Mechanical design of NESSI: New Mexico Tech Extrasolar Spectroscopic Survey Instrument

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ABSTRACT

NESSI: the **N**ew Mexico Tech **E**xtrasolar **S**pectroscopic **S**urvey **I**nstrument is a ground-based multi-object spectrograph that operates in the near-infrared. It will be installed on one of the Nasmyth ports of the Magdalena Ridge Observatory (MRO) 2.4-meter Telescope. NESSI operates stationary to the telescope fork so as not to produce differential flexure between internal opto-mechanical components during or between observations. In this paper we report on NESSI's detailed mechanical and opto-mechanical design, and the planning for mechanical construction, assembly, integration and verification.

Keywords: Exoplanet survey spectrograph

1. INTRODUCTION

1.1 Background

Spectroscopy of extrasolar planets (or exoplanets) is a relatively new field in astronomy and so far has been more successfully accomplished using space-based platforms [1,2]. As a growing field, there are currently a number of ongoing programs which will be based on both ground and space. Ground-based programs are more attractive due to a number of factors such as the lower cost and the ease of access, operation ability and maintenance. These programs are largely motivated by the possibility of the application of newer exoplanet observation techniques that should allow the accomplishment of ambitious scientific missions from the ground using small aperture telescopes [3]. Hence, the development of low-cost and highly-accessible ground-based instrumentation dedicated to the study of exoplanets has become very attractive to the astronomical community. NESSI: the **N**ew Mexico Tech **E**xtrasolar **S**pectroscopic **S**urvey **I**nstrument was born as a collaboration between the Magdalena Ridge Observatory (MRO) (a department of the New Mexico Institute of Mining and Technology (NMT)) and the NASA Jet Propulsion Laboratory to build a ground-based multi-object spectrograph that operates in the near-infrared (J, H and K-bands) [1]. It will be installed on the Nasmyth 'tine mounting surface' port of the MRO 2.4-meter Telescope sited in the Magdalena Mountains at an altitude of 3230m, about 48km west of Socorro – New Mexico (Figure 1). The telescope is a modified Ritchey-Chrétien alt-azimuth design, capable of tracking targets up to rates of 10°/sec along both elevation and azimuth axes.

Figure 1 – The MRO 2.4-meter Telescope (www.mro.nmt.edu).

NESSI is designed to provide an extremely stiff mechanical support which allows alignment of its optical components to be highly repeatable and stable over short and long observation timescales. A number of scientific fundamental goals were defined and combined with engineering top-level requirements resulting in an appropriate flow-down of technical requirements. The instrument is broken down into two major optical portions called warm optics and cold optics (Figure 2). The warm optics portion is composed of a field lens and field de-rotator, a re-imaging unit which includes a dichroic beamsplitter, and an auto-guider (Figure 3). The cold optics portion is composed of a multi-object mask wheel, collimator assembly, filter wheel, Lyot stop, grism wheel, camera assembly, field flattener and a detector (Figure 4). The purpose of this paper is to provide a detailed description of the NESSI mechanical and opto-mechanical design, as well as to show how mechanical construction, assembly, integration and verification are planned.

