



ISHELL TECHNICAL NOTE

GENERAL ALIGNMENT STRATEGY

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1 Introduction / Document Purpose

The purpose of this document is to roughly identify a first order alignment strategy for ISHELL and to clarify some of the more important details of that alignment strategy. The document is not meant to be a fully detailed “Optical Alignment Plan”, but simply a first order concept and an indicator as to what might be included in the final procedure.

2 Brief Summary of the Alignment Process

In very general terms, the alignment procedure would be as follows:

- Fabrication of the optical bench and all of the individual mounting fixtures to basic precision machine shop tolerances. Use of standard machine shop methods to achieve such tolerances (i.e. multiple machined surfaces from single set ups and some assembly before final machining) are anticipated.
- Use a standard coordinate measurement machine (CMM), or appropriate metrology equipment to probe optical element contact points for some of the more critical elements. A final machining process would ensue, based on the results of this metrology process.
- LASER ALIGNMENT I(a) – Adjustment of the alignment of all of the mirror elements along the optical path from the instrument entrance through to the slit viewer detector (tip/tilt of the elements only considered).
- LASER ALIGNMENT I(b) – Adjustment of the alignment of all of the fiducials required to for the mounting of the image rotator and the mounting of the lens barrels in the foreoptics (decentration from the nominal defined laser axis only considered).
- Internal alignment of the image rotator to its mounting fiducials. This would be a “stand alone” operation performed on an optical bench, separate from the rest of the instrument. It would be performed warm, and would include alignment of its internal elements to the axis defined by the mechanism’s bearings as well as the mechanism’s mounting fiducials.
- Internally mount the individual lenses within their barrels. The internal lens alignment is performed with respect to the barrel mounting fiducials. This would be a “stand alone” operation performed on an optical bench, possibly on a rotary stage. This procedure would be performed at room temperature.
- LASER ALIGNMENT II – Final mounting and alignment of the image rotator and lens barrels onto the optical bench. The existing laser path is utilized to mount the partially assembled image rotator and lens barrels onto the optical bench to the desired angular and decentration tolerances.
- Final instrument alignment onto the telescope. The instrument is mounted on the telescope and the “one time adjustable” shims are machined based on images taken with the pupil viewer (tip/tilt of the instrument is fine tuned)

All tolerances that need to be met by the initial alignment procedures are established in the document:

ISHELL TECHNICAL NOTE: Optical Error Budget – Final derivation.

A table summarizing these tolerances is given in Appendix A.

3 Alignment Process Details

3.1 Step 1: Initial Fabrication

The initial design and fabrication of the optical bench can be performed in such a way as to meet several of the tolerances required. In particular, many of the locational tolerances (non angular) can be established with standard shop practices to within 0.075 mm (the most likely minimal tolerance for three elements attached to each other with 0.025 mm fabrication tolerance on each element).

It may be possible to perform some of the final machining processes in a single set up in order to achieve this but the optical bench has been specifically designed to allow for this (i.e. the optical bench is easily machined from either side). In some cases, an assembly and “pinning” operation may be performed prior to the final machine process. This would allow for the removal of associated tolerance stack-up for the assembly.

During the initial fabrication, it will be necessary to machine several fiducials into the optical bench in order to facilitate repeatably installing the laser alignment system. These may be as simple as several surfaces that can be used as references, or possibly even “bored features” on the edges of the bench itself that can be easily sealed later. The entrance and exit port for the telescope light path would be excellent candidates for several of these fiducials. These fiducials must have excellent surface finish, be extremely repeatable.

3.2 Step 2: Assembly and Fabrication check with CMM

The locations of all of the relevant optical registration surfaces with respect to the actual fiducials located on the optical bench can then be refined through the use on a coordinate measuring machine (CMM). This will allow the tolerances on the optical element registration surfaces to be reduced from the “several thousands of an inch” regime to the “sub thousands of an inch” level.

Coordinate measuring machines are fairly common in machine industry these days, and several options are available. We could purchase our own dedicated machine, we could use one of several available at other IFA facilities, or we could approach a commercial machine shop to have them do the work required.

The CMM's are ideal for confirming tolerances over long distance, but will be of limited use when attempting to establish some of the tighter angular tolerances required. This is simply due to the fact the hard point locations used to register an optical element are not separated by a large enough distance to ensure the angles required can be established.

Two different methods of final machining the optical registration surfaces can be used and which method is chosen can be catered to the requirements of the individual elements themselves. The first method would be to final machine the seat for the optical element itself based on the measurements gathered from the CMM. The second method would be to machine some form of shim that is utilized between the element mount, and the optical bench.

The following table indicates all of the tolerances that can be met with the procedures established above.

