. smaller slope, change camera focus in pre-determined incremental steps and repeat steps 7 and 8 for each focus change until the maximum slope is obtained. 12. Shutdown system power, select another lenslet array or binning configuration or reset to normal operation setup, as required. **2.6 WFS transfer curve using FSM** This procedure takes into account the effect of the OMC aberrations on the WFS transfer curve. Here the FSM is used to change the tilt of the input wavefront to the WFS. The input wavefront is produced by the NCU on-axis point source. The procedure could be performed for off-axis points if the NFP mask is installed. Note that the NCU tip-tilt injection mirror could also be used in place of the FSM if desired.			

			1. Turn on power to WFS, FSM, DM, NCU white light source and control system. 2. Insert NCU beamsplitter and ISU mask. 3. Select predetermined WFS/NCU spectral and ND filters. 4. Set WFS ADC to zero deviation. 5. Select specified lenslet in lenslet wheel. 6. Select specified WFS CCD camera pixel binning configuration. 7. Set DM stage position in x and y from look-up table. 8. Set WFS camera focus position to pre-determined (look-up) focus. 9. Flatten DM. 10. Set FSM to servo zero position (open loop). 11. Move WFS probe to acquire NCU point source using pre-determined coordinates and close WFS_WFS pick-off loop to centre source in WFS field. 12. Open loop and verify Hartmann spot locations are satisfactory; if not readjust WFS probe position. 13. Incrementally change FSM azimuth (x-axis) angle over a pre-determined range and record Hartmann spot positions for each incremental change in tilt. 14. Generate transfer curve using measured spot positions for each incremental step. 15. Repeat steps 11 and 12 for FSM elevation motion and/or diagonal motions if desired. 16. Remove NCU beamsplitter and ISU mask. 17. Shutdown system power, repeat procedure for another lenslet array or binning configuration or reset to normal operation setup, as required. 18. Note that, if desired, this procedure may also be performed using the ”turbulence-broadened” NCU source. **2.7 FSM to WFS loop check** This procedure uses the tip/tilt injection capability of the NCU to check the performance of the FSM in closed loop operation when driven by tip/tilt error signals from the WFS. 1. Power up the system. 2. Turn on NCU white light source. 3. Insert the NCU beamsplitter and the ISU mask.			

			4. Flatten DM. 5. Set FSM to servo zero. 6. Select specified WFS lenslet array. 7. Select specified WFS camera pixel binning configuration. 8. Set WFS ADC to zero deviation. 9. Set DM stage to required x-y position from look-up table. 10. Set WFS probe to pre-determined co-ordinates to acquire NCU on-axis point source. 11. Optimise WFS probe position if required. 12. View source with acquisition camera. 13. Install camera or position sensor (TBD) on axis at optical science port (OSP) to view NCU point source. 14. Set NCU tip/tilt injection mirror to pre-determined amplitude and frequency. 15. Confirm frequency and amplitude of point source using acquisition camera (if former is within camera bandwidth). 16. Close FSM-WFS loop. 17. Observe/record residual spot jitter as seen by OSP camera/sensor. Compare to previous results obtained during integration. 18. Turn off NCU white light source. 19. Remove NCU beamsplitter and ISU mask. 20. Shutdown system power or reset to normal operation setup, as required **2.8 Nasmyth focal plane to WFS probe space** Here the Nasmyth focal plane (NFP) mask with its array of pinholes is used to calibrate the WFS probe space. 1. Manually install the NFP mask at the Nasmyth focal plane. 2 Turn on power to WFS, FSM, DM, NCU white light source and control system. 3 Insert NCU beamsplitter. 4 Select predetermined WFS/NCU spectral and ND filters. 5 Set WFS ADC to zero deviation. 6 Select specified WFS camera pixel binning			

			configuration. 7 Select full aperture doublet in lenslet wheel. 8 Set WFS camera focus position to pre-determined (look up) focus. 9 Flatten DM. 10 Set FSM to servo zero position (open loop). 11 Move WFS probe in x and y to acquire each NFP point source in turn. Centre each point source image in the camera and record the WFS probe coordinates. 12 Generate look-up table of NFP position vs. WFS probe position. 13 Remove NFP mask. 14 Remove NCU beamsplitter and turn off the NCU white light source. 15 Shutdown system power or reset to normal operation setup, as required.			
3	Repeat acceptance tests performed at Durham to verify that system performance has not degraded.	??	1.			
4	Measure non-common-path offsets between WFS and INGRID using the NCU as a reference source.	??	1.			