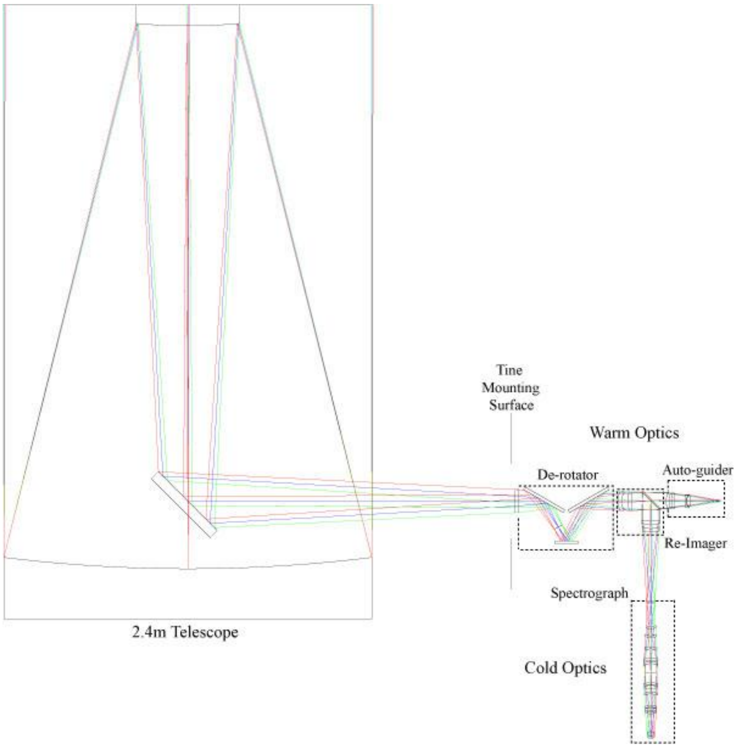

Figure 2 – NESSI optical layout with ray trace.

1.2 Flow-down of technical requirements

The NESSI top-level requirements have been established by defining a set of science drivers and design goals [1,4]. From a mechanical engineering perspective, these requirements can flow down to the need of an extremely stiff and lightweight instrument platform (with first resonant frequency greater than 60Hz) which allows alignment of its optical components to be highly repeatable and stable over both short and long observation timescales, and within a wide-range of temperature variation. This calls for a feasible mechanical design and material selection to allow proper linear/angular stability for the optical components to within the temperature variation expected inside the enclosure where the 2.4-meter Telescope is installed. Therefore, creeping between the various mechanical subsystems should be minimized so as to maintain optical alignment stable over a short term observation time (generally over four hours or a full night) and long term (over a few months).

Also important is that the de-rotator does not transmit vibration during operation or beam wander into the downstream optics over a full 360° rotation. Thus, the maximum differential flexure between any two orientations of the de-rotator, as separated by the minimum incremental rate of its rotation stage, must not transmit motion of the beam on the multi-object mask inside the spectrograph by more than 0.3 arcsec.

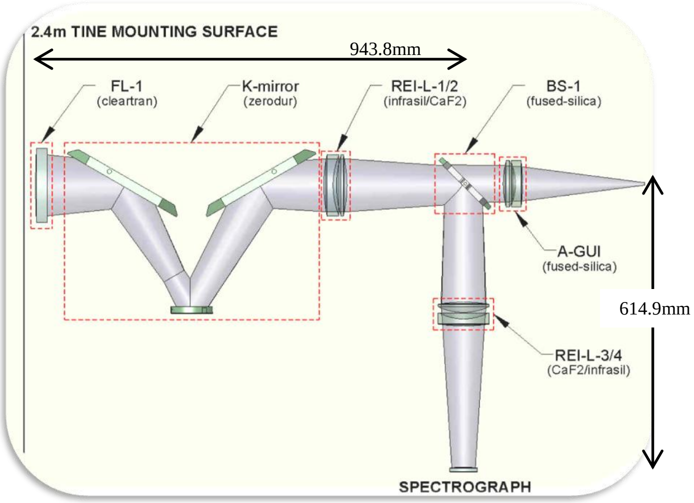

Figure 3 – NESSI warm optical layout.

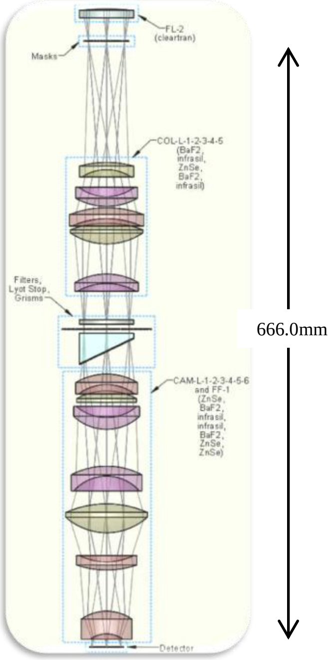

Figure 4 – NESSI cold optical layout.

2. NESSI MECHANICAL DESIGN REPORT

The NESSI mechanical design is characterized by its modularity. This has facilitated its design process and will be key during procurement for fabrication, pre-alignment and performance testing in the lab, as well as installation and alignment at the telescope site. The design is broken down into three major mechanical subsystems (Figure 5). Following the order that they appear to the incoming beam of light these subsystems are the <u>instrument structure</u>, <u>warm-NESSI opto-mechanics</u>, and <u>cold-NESSI opto-mechanics</u> (Figures 2 and 5). The following sections describe these mechanical subsystems.