ASSEMBLY TOLERANCES - POST CMM ALIGNMENT		
INSTRUMENT WINDOW	THIRD FOLD MIRROR	SV COLLIMATOR LENS BARREL
+/- 0.0184 deg tilt about X	+/- 0.153 mm despadding along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.0184 deg tilt about Y	+/- 0.031 deg tilt about X	+/- 0.122 deg tilt in X of barrel
	+/- 0.031 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
INSTRUMENT FLEXURE (about CofG)		+/- 0.061 mm decentration in X of barrel
+/- 0.122 mm decentration in X	LENS BARREL	+/- 0.061 mm decentration in Y of barrel
+/- 0.122 mm decentration in Y	+/- 0.153 mm translation along barrel axis	FIRST LENS (BAF2) mounting
+/- 0.012 deg tilt about X	+/- 0.122 deg tilt in X of barrel	+/- 0.061 mm despadding along element axis
+/- 0.012 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel	+/- 0.061 deg tilt about X
+/- 0.031 deg rotation about Z	+/- 0.153 mm decentration in X of barrel	+/- 0.061 deg tilt about Y
+/- 0.306 mm despadding along Z	+/- 0.153 mm decentration in Y of barrel	+/- 0.061 mm decentration in X
	FIRST LENS (BAF2) mounting	+/- 0.061 mm decentration in Y
FIRST FOLD MIRROR	+/- 0.061 mm despadding along element axis	SECOND LENS (LIF) mounting
+/- 0.122 mm despadding along element axis	+/- 0.061 deg tilt about X	+/- 0.061 mm despadding along element axis
+/- 0.012 deg tilt about X	+/- 0.061 deg tilt about Y	+/- 0.061 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in X	+/- 0.061 deg tilt about Y
	+/- 0.061 mm decentration in Y	+/- 0.061 mm decentration in X
COLLIMATOR MIRROR	SECOND LENS (LIF) mounting	+/- 0.061 mm decentration in Y
+/- 0.122 mm despadding along element axis	+/- 0.061 mm despadding along element axis	
+/- 0.031 mm decentration in X	+/- 0.061 deg tilt about X	FILTER
+/- 0.031 mm decentration in Y	+/- 0.061 deg tilt about Y	+/- 0.153 mm despadding along element axis
+/- 0.012 deg tilt about X	+/- 0.061 mm decentration in X	+/- 0.122 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in Y	+/- 0.122 deg tilt about Y
SECOND FOLD MIRROR	FOURTH FOLD MIRROR	SV CAMERA LENS BARREL
+/- 0.031 mm despadding along element axis	+/- 0.153 mm despadding along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.031 deg tilt about X	+/- 0.024 deg tilt about X	+/- 0.122 deg tilt in X of barrel
+/- 0.031 deg tilt about Y	+/- 0.024 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
		+/- 0.153 mm decentration in X of barrel
		+/- 0.153 mm decentration in Y of barrel
IMAGE ROTATOR MECHANISM	SLIT	FIRST LENS (LIF) mounting
+/- 0.153 mm translation along bearing axis	+/- 0.024 deg tilt about X	+/- 0.061 mm despadding along element axis
+/- 0.061 deg tilt in X of mechanism	+/- 0.024 deg tilt about Y	+/- 0.061 deg tilt about X
+/- 0.061 deg tilt in Y of mechanism		+/- 0.061 deg tilt about Y
+/- 0.153 mm decentration in X of mechanism	FIFTH FOLD MIRROR	+/- 0.061 mm decentration in X
+/- 0.153 mm decentration in Y of mechanism	+/- 0.153 mm despadding along element axis	+/- 0.061 mm decentration in Y
IMAGE ROTATOR F1	+/- 0.024 deg tilt about X	SECOND LENS (BAF2) mounting
+/- 0.061 mm despadding along element axis	+/- 0.024 deg tilt about Y	+/- 0.061 mm despadding along element axis
+/- 0.031 deg tilt about X		+/- 0.061 deg tilt about X
+/- 0.031 deg tilt about Y		+/- 0.061 deg tilt about Y
IMAGE ROTATOR F2		+/- 0.061 mm decentration in X
+/- 0.061 mm despadding along element axis		+/- 0.061 mm decentration in Y
+/- 0.031 deg tilt about X		
+/- 0.031 deg tilt about Y		
IMAGE ROTATOR F3		
+/- 0.061 mm despadding along element axis	Indicate Tolerances that have been established by the CMM alignment procedures	
+/- 0.031 deg tilt about X		
+/- 0.031 deg tilt about Y		

Note that the highlighted elements are all registered in X, Y, and Z but still require alignment in Rx, Ry, and Rz.

3.3 Step 3: Laser Alignment I(a) – Mirror Element Alignment

Once elements are located in their mounts, it becomes possible to refine their angular tolerances based upon information garnished from an alignment laser. Essentially, a laser is utilized in order to establish the correct alignment angle for each of the elements along the optical path. A repeatable mounting of the laser first needs to be established, and then sequentially, each element along the optical path is adjusted into its final alignment.

Details of the full procedure are specified in the following document:

ISHELL TECHNICAL DOCUMENT: Preliminary Alignment Plan – Laser Alignment I.

The following table indicates the tolerances that can be met with the Laser Alignment I procedures.