First Light: Preliminary Commissioning Tests

Code	Objective(s)	Requirements	Description of Test	Date & Examiner	Pass/ Fail	Comments
5	Demonstrate the satisfactory completion of the set-up procedures in preparation for observation of a science object.	??	**5.1 Initialise WFS** This procedure uses only an artificial star to initialise the WFS and thus it does not determine the effect of the WHT aberrations. The effects of differential aberrations between the on-axis and off-axis images, for example, may be handled by look-up tables. One may find that this procedure best serves as a check on the repeatability and stability of NAOMI. This will perform the following operations: 1. Power up the system. 2. Insert NCU beamsplitter , predetermined NCU filters and ISU mask. 3. Set WFS probe to on-axis position. 4. Set WFS filters to predetermined values. 5. Set WFS ADCs to zero dispersion. 6. Select predetermined lenslet array. 7. Select specified WFS camera pixel binning configuration. 8. Set DM stage positions in x and y from look-up table. 9. Turn on NCU white light source. 10. Set Science Camera to snapshot mode. 11. Flatten deformable mirror and zero tip-tilt mirror. 12. Determine Hartmann spot centroids on WFS 13. Close loop on on-axis point source. 14. With feed-back from Science camera determine optimum centroid offsets and pistons 15. Repeat step 14 for other lenslet arrays. 16. Open loop. 17. Display information on WFS set-up, if acceptable proceed. 18. Switch off NCU white light source. 19. Remove NCU beam-splitter. 20. Shutdown power or reset to normal operational			

			setup. **5.2 TCS Calibrate** There are two possible approaches to this calibration. The first is to use the acquisition camera. This approach is preferred for its simplicity. Current estimates from the ING predict a camera sensitivity of 18th visual magnitude after initial commissioning tests. This sensitivity should be more than adequate for a standard TCS calibration. The second approach is to use the WFS to determine the relative positions of the artificial (from the NCU) and natural guide stars. This approach should offer somewhat higher accuracy if required. Note that both approaches have been successfully used during MARTINI runs. As a calibration accuracy of around 1 arcsecond is acceptable for most observing scenarios there is usually no requirement for a compensated NGS image. The first approach involves the following operations: 1. Turn on power to NCU, acquisition camera and associated display and electronics. 2. Insert NCU beam-splitter and ISU mask 3. Select predetermined NCU spectral and ND filters 4. Turn on NCU on-axis white light source 5. Display point-source image (artificial star) in acquisition camera field 6. Determine and record image position taking into account any allowance for the beamsplitter offset 7. Turn-off NCU white light source and remove ISU mask 8. Command TCS to selected natural star (reference star) 9. Determine and record time-averaged natural star position 10. Repeat steps 7 and 8 as needed for other reference stars 11. Remove NCU beam-splitter and ISU mask The second approach involves the following operations: 1. Turn on NAOMI power 2. Put in NCU beam-splitter 3. Select WFS doublet, predetermined filters and zero WFS pick-off offsets 4. Flatten DM			

			5. FSM to zero 6. Turn on NCU on-axis artificial star 7. Acquire with WFS and centre in its field by closing WFS_WFS pick-off loop 8. Turn off artificial star and open WFS_WFS pick-off loop 9. Command TCS to selected natural reference star 10. Verify acquisition with acquisition camera and record position in acquisition field. 11. Remove NCU beamsplitter 12. Acquire reference star and centre in WFS field by adjusting TCS pointing. 13. Verify star centration in WFS by time-averaging its position; adjust TCS pointing if required. 14. Insert NCU beamsplitter and determine new star position in acquisition camera field. 15. Difference between initial and final TCS gives TCS correction required. 16. Repeat steps 9 to 15 for other reference stars if required **5.3 Acquire Set-up Star** Here we acquire and observe a corrected image of a suitable bright star within a few arcseconds of the science object of interest. The star will be used to check the AO system closed-loop performance, check the focus of the INGRID and determine the seeing parameters. The assumption is made that the system power is already on. Acquisition involves the following operations: 1. Select suitable bright star 2. Select WFS specified lenslet array 3. Set DM and FSM loops open 4. Flatten DM 5. Set FSM to zero 6. Turn on the acquisition camera and insert NCU beamsplitter 7. Set all colour and ND filters to predetermined values 8. Centre star within acquisition camera field			

