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Mechanical Subsystem Specification

Altair Turbulence Simulator "Turbulator"

Document #GAZ1508

Project: Altair

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			Date:
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Sub-System Documentation Standard
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   Reason for / items changed: 1) Added drawings and assembly info.

1 Applicable Documents

- Altair Critical Design Review Documents, Gemini North Adaptive Optics System, February 10-11, 1999
- Altair Preliminary Design Review Documents, Gemini North Adaptive Optics System
- Profiles of night time turbulence above Mauna Kea and isoplanatism extension in adaptive optics. Rene Racine & Brent Ellerbroek SPIE vol. 2534 p.248
- Roddier, F. The effects of atmospheric turbulence in optical astronomy. Progress in Optics, XIX. p. 280-376. E.Wolf, North-Holland 1981.
- Le Louarn et al. MNRAS (2000), see Astro-ph/0004065 5 April 2000

2 Acronyms and Abbreviations

AIFP	–	Altair Input Focal Plane
DM	–	Deformable Mirror
FOV	–	Field of View
ISS	–	Instrument Support Structure
NGS	–	Natural Guide Star
LGS	–	Laser Guide Star
OPD	–	Optical Path Difference
PSF	–	Point Spread Function
S1	–	On axis source
S2	–	Off axis source
WFS	–	Wavefront Sensor
CCD	–	Charge-Coupled Device
SNR	–	Signal to Noise Ratio

3 Scope

3.1 Document

This is the principal design review document for the Altair Turbulence Simulator, or "Turbulator".

3.2 Device

The turbulator is an opto-mechanical device whose task is to simulate the turbulence corrugated output beam of Gemini North, within the 2 arcmin Altair FOV. The purpose of the simulation is to test the ability of Altair to correct the corrugated central beam, particularly with an off-axis NGS. More precisely, this device must allow closing the loop with an off-axis NGS.

4 Context

The turbulator is to be placed in front of Altair (or inside it) during the optical tests in the laboratory.

5 Definitions

5.1 Altair Input Focal Plane (AIFP)

In coincidence with the Cassegrain focal plane of the Gemini telescope.

5.2 Coordinate system for the turbulator

The centre of AIFP – where the optical axis cross the AIFP – is the point zero for the coordinate system. Z-axis is along the optical axis, positive in the direction of the light-beam.

6 Functional Specifications

6.1 Mauna Kea / Gemini Atmospheric Turbulence

The corrugated output wavefront of the turbulator must replicate the following conditions

- r_0=19.1 cm @ 550 nm (median seeing at 45° zenith distance).
  This value gives D/ r_0=41.36 considering Gemini's M1 diameter D=7.9 m. This ratio must be replicate in the turbulator output beams.
- Mean wind speed across the aperture V=20 m/s. It gives a ratio V/D=2.53 which must be replicate in the turbulator output beams.

6.2 Optical Elements of the Turbulator

In the following, we give the list of the main optical component the turbulator should have. From the input to the output:

- A minimum of two light-sources, one on-axis to simulate an on-axis scientific target, one off-axis to simulate the NGS.
- Input lenses, to configure the optical beam from the light-sources across the following atmospheric turbulence element.
- Two Phase Screens, which impose a Kolmogorov turbulence to the wavefront. Two screens permits the generation of a grater amount of turbulence in the beam, and gives more flexibility to set the isoplanatic angle.
- A pupil stop, to define the extension of the beam across the phase screens and possibly replicate a central obscuration, (although not required).
- Output lenses, to replicate the Gemini Exit Pupil.

Note Images in the AIFP do not have to be real, because we do not plan to put any detector in this plane. Then, AIFP can be somewhere inside the turbulator.

6.3 Light sources

6.3.1 Tasks

To test the ability of Altair to correct the on-axis beam using an off-axis NGS, two stellar point sources are needed: one on axis (S1), which will simulate the infrared scientific target, and a second one off axis (S2), which will simulate the visual off-axis NGS. It may also be desirable to test Altair when S1 and S2 are coincident, and both on axis.