ASSEMBLY TOLERANCES - POST LASER I ALIGNMENT		
INSTRUMENT WINDOW	THIRD FOLD MIRROR	SV COLLIMATOR LENS BARREL
+/- 0.0184 deg tilt about X	+/- 0.153 mm despadding along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.0184 deg tilt about Y	+/- 0.031 deg tilt about X	+/- 0.122 deg tilt in X of barrel
	+/- 0.031 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
INSTRUMENT FLEXURE (about CofG)		+/- 0.061 mm decentration in X of barrel
+/- 0.122 mm decentration in X	LENS BARREL	+/- 0.061 mm decentration in Y of barrel
+/- 0.122 mm decentration in Y	+/- 0.153 mm translation along barrel axis	FIRST LENS (BAF2) mounting
+/- 0.012 deg tilt about X	+/- 0.122 deg tilt in X of barrel	+/- 0.061 mm despadding along element axis
+/- 0.012 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel	+/- 0.061 deg tilt about X
+/- 0.031 deg rotation about Z	+/- 0.153 mm decentration in X of barrel	+/- 0.061 deg tilt about Y
+/- 0.306 mm despadding along Z	+/- 0.153 mm decentration in Y of barrel	+/- 0.061 mm decentration in X
	FIRST LENS (BAF2) mounting	+/- 0.061 mm decentration in Y
FIRST FOLD MIRROR	+/- 0.061 mm despadding along element axis	SECOND LENS (LIF) mounting
+/- 0.122 mm despadding along element axis	+/- 0.061 deg tilt about X	+/- 0.061 mm despadding along element axis
+/- 0.012 deg tilt about X	+/- 0.061 deg tilt about Y	+/- 0.061 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in X	+/- 0.061 deg tilt about Y
	+/- 0.061 mm decentration in Y	+/- 0.061 mm decentration in X
COLLIMATOR MIRROR	SECOND LENS (LIF) mounting	+/- 0.061 mm decentration in Y
+/- 0.122 mm despadding along element axis	+/- 0.061 mm despadding along element axis	
+/- 0.031 mm decentration in X	+/- 0.061 deg tilt about X	FILTER
+/- 0.031 mm decentration in Y	+/- 0.061 deg tilt about Y	+/- 0.153 mm despadding along element axis
+/- 0.012 deg tilt about X	+/- 0.061 mm decentration in X	+/- 0.122 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in Y	+/- 0.122 deg tilt about Y
	FOURTH FOLD MIRROR	SV CAMERA LENS BARREL
SECOND FOLD MIRROR	+/- 0.153 mm despadding along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.031 mm despadding along element axis	+/- 0.024 deg tilt about X	+/- 0.122 deg tilt in X of barrel
+/- 0.031 deg tilt about X	+/- 0.024 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
+/- 0.031 deg tilt about Y		+/- 0.153 mm decentration in X of barrel
		+/- 0.153 mm decentration in Y of barrel
IMAGE ROTATOR MECHANISM	SLIT	FIRST LENS (LIF) mounting
+/- 0.153 mm translation along bearing axis	+/- 0.024 deg tilt about X	+/- 0.061 mm despadding along element axis
+/- 0.061 deg tilt in X of mechanism	+/- 0.024 deg tilt about Y	+/- 0.061 deg tilt about X
+/- 0.061 deg tilt in Y of mechanism		+/- 0.061 deg tilt about Y
+/- 0.153 mm decentration in X of mechanism	FIFTH FOLD MIRROR	+/- 0.061 mm decentration in X
+/- 0.153 mm decentration in Y of mechanism	+/- 0.153 mm despadding along element axis	+/- 0.061 mm decentration in Y
IMAGE ROTATOR F1	+/- 0.024 deg tilt about X	SECOND LENS (BAF2) mounting
+/- 0.061 mm despadding along element axis	+/- 0.024 deg tilt about Y	+/- 0.061 mm despadding along element axis
+/- 0.031 deg tilt about X		+/- 0.061 deg tilt about X
+/- 0.031 deg tilt about Y		+/- 0.061 deg tilt about Y
IMAGE ROTATOR F2		+/- 0.061 mm decentration in X
+/- 0.061 mm despadding along element axis		+/- 0.061 mm decentration in Y
+/- 0.031 deg tilt about X		
+/- 0.031 deg tilt about Y		
IMAGE ROTATOR F3	Indicate Tolerances that have been established by the LASER I - alignment procedures	
+/- 0.061 mm despadding along element axis	Indicate Tolerances that have been established by the previous alignment procedures	
+/- 0.031 deg tilt about X		
+/- 0.031 deg tilt about Y		

3.4 Step 4: Laser Alignment I(b) – Refinement of Fiducial Alignment

Once the laser axis has been aligned through the instrument all the way to the detector(s), it will then be possible to use the laser for refinement of the fiducials used for locating some of the more complex mechanisms (i.e. the image rotator, or the assembled lens barrels). Use of a previously calibrated CCD mounted in an appropriate jig will allow for the determination of any adjustments (or final machining) required for these mounts. Note that only decentration tolerances can be refined with this procedure as opposed to angular tolerances or tolerances parallel to the optical path.

3.5 Step 5: Internal Image Rotator Alignment

The three mirror elements, the mechanism bearings, and the mounting fiducials of the image rotator mechanism can all be independently aligned, prior to installation onto the optical bench.