			9. Move telescope to required field such that light from bright star passes into the WFS (drag and drop operation) then remove NCU beamsplitter. 10. Set DM position in x and y from look-up table 11. Set WFS ADC to PA 12. Further adjustment of telescope might be required to align star perfectly. 13. Close DM and FSM loops with low gain **5.4 Set TCS Focus** An iterative approach is suggested. The primary operation here is to set the WHT secondary mirror position to provide the optimum focus at the science instrument (INGRID during initial operation). One must also ensure that for this condition the WFS focus is such that the focus offload to the secondary is zero. 1. Set TCS focus to predetermined value (believed to best focus for INGRID) 2. Check uncorrected science image of suitable bright star and correct if obvious defocus 3. Close loop following steps 3 to 13 in section 4.3 above 4. Change WFS focus so that offload to TCS is zero. 5. Time average several science frames and inspect PSF 6. Change WHT secondary focus by distance TBD 7. Change WFS focus so that offload to TCS is zero. 8. Time average several science frames and inspect PSF 9. Compare PSF to previous PSF 10. Repeat steps 6, 7, 8 and 9 as appropriate until PSF indicates best focus has been obtained **5.5 Determine Seeing Parameters** With open-loop operation on bright star the following seeing parameters will be determined: 1. Determine r_0, t_0 from WFS data 2. Determine optimum lenslet array size and focal length (set by guide star brightness and turbulence conditions – may be a look-up table)			

			3. Determine optimum conjugate height *(upgrade only – method TBD)* 4. Query astronomer if suggested lenslet array (*and conjugate choice – upgrade*) acceptable, if so continue, if not enter own choice. 5. Set lenslet array 6. Set conjugate lens (*upgrade only)* If lenslet array or conjugate lens changed redo WFS initialisation. **5.6 Determine Sky Background For WFS** This procedure determines the level of sky background that will be seen by the WFS during the observations. The assumption is made that this procedure immediately follows the determination of seeing parameters, i.e. one can point the telescope such that the WFS sees the sky background in the region of the science object(s) and the astronomer knows the WFS operating parameters to be used while observing. 1. Move WFS probe to appropriate region of sky. 2. Select pre-determined WFS lenslet array, filters and WFS camera operating mode. 3. Record WFS signals over integration period and number of frames TBD.			
6	Implement the observational procedure and establish WFS response using star(s) of known magnitude and spectral characteristics.	??	Here a typical observational procedure is followed using various stars to establish the WFS response. Suitable stars shall be selected prior to commissioning. **6.1 Set up target (guide star) parameters** The following observing options must be set; these can either be set before the run and stored in a data file or interactively set for a new target. 1. Co-ordinates of science target 2. desired field position of science object 3. Set Sky PA 4. WFS guide star offsets + spectral type and magnitude if available 5. WFS Colour/ND Filters 6. Wide/Narrow field correction required (depending on science field of interest) 7. Sky chopping offsets and direction			

			8. Continuous optimisation during exposure on/off **6.2 Acquire target** This will perform the following: 1. Open all mirror loops 2. Move telescope to required field (start slew) **-** this is a command to place the guide star onto the WFS probe position 3. Set sky PA 4. Insert NCU beamsplitter 5. Verify guide star location in acquisition camera field 6. Move WFS probe to guide star location 7. Remove NCU beamsplitter 8. Flatten DM and zero FSM servo 9. Set DM stage to x and y positions from look-up table 10. Select specified lenslet array (determined in section 4.5) 11. Set WFS offsets and filters 12. Set WFS ADC 13. Display WFS acquisition display and verify target in field **6.3 Align science target/guide star** Two displays will be available. 1. Science camera field. 2. Display of the WFS image and signals. On the acquisition display a target star might be positioned on the WFS pick-off by moving the telescope. This might perhaps be done by clicking on the star and dragging it to sensor pick-off position or by moving the pick-off by clicking on the sensor pick-off box and dragging it onto the star. A possible alignment procedure might proceed as follows: 1. Close WFS-FSM loop {select lenslets} and commence TCS offload . Engage tilt bandwidth optimisation. CHECK: photon levels against expectation and system limits.			

			2. If astronomical object is visible on the science camera use this to move it to the desired field position if required. This move will be performed by executing a probe offset procedure with the FSM loop closed (at least before and after). The displays and user interface must provide a mechanism for determining and executing this offset. **6.4 Determine closed-loop parameters** This will perform the following operations: 1. Close DM loop 2. Initiate automatic control loop optimisation CHECK: performance metrics (automatic) NOTE: this is the point at which on-sky WFS offset optimisation could be performed if there is a bright IR object in the field to use as a metric. 3. Show astronomer selected optimised parameters and performance metrics (oscilloscope display). Astronomer can enter own parameters if desired. **6.5 Science camera exposure (if desired for information purposes)** Exposures may now be taken. At end of exposure the following information to image header file: 1. Observing options which were selected 2. r_0, t_0 estimate 3. Guide star count rate 4. RMS residuals on wavefront 5. Tag to file containing further seeing/performance parameters			
7	Establish closed loop limit for "current" seeing, i.e. determine limiting stellar magnitude at which a satisfactory loop	??	This test may be regarded as an extension of the previous test (Procedures 6.1 to 6.5). Loop closure (6.4) is attempted with successively fainter stars (TBD) until a satisfactory closure cannot be obtained.			

	closure can be achieved.		The limit variation as a function of star spectral class and integration time should be explored subject to schedule constraints and weather conditions.			
8	Determine maximum no-oscillation bandwidth and gains with “current” seeing using a bright star.		1. A bright guide star is acquired and observed closed loop following the observational procedures 6.1 to 6.5. 2. The WFS integration time is progressively reduced to allow operation at higher bandwidths. The effect of gain variations are explored as part of this process.			