6.3.2 Positions

As the expected FOV of Altair is 2 arcmin (+/- 1 arcmin), there should be at least one off axis location for S2, perpendicular to the optical axis of the turbulator, at distances up to 30 arc-sec. This positioning of the off axis guide stars must be achieved in a reproducible way.

6.3.3 Orientation

The phase screens, as we will see below, are off-centred from the optical axis. To limit the rotation effect on the phase translation, it is better to move S2 perpendicularly to the radius of the phase screens rather than along the radius. Then, the chief ray plane of S2 – where the S2 chief ray moves - must be perpendicular to the phase screens radius.

6.3.4 Wavelengths

The optical bandwidth for the WFS beam is between 400 nm and 830 nm. Therefore, S2 should have a spectrum which includes any (or the totality) of these wavelengths. S2 could be monochromatic.

For the science source to pass through the beamsplitter, it must produce a spectrum which extends beyond 830 nm, but it may also include any wavelengths in the visible range. It is also desirable to image the science source with a CCD camera instead of an infrared detector. Since the CCD response cuts off above 1000 nm, the science source should ideally contain any wavelengths between 830 nm and 1000 nm. This source could also be monochromatic.

6.3.5 Brightness

Whatever the source spectrums, the photon flux in the output beam of the turbulator, considering its overall transmission, must be between 10^8 and 10^{10} photon/s for S1 and S2. This will ensure a good enough SNR on wavefront and PSF acquisitions, and avoid saturating the WFS CCD and the science camera.

6.3.6 Flux distribution across the beams

To avoid additional complications reading the WFS, and to get a nearly Airy pattern in the corrected focus, the fixed flux variations in the beam should be around +/-10% of the mean value.

6.3.7 Size
The size of the sources (pinhole diameter) should be small enough so that they can be considered as point sources from Altair's point-of-view. For this, the linear width of the geometrical images of these sources (without diffraction or aberrations) in the AIFP must be less than 1/4 of NA*λ(S1,2) where NA=16.2 is Gemini's numerical aperture and λ(S1,2) is the central wavelength of S1/S2. This will ensure a PSF FWHM only ~ 3 % larger than the theoretical one.

6.3.8 Light-tightness
It is required that the turbulator and its accessories NOT leak light into the room.

6.4 Phase Screens

6.4.1 Principle
The phase screens are manufactured following the NALUX (www.nalux.co.jp) technology. Its principle consists of moulded polymer disks copying the shape of a Kolmogorov realisation of a turbulence-corrugated wavefront. The OPD through the disk at a certain point is simply given by the thickness of the disk – which follow the wavefront shape - times the refractive index of the polymer – which is constant. Sending the turbulator beam through the rotating disk allow us to replicate the effect of a turbulent layer crossing perpendicularly the telescope beam.

6.4.2 Fried parameter r_0
These disks are moulded so that an 8-millimetre diameter patch simulates $D/r_0 = 5$ @ 2.2 µm, i.e. r_0=0.303 mm @ 550 nm (in the following, we will suppose that r_0 is given @ 550 nm, otherwise specified). The mould was machined from a wavefront generated by H. Takumi, Subaru Project. As the r_0 added in a –5/3 power law, two such a screen gives a total r_0 = 0.200 mm.

6.4.3 Dimensions
Each phase screen is a 36 mm diameter disk, with the usable pattern etched between r_{min} = 5 mm and r_{max} = 15 mm. So the phase screen are to be placed 10 mm off-centre with respect to the optical axis, i.e. the S2 chief ray plane cross the phase screen 10 mm from their centre.

6.4.4 Beam diameter trough the phase screens
To get the same D/r_0 as for Gemini at Mauna Kea, the diameter of the light beam inside the turbulator trough the two phase screen must be equal to
D_{beam} = 41.36 * 0.2 mm = 8.27 mm.
This value matches the available space between the inner and outer radius of the etched pattern on the phase screens, which is 10 mm.