The details of this procedure are defined in the following document:

ISHELL TECHNICAL NOTE: Preliminary Alignment Plan – Image Rotator.

The following table indicates the tolerances that can be met with the internal image rotator alignment procedures.

ASSEMBLY TOLERANCES - POST IMAGE ROTATOR ALIGNMENT		
INSTRUMENT WINDOW	THIRD FOLD MIRROR	SV COLLIMATOR LENS BARREL
+/- 0.0184 deg tilt about X	+/- 0.153 mm despadding along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.0184 deg tilt about Y	+/- 0.031 deg tilt about X	+/- 0.122 deg tilt in X of barrel
	+/- 0.031 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
INSTRUMENT FLEXURE (about CofG)		+/- 0.061 mm decentration in X of barrel
+/- 0.122 mm decentration in X	LENS BARREL	+/- 0.061 mm decentration in Y of barrel
+/- 0.122 mm decentration in Y	+/- 0.153 mm translation along barrel axis	FIRST LENS (BAF2) mounting
+/- 0.012 deg tilt about X	+/- 0.122 deg tilt in X of barrel	+/- 0.061 mm despadding along element axis
+/- 0.012 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel	+/- 0.061 deg tilt about X
+/- 0.031 deg rotation about Z	+/- 0.153 mm decentration in X of barrel	+/- 0.061 deg tilt about Y
+/- 0.306 mm despadding along Z	+/- 0.153 mm decentration in Y of barrel	+/- 0.061 mm decentration in X
	FIRST LENS (BAF2) mounting	+/- 0.061 mm decentration in Y
FIRST FOLD MIRROR	+/- 0.061 mm despadding along element axis	SECOND LENS (LIF) mounting
+/- 0.122 mm despadding along element axis	+/- 0.061 deg tilt about X	+/- 0.061 mm despadding along element axis
+/- 0.012 deg tilt about X	+/- 0.061 deg tilt about Y	+/- 0.061 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in X	+/- 0.061 deg tilt about Y
	+/- 0.061 mm decentration in Y	+/- 0.061 mm decentration in X
COLLIMATOR MIRROR	SECOND LENS (LIF) mounting	+/- 0.061 mm decentration in Y
+/- 0.122 mm despadding along element axis	+/- 0.061 mm despadding along element axis	
+/- 0.031 mm decentration in X	+/- 0.061 deg tilt about X	FILTER
+/- 0.031 mm decentration in Y	+/- 0.061 deg tilt about Y	+/- 0.153 mm despadding along element axis
+/- 0.012 deg tilt about X	+/- 0.061 mm decentration in X	+/- 0.122 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in Y	+/- 0.122 deg tilt about Y
SECOND FOLD MIRROR	FOURTH FOLD MIRROR	SV CAMERA LENS BARREL
+/- 0.031 mm despadding along element axis	+/- 0.153 mm despadding along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.031 deg tilt about X	+/- 0.024 deg tilt about X	+/- 0.122 deg tilt in X of barrel
+/- 0.031 deg tilt about Y	+/- 0.024 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
		+/- 0.153 mm decentration in X of barrel
IMAGE ROTATOR MECHANISM	SLIT	+/- 0.153 mm decentration in Y of barrel
+/- 0.153 mm translation along bearing axis	+/- 0.024 deg tilt about X	FIRST LENS (LIF) mounting
+/- 0.061 deg tilt in X of mechanism	+/- 0.024 deg tilt about Y	+/- 0.061 mm despadding along element axis
+/- 0.061 deg tilt in Y of mechanism		+/- 0.061 deg tilt about X
+/- 0.153 mm decentration in X of mechanism	FIFTH FOLD MIRROR	+/- 0.061 deg tilt about Y
+/- 0.153 mm decentration in Y of mechanism	+/- 0.153 mm despadding along element axis	+/- 0.061 mm decentration in X
IMAGE ROTATOR F1	+/- 0.024 deg tilt about X	+/- 0.061 mm decentration in Y
+/- 0.061 mm despadding along element axis	+/- 0.024 deg tilt about Y	SECOND LENS (BAF2) mounting
+/- 0.031 deg tilt about X		+/- 0.061 mm despadding along element axis
+/- 0.031 deg tilt about Y		+/- 0.061 deg tilt about X
IMAGE ROTATOR F2		+/- 0.061 deg tilt about Y
+/- 0.061 mm despadding along element axis		+/- 0.061 mm decentration in X
+/- 0.031 deg tilt about X		+/- 0.061 mm decentration in Y
+/- 0.031 deg tilt about Y		
IMAGE ROTATOR F3	Indicate Tolerances that have been established by the IMAGE ROTATOR - alignment procedures	
+/- 0.061 mm despadding along element axis	Indicate Tolerances that have been established by the previous alignment procedures	
+/- 0.031 deg tilt about X		
+/- 0.031 deg tilt about Y		

3.6 Step 6: Internal Lens Barrel Alignment

The individual lenses mounted within the lens barrels can be aligned to their much tighter “internal” tolerances prior to installation onto the optical bench. This process would also align the lenses to the mounting fiducials on the barrel, and would be performed warm.