Advanced Characterisation

Code	Objective(s)	Requirements	Description of Test	Date & Examiner	Pass/ Fail	Comments
9	Determine the effect of binary objects as a WFS reference on system performance.					
10	Assess system stability					
11	Evaluate schemes for measuring off-axis WFS offsets for optimum IR imaging.		Two options are proposed. Selection of the best method will be made during commissioning. The selection process will be driven by the linearity and stability of the DM and WFS offsets. From the viewpoint of simplicity the first procedure is currently regarded as the default. **Use of DM to measure differential aberrations between science object and guide star** 1. Power up the system. 2. Set PA using TCS to place guide star at location within the science field where science object will be placed. FSM and DM loops are open (FSM at servo zero and DM flattened). 3. Select specified WFS lenslet array and camera pixel binning configuration. 4. Set WFS AtDC for PA. 5. Set DM stage position in x and y from look-up table. 6. Position WFS probe to acquire guide star and close WFS-WFS pick-off offset loop. (Note: This loop automatically centres the WFS probe on the guide star and it is not be confused with offsets of the Hartmann spots. The latter are referred to as the WFS offsets.) 7. Close FSM and DM loops. 8. Optimise IR image (method TBD) and record time-averaged WFS and/or DM offsets. 9. Position the guide star at its operating position and re-acquire with the WFS as in step 6. 10. Close FSM loop. 11. Differential WFS offsets are determined by either: keeping the DM offsets at the values determined in step 8 and noting the time-averaged change in WFS offsets or servoing the WFS offsets to be the same as those determined			

			in step 8 and noting the change in the time-averaged DM offsets. 12. Shutdown power or reset to normal operating configuration. **Use of an NCU diffraction limited on-axis source** 1. Power up the system. 2. Manually install the NFP mask. 3. Select predetermined WFS/NCU spectral and ND filters. 4. Turn on NCU white light source and insert NCU beamsplitter. 5. Select specified WFS lenslet array and camera pixel binning configuration. 6. Set WFS AtDC to zero deviation. 7. Set DM stage position in x and y using look-up table. 8. Flatten DM and zero FSM servo. 9. Move WFS in x and y to centre on each pinhole source within FOV covered by the science camera. Use method (TBD) to optimise each IR image and determine the DM and/or WFS offsets. 10. Remove NFP mask, turn off NCU source and remove beamsplitter.. 11. Produce map of differential aberrations between on-axis and off-axis images 12. Acquire an on-axis guide star (see Section___) and measure time-averaged WFS offsets. 13. Insert NCU beamsplitter and repeat step 11. Offload focus error introduced by beamsplitter to TCS. Note that the differential WFS offsets between steps 12 and 13 give the aberrations (>defocus) introduced by the beamsplitter. Note also that the chromatic shift between visible and K-band should be negligible but should be checked during commissioning. 14. Insert ISU mask and turn on NCU white light source to give diffraction-limited K-band and visible sources on axis. 15. Use TCS to move guide star approximately 10 arcseconds off axis with WFS centred on the NCU on-axis visible point source. 16. Optimise image of NCU K-band source in science camera. Record the DM and/or WFS offsets.			

			17. Use TCS to place guide star at position to be used during observations. 18. Move WFS to acquire guide star. 19. Optimise IR image of on-axis NCU source. Note science object may be used instead for this optimisation if it is bright enough. Record the DM and/or WFS offsets. 20. Record the differential offsets between steps 15 and 18; these data provide the off-axis telescope aberrations. 21. Remove NCU beamsplitter and ISU mask. Turn off the NCU white light source. All differential offsets can then be used to calculate the operational WFS offsets with guide star and science object as shown in Figure 1a. *Off-axis offsets* For NAOMI + camera from data in step 12. For telescope from data in steps 16 and 19. *Beamsplitter offsets* Offsets due to the insertion of the NCU beamsplitter are given by data from steps 12 and 13.			
12	Demonstrate the ability to maintain loop closure during dithering. (Requirement?)					