As the r_0 value above Mauna Kea is a median value, it does not make sense to respect the calculated D_{beam} value with a high level of precision. A value between 8.2 mm and 8.4 mm is acceptable. The diameter of the beam will be fixed by the turbulator stop diameter (see below).

6.4.5 Phase Screen positions along the optical axis

According to Le Louarn et al. (MNRAS 2000), the isoplanatic angle through a certain Cn^2 vertical profile and for a DM at an altitude H is given by

Theta^(-3/5) = 2.905*k^2*integral(Cn2(h)*F(h) dh) [rad] (1)

where k is the optical wave-number and

F(h) = | h-H | ^ (5/3) (2)

When the angular distance between the NGS and the scientific target is equal to Theta, the phase error variance reaches 1 rad^2.

In the case of two infinitesimal identical layers (or two phase screens) at an altitude of μ_1 and μ_2 over the ground, we found, for a Mauna-Kea like r0 @ 1600 nm,

Theta = 67748 * [| μ_1-H |^(5/3)+| μ_2-H |^(5/3)]^(-3/5) [asec] (3),

where Theta is now given in arc seconds.

If the two layers are conjugated with the DM, μ = H and the isoplanatic angle is infinite.

In the appendix, we show a graph of Theta versus the mean altitude of the two phase screens, considering a scaling ratio of 1 mm in the turbulator for 1.6 Km in the atmosphere. This graph should be used to choose the final positions of the phase screens, i.e. distance from the DM conjugated altitude H and distance between them.

6.4.6 Phase Screen removal

For focusing the undistorted beam, a removable phase screen arrangement is desirable.

6.4.7 Phase Screen angular velocities

There are two requirements concerning the angular velocities of the phase screens:

1. The Gemini ratio V/D=20/7.9 must be replicated. Then, the mean velocity of the two phase screens across the 8.272 mm diameter beam must be v_{ph} = 8.272*20/7.9 = 20.942 mm/s
2. The period of repetition of the beam distortion should not be less than approximately 3-5 minutes. Indeed, as the phase screens are rotating, there could be some periodicity in the corrugation of the beam and we do not want short temporal sequences.

According to Roddier (see applicable documents), the characteristic velocity of a two identical layers scheme – whatever their altitude - is given by the following mean 5/3 power law

v_{ph}^(5/3)=(v_1^(5/3)+v_2^(5/3))/2 (4)

Choosing v_1 & v_2 with the same sign (+), we can see that the interval for the velocities is from >0 to 31.742 mm/s. Note that when one of the two velocities are zero, the phase velocity is not given by (4), but by the velocity of the moving phase screen.

We can choose any v_1 value between these two limits, and calculate v_2 following (4). After that, we have to check if the repeatability is more than 3 or 5 minutes. As there is no analytic solution to this problem, we use a try and error procedure, and have found that if the angular velocities of the screens are in the following interval

- v_1 = 21.008 +/- 0.065 mm/s
- v_2 = 20.876 +/- 0.065 mm/s

i.e. with a radius of 10 mm, angular velocities of

- w_1 = 20.061 +/- 0.062 rev/min
- w_2 = 19.935 +/- 0.062 rev/min

then the minimum period is 240 s, i.e. 4 minutes which is acceptable. In conclusion, the last values will give the requirements for the angular velocities of the phase screens. Either of the two screens can be the fastest or the slowest.

Finally, as we are interested in testing Altair with different velocity schemes, we can set as a goal the ability to choose any angular velocities between 0 and 50 rev/min

6.5 Exit Pupil

The turbulator exit pupil must replicate the exit pupil of Gemini, which coincide with its secondary mirror. This is an absolute requirement. It is the only way to:

1) Replicate the relationship between the inclination and the position of the chief ray in the AIFP.
2) Replicate the numerical aperture of Gemini (f/16.2).

- Gemini Exit Pupil position Z = - 16539.33 mm
- Gemini Exit Pupil diameter D = 1020.79 mm

The output lenses should achieve this task.