The details of this procedure are defined in the following document:

ISHELL TECHNICAL NOTE: Preliminary Alignment Plan – Lens Barrels.

The following table indicates the tolerances that can be met with the internal lens barrel alignment procedures.

ASSEMBLY TOLERANCES - POST LENS BARREL ALIGNMENT		
INSTRUMENT WINDOW	THIRD FOLD MIRROR	SV COLLIMATOR LENS BARREL
+/- 0.0184 deg tilt about X	+/- 0.153 mm despadding along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.0184 deg tilt about Y	+/- 0.031 deg tilt about X	+/- 0.122 deg tilt in X of barrel
	+/- 0.031 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
INSTRUMENT FLEXURE (about CofG)		+/- 0.061 mm decentration in X of barrel
+/- 0.122 mm decentration in X	LENS BARREL	+/- 0.061 mm decentration in Y of barrel
+/- 0.122 mm decentration in Y	+/- 0.153 mm translation along barrel axis	FIRST LENS (BAF2) mounting
+/- 0.012 deg tilt about X	+/- 0.122 deg tilt in X of barrel	+/- 0.061 mm despadding along element axis
+/- 0.012 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel	+/- 0.061 deg tilt about X
+/- 0.031 deg rotation about Z	+/- 0.153 mm decentration in X of barrel	+/- 0.061 deg tilt about Y
+/- 0.306 mm despadding along Z	+/- 0.153 mm decentration in Y of barrel	+/- 0.061 mm decentration in X
	FIRST LENS (BAF2) mounting	+/- 0.061 mm decentration in Y
FIRST FOLD MIRROR	+/- 0.061 mm despadding along element axis	SECOND LENS (LIF) mounting
+/- 0.122 mm despadding along element axis	+/- 0.061 deg tilt about X	+/- 0.061 mm despadding along element axis
+/- 0.012 deg tilt about X	+/- 0.061 deg tilt about Y	+/- 0.061 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in X	+/- 0.061 deg tilt about Y
	+/- 0.061 mm decentration in Y	+/- 0.061 mm decentration in X
COLLIMATOR MIRROR	SECOND LENS (LIF) mounting	+/- 0.061 mm decentration in Y
+/- 0.122 mm despadding along element axis	+/- 0.061 mm despadding along element axis	
+/- 0.031 mm decentration in X	+/- 0.061 deg tilt about X	FILTER
+/- 0.031 mm decentration in Y	+/- 0.061 deg tilt about Y	+/- 0.153 mm despadding along element axis
+/- 0.012 deg tilt about X	+/- 0.061 mm decentration in X	+/- 0.122 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in Y	+/- 0.122 deg tilt about Y
SECOND FOLD MIRROR	FOURTH FOLD MIRROR	SV CAMERA LENS BARREL
+/- 0.031 mm despadding along element axis	+/- 0.153 mm despadding along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.031 deg tilt about X	+/- 0.024 deg tilt about X	+/- 0.122 deg tilt in X of barrel
+/- 0.031 deg tilt about Y	+/- 0.024 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
		+/- 0.153 mm decentration in X of barrel
IMAGE ROTATOR MECHANISM	SLIT	+/- 0.153 mm decentration in Y of barrel
+/- 0.153 mm translation along bearing axis	+/- 0.024 deg tilt about X	FIRST LENS (LIF) mounting
+/- 0.061 deg tilt in X of mechanism	+/- 0.024 deg tilt about Y	+/- 0.061 mm despadding along element axis
+/- 0.061 deg tilt in Y of mechanism		+/- 0.061 deg tilt about X
+/- 0.153 mm decentration in X of mechanism	FIFTH FOLD MIRROR	+/- 0.061 deg tilt about Y
+/- 0.153 mm decentration in Y of mechanism	+/- 0.153 mm despadding along element axis	+/- 0.061 mm decentration in X
IMAGE ROTATOR F1	+/- 0.024 deg tilt about X	+/- 0.061 mm decentration in Y
+/- 0.061 mm despadding along element axis	+/- 0.024 deg tilt about Y	SECOND LENS (BAF2) mounting
+/- 0.031 deg tilt about X		+/- 0.061 mm despadding along element axis
+/- 0.031 deg tilt about Y		+/- 0.061 deg tilt about X
IMAGE ROTATOR F2		+/- 0.061 deg tilt about Y
+/- 0.061 mm despadding along element axis		+/- 0.061 mm decentration in X
+/- 0.031 deg tilt about X		+/- 0.061 mm decentration in Y
+/- 0.031 deg tilt about Y		
IMAGE ROTATOR F3	Indicate Tolerances that have been established by the LENS BARREL - alignment procedures	
+/- 0.061 mm despadding along element axis	Indicate Tolerances that have been established by the previous alignment procedures	
+/- 0.031 deg tilt about X		
+/- 0.031 deg tilt about Y		

3.7 Step 7: Laser Alignment II – Image Rotator and Lens Barrel Mounting

Once the image rotator and the lens barrels are all internally aligned, final assembly onto the optical bench may proceed. In the case of the image rotator, direct assembly onto the bench is possible as the alignment laser can still be passed through the mechanism. In the case of the lens barrels, each must be installed sequentially, starting from the slit viewing detector and working backwards. Refinements to the barrel tilts will be established based upon reflections from the alignment laser, back through the system.

The details of this procedure are defined in the following document:

ISHELL TECHNICAL NOTE: Preliminary Alignment Plan – Laser Alignment II.

The following table indicates the tolerances that can be met with the procedures in the Laser Alignment II plan.

ASSEMBLY TOLERANCES - POST LASER II ALIGNMENT		
INSTRUMENT WINDOW	THIRD FOLD MIRROR	SV COLLIMATOR LENS BARREL
+/- 0.0184 deg tilt about X	+/- 0.153 mm despadding along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.0184 deg tilt about Y	+/- 0.031 deg tilt about X	+/- 0.122 deg tilt in X of barrel
	+/- 0.031 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
INSTRUMENT FLEXURE (about CofG)		+/- 0.061 mm decentration in X of barrel
+/- 0.122 mm decentration in X	LENS BARREL	+/- 0.061 mm decentration in Y of barrel
+/- 0.122 mm decentration in Y	+/- 0.153 mm translation along barrel axis	FIRST LENS (BAF2) mounting
+/- 0.012 deg tilt about X	+/- 0.122 deg tilt in X of barrel	+/- 0.061 mm despadding along element axis
+/- 0.012 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel	+/- 0.061 deg tilt about X
+/- 0.031 deg rotation about Z	+/- 0.153 mm decentration in X of barrel	+/- 0.061 deg tilt about Y
+/- 0.306 mm despadding along Z	+/- 0.153 mm decentration in Y of barrel	+/- 0.061 mm decentration in X
	FIRST LENS (BAF2) mounting	+/- 0.061 mm decentration in Y
FIRST FOLD MIRROR	+/- 0.061 mm despadding along element axis	SECOND LENS (LIF) mounting
+/- 0.122 mm despadding along element axis	+/- 0.061 deg tilt about X	+/- 0.061 mm despadding along element axis
+/- 0.012 deg tilt about X	+/- 0.061 deg tilt about Y	+/- 0.061 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in X	+/- 0.061 deg tilt about Y
	+/- 0.061 mm decentration in Y	+/- 0.061 mm decentration in X
COLLIMATOR MIRROR	SECOND LENS (LIF) mounting	+/- 0.061 mm decentration in Y
+/- 0.122 mm despadding along element axis	+/- 0.061 mm despadding along element axis	
+/- 0.031 mm decentration in X	+/- 0.061 deg tilt about X	FILTER
+/- 0.031 mm decentration in Y	+/- 0.061 deg tilt about Y	+/- 0.153 mm despadding along element axis
+/- 0.012 deg tilt about X	+/- 0.061 mm decentration in X	+/- 0.122 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in Y	+/- 0.122 deg tilt about Y
SECOND FOLD MIRROR	FOURTH FOLD MIRROR	SV CAMERA LENS BARREL
+/- 0.031 mm despadding along element axis	+/- 0.153 mm despadding along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.031 deg tilt about X	+/- 0.024 deg tilt about X	+/- 0.122 deg tilt in X of barrel
+/- 0.031 deg tilt about Y	+/- 0.024 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
IMAGE ROTATOR MECHANISM	SLIT	+/- 0.153 mm decentration in X of barrel
+/- 0.153 mm translation along bearing axis	+/- 0.024 deg tilt about X	+/- 0.153 mm decentration in Y of barrel
+/- 0.061 deg tilt in X of mechanism	+/- 0.024 deg tilt about Y	FIRST LENS (LIF) mounting
+/- 0.061 deg tilt in Y of mechanism		+/- 0.061 mm despadding along element axis
+/- 0.153 mm decentration in X of mechanism	FIFTH FOLD MIRROR	+/- 0.061 deg tilt about X
+/- 0.153 mm decentration in Y of mechanism	+/- 0.153 mm despadding along element axis	+/- 0.061 deg tilt about Y
IMAGE ROTATOR F1	+/- 0.024 deg tilt about X	+/- 0.061 mm decentration in X
+/- 0.061 mm despadding along element axis	+/- 0.024 deg tilt about Y	+/- 0.061 mm decentration in Y
+/- 0.031 deg tilt about X		SECOND LENS (BAF2) mounting
+/- 0.031 deg tilt about Y		+/- 0.061 mm despadding along element axis
IMAGE ROTATOR F2		+/- 0.061 deg tilt about X
+/- 0.061 mm despadding along element axis		+/- 0.061 deg tilt about Y
+/- 0.031 deg tilt about X		+/- 0.061 mm decentration in X
+/- 0.031 deg tilt about Y		+/- 0.061 mm decentration in Y
IMAGE ROTATOR F3		
+/- 0.061 mm despadding along element axis	Indicate Tolerances that have been established by the LASER II - alignment procedures	
+/- 0.031 deg tilt about X	Indicate Tolerances that have been established by the previous alignment procedures	
+/- 0.031 deg tilt about Y		

3.8 Step 8: Instrument Mounting Procedures

During the final mounting of the optical bench within the cryostat jacket, and the mounting of the instrument onto the telescope, the remaining final alignment tolerances are met. The decentration and axial despacing (focus) of the instrument are fairly loose tolerances, and can easily be met with general fabrication methods; however the tip and tilt of the instrument are fairly tight and need to be addressed in a separate procedure.