6.6 Pupil Stop

1. Limits the beam transverse extension so as to set the required beam diameter at the level of the phase screens (see 6.4).
2. May be used to replicate the beam central obscuration. Obviously, it must be conjugated with the exit pupil defined above. Gemini Central Obscuration e = 1021 / 7900 = 0.13. This value is not critical, and we can accept a value between, says, 0.12 and 0.14.

The diameter and the position of the stop are left free, and are to be chosen during the optical design to reach the two above requirements.

6.7 Field Curvature

We recall that the output focal plane of the turbulator must be in coincidence with the AIFP, but can be either real or virtual (the images in this plane can be real or virtual).

The field curvature of Gemini's focal plane does not have to be replicate here. Indeed, this off axis defocalisation can be re-adjusted with the diagnostic camera during the tests. Nevertheless, the turbulator focal plane field curvature must not be larger than Gemini's one, i.e. must be between 0 and 0.5 m^{-1}, and concave as seen from the turbulator.

6.8 Aberrations

The static on-axis and off-axis aberrations in the turbulator output beam – that is to say, without turbulence – should not exceed the Gemini off-axis aberrations.

6.9 Thermal stability

The device parasitic (heat-induced and drag-induced) turbulence should be kept at the lowest possible level. While the latter seems at this point to be negligible, temperature differences within the optical path due to instrument operation (light source heating, motor heat dissipation, etc.) are to be kept within ± 0.1°C.

7 Interfaces

7.1 Turbulator to Optical Bench Mechanical Mounting

The turbulator shall be designed as a stand-alone integral unit to be easily attached to the Optical Bench (OB) trough the side panels of the system enclosure. It shall not require the removal of any other part or subsystem. The turbulator assembly shall attach to the optical bench by its own supporting structure, with dedicated mounting holes provided for, in the fore end of the OB.

Since it will never be on the telescope during scientific observation and since available space is not at a premium; size, weight and CofG budgets will not be limited during the design. Hence the attaching structural members shall be designed to be rigid enough to reproduce the location of the turbulator within the location error budget required. This requirement takes into account the initial small adjustments provided by fastener clearances. However, a linear degree of freedom of ±5 mm. along the optical axis shall be provided for focusing purposes.

7.2 Turbulator to Calibration Unit Motion Clearance

When the turbulator is installed in Altair, the calibration unit must be left in its park position. Although the two devices cannot physically collide, the fibre optic cables attached to the calibration unit can touch the turbulator during motion. If they were to become caught on the turbulator, damage to the fibres could result.

7.3 Control Software

There are two aspects involved in the control of the turbulator.

The light source status

Discrete ON – OFF commands will control the power supplied to each LED in the light source assembly. It may also be desirable to adjust the intensity of these sources.

The Phase Screen rotation

To control of the variable speed rotation of the disk(s), each motor shall be equipped with encoder feedback.

7.4 Turbulator Mechanics to Electronics

All wiring for the light sources, motor power, encoder signals and proximity sensors will be strain relieved on the turbulator, and attached to mounting blocks that are provided. This wiring bundle will exit the instrument enclosure through a light-tight grommet which is to be determined.

8 Design Description

8.1 Overall Design

The overall design of the turbulator includes 2 optical barrels which contain the collimator and imager optics, an assembly to mount and rotate the 2 phase screens, and a mounting structure.

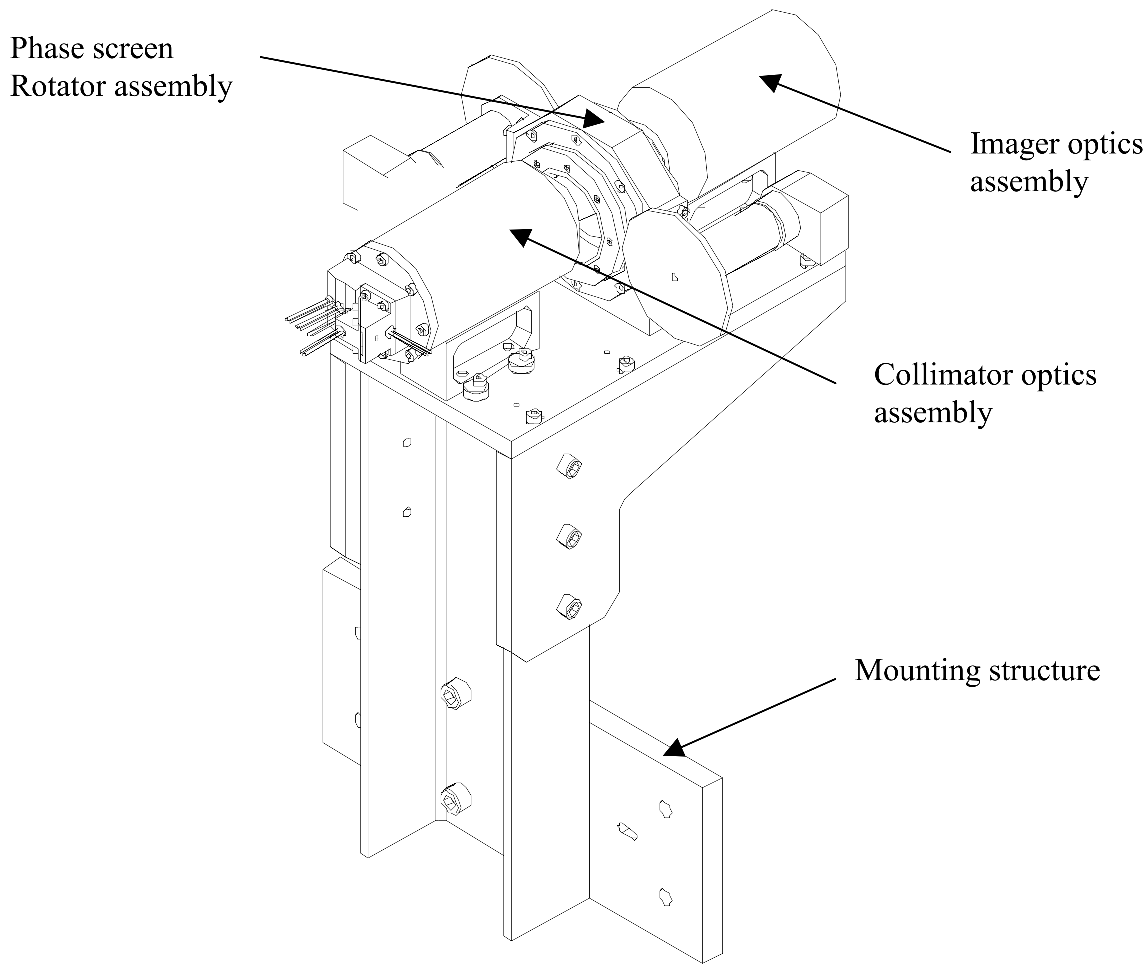

Figure 1: Overall view of turbulator

8.2 Phase Screen Rotator

The phase screens are mounted in an assembly which is similar in function to the Altair NGS ADC. The screens are attached to bearings, which provide the rotational degree of freedom. The screens are then independently driven by a DC servo motor through an anti-backlash spur gear system.

The motors are MicroMo 2233 coreless DC servos with HEDL5540 encoders attached. The encoders output 500 counts per revolution as well as one index pulse. The gearheads are MicroMo 22/5 (zero-backlash), with a ratio of 29.6:1. The large spur gears, which connect the gearheads to the phase screen rotators, have a gear ratio of 1:1.