Once the instrument is on the telescope, the final tipping and tilting adjustments can be made to the instrument with information gathered from the pupil viewer. The telescope must first be carefully collimated, and a source near zenith chosen as a target. Any tip or tilt misalignment of the instrument will effectively misalign the cold stop within the instrument with the secondary mirror. It is thus possible to use the pupil viewer to realign the two pupils.

NOTE: NEED MORE THOUGHT REGARDING THE MOUNTING OF THE WINDOW

The following table indicates the tolerances that can be met with the procedures established above.

ASSEMBLY TOLERANCES - POST INSTRUMENT MOUNTING		
INSTRUMENT WINDOW	THIRD FOLD MIRROR	SV COLLIMATOR LENS BARREL
+/- 0.0184 deg tilt about X	+/- 0.153 mm despacing along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.0184 deg tilt about Y	+/- 0.031 deg tilt about X	+/- 0.122 deg tilt in X of barrel
	+/- 0.031 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
INSTRUMENT FLEXURE (about CofG)		+/- 0.061 mm decentration in X of barrel
+/- 0.122 mm decentration in X	LENS BARREL	+/- 0.061 mm decentration in Y of barrel
+/- 0.122 mm decentration in Y	+/- 0.153 mm translation along barrel axis	FIRST LENS (BAF2) mounting
+/- 0.012 deg tilt about X	+/- 0.122 deg tilt in X of barrel	+/- 0.061 mm despacing along element axis
+/- 0.012 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel	+/- 0.061 deg tilt about X
+/- 0.031 deg rotation about Z	+/- 0.153 mm decentration in X of barrel	+/- 0.061 deg tilt about Y
+/- 0.306 mm despacing along Z	+/- 0.153 mm decentration in Y of barrel	+/- 0.061 mm decentration in X
	FIRST LENS (BAF2) mounting	+/- 0.061 mm decentration in Y
FIRST FOLD MIRROR	+/- 0.061 mm despacing along element axis	SECOND LENS (LIF) mounting
+/- 0.122 mm despacing along element axis	+/- 0.061 deg tilt about X	+/- 0.061 mm despacing along element axis
+/- 0.012 deg tilt about X	+/- 0.061 deg tilt about Y	+/- 0.061 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in X	+/- 0.061 deg tilt about Y
	+/- 0.061 mm decentration in Y	+/- 0.061 mm decentration in X
COLLIMATOR MIRROR	SECOND LENS (LIF) mounting	+/- 0.061 mm decentration in Y
+/- 0.122 mm despacing along element axis	+/- 0.061 mm despacing along element axis	
+/- 0.031 mm decentration in X	+/- 0.061 deg tilt about X	FILTER
+/- 0.031 mm decentration in Y	+/- 0.061 deg tilt about Y	+/- 0.153 mm despacing along element axis
+/- 0.012 deg tilt about X	+/- 0.061 mm decentration in X	+/- 0.122 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in Y	+/- 0.122 deg tilt about Y
SECOND FOLD MIRROR	FOURTH FOLD MIRROR	SV CAMERA LENS BARREL
+/- 0.031 mm despacing along element axis	+/- 0.153 mm despacing along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.031 deg tilt about X	+/- 0.024 deg tilt about X	+/- 0.122 deg tilt in X of barrel
+/- 0.031 deg tilt about Y	+/- 0.024 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
		+/- 0.153 mm decentration in X of barrel
IMAGE ROTATOR MECHANISM	SLIT	+/- 0.153 mm decentration in Y of barrel
+/- 0.153 mm translation along bearing axis	+/- 0.024 deg tilt about X	FIRST LENS (LIF) mounting
+/- 0.061 deg tilt in X of mechanism	+/- 0.024 deg tilt about Y	+/- 0.061 mm despacing along element axis
+/- 0.061 deg tilt in Y of mechanism		+/- 0.061 deg tilt about X
+/- 0.153 mm decentration in X of mechanism	FIFTH FOLD MIRROR	+/- 0.061 deg tilt about Y
+/- 0.153 mm decentration in Y of mechanism	+/- 0.153 mm despacing along element axis	+/- 0.061 mm decentration in X
IMAGE ROTATOR F1	+/- 0.024 deg tilt about X	+/- 0.061 mm decentration in Y
+/- 0.061 mm despacing along element axis	+/- 0.024 deg tilt about Y	SECOND LENS (BAF2) mounting
+/- 0.031 deg tilt about X		+/- 0.061 mm despacing along element axis
+/- 0.031 deg tilt about Y		+/- 0.061 deg tilt about X
IMAGE ROTATOR F2		+/- 0.061 deg tilt about Y
+/- 0.061 mm despacing along element axis		+/- 0.061 mm decentration in X
+/- 0.031 deg tilt about X		+/- 0.061 mm decentration in Y
+/- 0.031 deg tilt about Y		
IMAGE ROTATOR F3	Indicate Tolerances that have been established by the INSTRUMENT MOUNTING procedures	
+/- 0.061 mm despacing along element axis	Indicate Tolerances that have been established by the previous alignment procedures	
+/- 0.031 deg tilt about X		
+/- 0.031 deg tilt about Y		