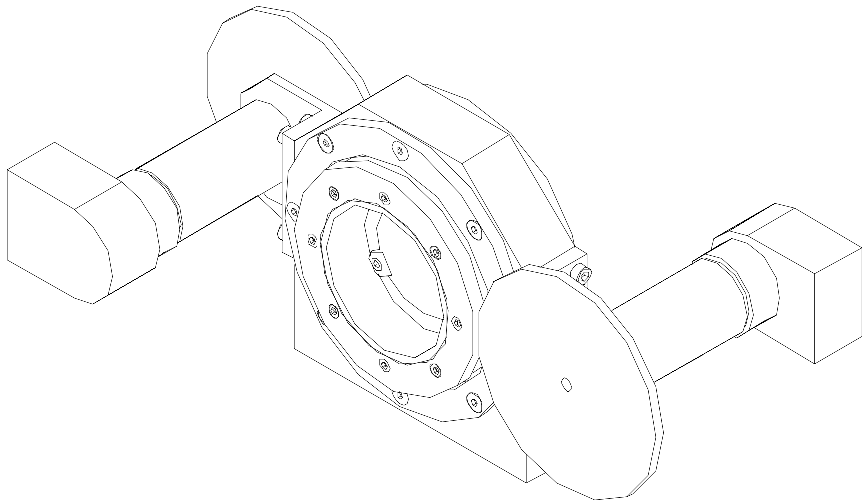

Figure 2: Phase screen rotator assembly

8.3 Source and Collimator Optic Assembly

The collimator optics assembly includes a source housing (with 5 source LED's), collimating optics and a pupil stop. The science source is a single infrared LED (λ=940 nm), which is located on the optical axis (see Appendix A). The guide-star sources are red LED's (λ=650 nm), positioned at 0, 10, 20 and 30 arc-sec off axis. The beams from the infrared LED and the on-axis red LED are combined using a beamsplitter.

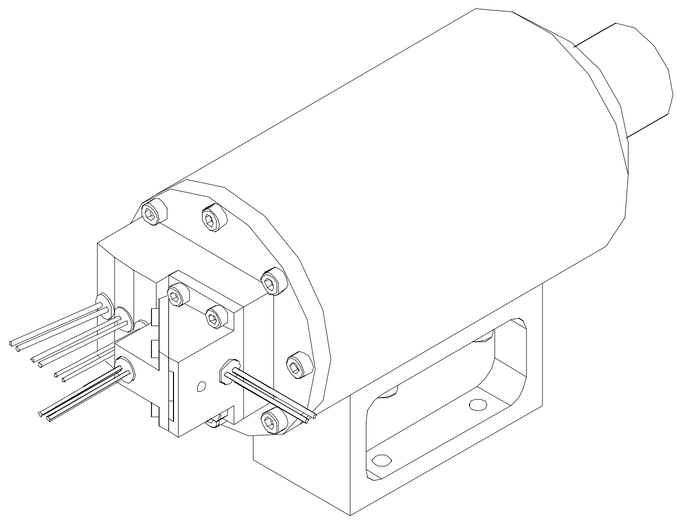

Figure 3: Collimator barrel and source housing

8.4 Imaging Optics Assembly

The imaging optical barrel contains one doublet and one singlet lens. These lenses should be handled very carefully since they are made out of S-FPL53 glass, which is extremely sensitive to shock and thermal gradients.

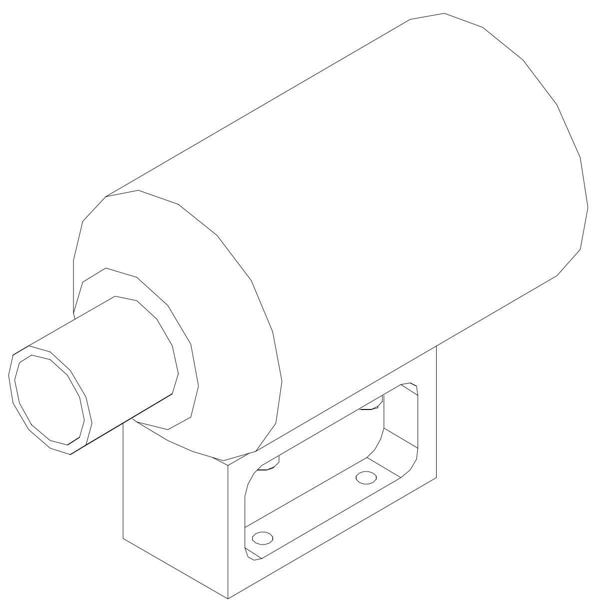

Figure 4: Imager optics assembly

8.5 Mounting System

The mounting system attaches the turbulator optical components to the optical bench of Altair. The point of attachment to the OB includes a “pin and slot” locating interface, to allow for repeatable removal and mounting of the turbulator assembly.

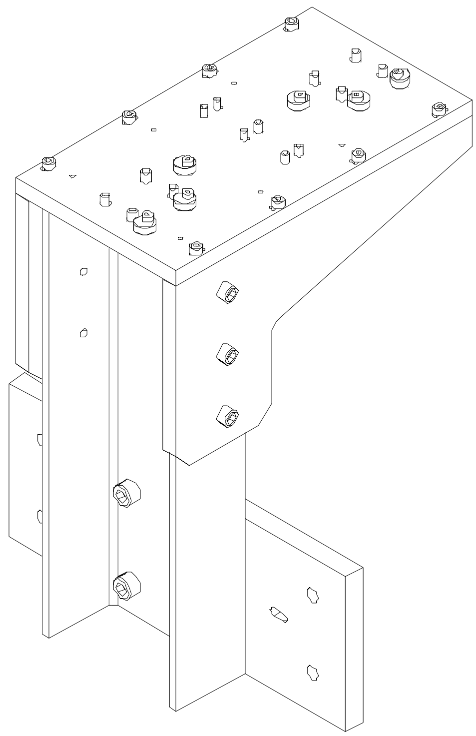

Figure 5: Mounting structure

9 Manufacturing Specifications

To limit the amount of custom fabrication, the design shall utilise purchased, off-the-shelf mechanical, electrical and optical components where possible.

10 Assembly Instructions

10.1 Attaching the Sub-Assemblies

Build the sub-assemblies according to drawings GAD1464, GAD1465 and GAD1466. In order to attach these sub-assemblies to the mounting structure, it is necessary to mount the phase rotator first, then the optical barrels. This is necessary because in order to minimize stray light leakage, the barrels have been designed to extend inside the limits of the phase rotator structure.

Once the barrels are mounted and aligned for the first time, the eccentric buttons should be tightened in place to provide a 3-point locating interface for the barrel assemblies. This allows them to be removed and replaced without further alignment.

10.2 Mounting the completed assembly

The turbulator bolts to the front edge of the OB (nearest to the ISS). Clearance holes and slotted holes have been provided to allow adjustment of the X,Y and focus position of the optical components. This adjustment is necessary to bring the focus position of the pinholes coincident with the input focus of Altair.

10.3 Removal of the Phase Screens

To remove one (or two) of the phase screens, one (or both) of the optical barrels must first be removed. Once the optical barrel is removed, the screen can be accessed through the central hole in the phase rotator. Remove the 3 supports which clamp the screen in its cell, and then remove the screen itself. Once finished, replace the optical barrel(s).

11 Integration and Test Procedures

11.1 Initial optical alignment

The initial I&T work will involve alignment of the 2 optical barrels. The barrels should be mounted on the baseplate, and adjusted until acceptable images are formed at the correct focal position. The eccentric buttons should then be tightened in place to preserve the alignment in case the barrel assemblies need to be removed.

11.2 Control of the phase rotator assembly

The phase rotator needs to be checked for accurate velocity control. The encoder feedback can be used to calculate the disk angular velocity. The control electronics and/or software is then adjusted until the velocity is within specification.

11.3 Final alignment

Once the optics are mounted on the support structure, and the support structure is mounted on the OB, the final optical alignment must be checked. If the focus position requires movement, clearance holes in the mounting components can be used to adjust the X and Y field position. Slotted holes have been provided in the baseplate supporting the optical assembly for final focus adjustment.

12 Maintenance

Since the turbulator will only be used during the initial integration and test phase of Altair, no routine maintenance will be required.

13 Safety Issues

none

14 Additional Equipment

none

15 Appendix A