4 Appendix A

Initial assembly alignment tolerances that need to be met:

FINAL COMBINED TOLERANCES - Assembly Misalignment (61.2% of total)		
INSTRUMENT WINDOW	THIRD FOLD MIRROR	SV COLLIMATOR LENS BARREL
+/- 0.0184 deg tilt about X	+/- 0.153 mm despadding along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.0184 deg tilt about Y	+/- 0.031 deg tilt about X	+/- 0.122 deg tilt in X of barrel
	+/- 0.031 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
INSTRUMENT FLEXURE (about CofG)		+/- 0.061 mm decentration in X of barrel
+/- 0.122 mm decentration in X	LENS BARREL	+/- 0.061 mm decentration in Y of barrel
+/- 0.122 mm decentration in Y	+/- 0.153 mm translation along barrel axis	FIRST LENS (BAF2) mounting
+/- 0.012 deg tilt about X	+/- 0.122 deg tilt in X of barrel	+/- 0.061 mm despadding along element axis
+/- 0.012 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel	+/- 0.061 deg tilt about X
+/- 0.031 deg rotation about Z	+/- 0.153 mm decentration in X of barrel	+/- 0.061 deg tilt about Y
+/- 0.306 mm despadding along Z	+/- 0.153 mm decentration in Y of barrel	+/- 0.061 mm decentration in X
	FIRST LENS (BAF2) mounting	+/- 0.061 mm decentration in Y
FIRST FOLD MIRROR	+/- 0.061 mm despadding along element axis	SECOND LENS (LIF) mounting
+/- 0.122 mm despadding along element axis	+/- 0.061 deg tilt about X	+/- 0.061 mm despadding along element axis
+/- 0.012 deg tilt about X	+/- 0.061 deg tilt about Y	+/- 0.061 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in X	+/- 0.061 deg tilt about Y
	+/- 0.061 mm decentration in Y	+/- 0.061 mm decentration in X
COLLIMATOR MIRROR	SECOND LENS (LIF) mounting	+/- 0.061 mm decentration in Y
+/- 0.122 mm despadding along element axis	+/- 0.061 mm despadding along element axis	
+/- 0.031 mm decentration in X	+/- 0.061 deg tilt about X	FILTER
+/- 0.031 mm decentration in Y	+/- 0.061 deg tilt about Y	+/- 0.153 mm despadding along element axis
+/- 0.012 deg tilt about X	+/- 0.061 mm decentration in X	+/- 0.122 deg tilt about X
+/- 0.012 deg tilt about Y	+/- 0.061 mm decentration in Y	+/- 0.122 deg tilt about Y
SECOND FOLD MIRROR	FOURTH FOLD MIRROR	SV CAMERA LENS BARREL
+/- 0.031 mm despadding along element axis	+/- 0.153 mm despadding along element axis	+/- 0.153 mm translation along barrel axis
+/- 0.031 deg tilt about X	+/- 0.024 deg tilt about X	+/- 0.122 deg tilt in X of barrel
+/- 0.031 deg tilt about Y	+/- 0.024 deg tilt about Y	+/- 0.122 deg tilt in Y of barrel
		+/- 0.153 mm decentration in X of barrel
IMAGE ROTATOR MECHANISM	SLIT	+/- 0.153 mm decentration in Y of barrel
+/- 0.153 mm translation along bearing axis	+/- 0.024 deg tilt about X	FIRST LENS (LIF) mounting
+/- 0.061 deg tilt in X of mechanism	+/- 0.024 deg tilt about Y	+/- 0.061 mm despadding along element axis
+/- 0.061 deg tilt in Y of mechanism		+/- 0.061 deg tilt about X
+/- 0.153 mm decentration in X of mechanism	FIFTH FOLD MIRROR	+/- 0.061 deg tilt about Y
+/- 0.153 mm decentration in Y of mechanism	+/- 0.153 mm despadding along element axis	+/- 0.061 mm decentration in X
IMAGE ROTATOR F1	+/- 0.024 deg tilt about X	+/- 0.061 mm decentration in Y
+/- 0.061 mm despadding along element axis	+/- 0.024 deg tilt about Y	SECOND LENS (BAF2) mounting
+/- 0.031 deg tilt about X		+/- 0.061 mm despadding along element axis
+/- 0.031 deg tilt about Y		+/- 0.061 deg tilt about X
IMAGE ROTATOR F2		+/- 0.061 deg tilt about Y
+/- 0.061 mm despadding along element axis		+/- 0.061 mm decentration in X
+/- 0.031 deg tilt about X		+/- 0.061 mm decentration in Y
+/- 0.031 deg tilt about Y		
IMAGE ROTATOR F3		
+/- 0.061 mm despadding along element axis		
+/- 0.031 deg tilt about X		
+/- 0.031 deg tilt about Y		