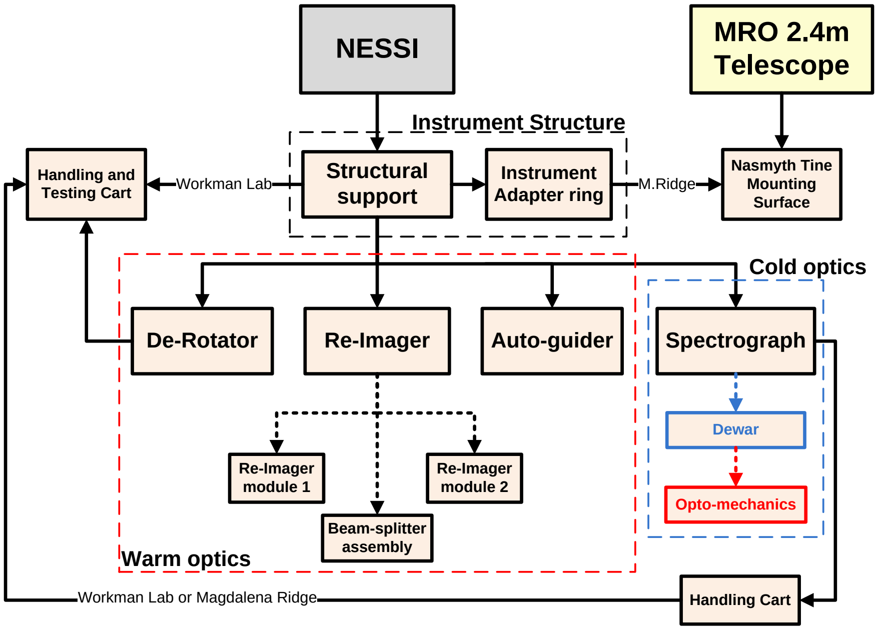

Figure 5 – Flowchart of NESSI mechanical subsystems.

2.1 Instrument structure and interfaces

NESSI operates stationary to the telescope fork so as not to introduce differential flexure between internal optical elements during or between observations (the instrument support does not experience any variation in the gravity loading as the telescope tracks across the sky). This means that after NESSI is aligned it is feasible to maintain the registration between the telescope and instrument optics to the required accuracy by using a very stiff overall structure [5]. Thus, a substantial aluminum structure composed of an interface mounting ring and six structural plates is designed to support the NESSI opto-mechanical components and Dewar spectrograph (Figure 6). External dimensions are: 1156mm (depth from the tine mounting surface), 1240mm (height), 730mm (width), and 1280mm (external diameter of the interface mounting ring). The structural plates are fabricated using the 6061-T6 aluminum alloy stock plates, cut with a water-jet machine. Precision milling is only needed on surfaces that require proper mating with other plates or for opto-mechanical interfaces. A build-to-print methodology and the use of dowel pins for final assembly guarantee appropriate squareness, high shear strength and that the as-built structural performance and opto-mechanical interfaces meet specification with minimum adjustments. Helicoils are extensively used for higher strength in the joints. These are designed to work by causing dilation when installed and, consequently, providing full contact between aluminum threads in the plates and the helicoil.

Lightweight openings are incorporated into the structural plates and the behavior of the overall structural support is optimized for displacement and stress using Finite Element Analysis (FEA). When the instrument is fully populated (estimated weight of 550kg), a maximum static flexure of 32.8μm at the lower part of the structure produces a misalignment of the spectrograph with respect to the NESSI optical axis that can be removed by adjusting the beamsplitter. Von Mises stress and angular deviation of mounting surfaces induced by static flexure are considered negligible. The first resonant frequency of 68Hz is the pitch motion of the instrument support induced by the spectrograph loading. The second resonant frequency of 72Hz is the roll motion of the support also induced by the spectrograph loading.

The lightweight openings of the structural support are covered with aluminum plates and bolted/glued in place for reinforcement. All joints are sealed to make them light tight. Access ports for installation, final alignment and removal of opto-mechanical subassemblies are placed on the top, front and bottom of the structural support. Locating dowel pins are installed in order to guarantee reproducibility of these subassemblies.

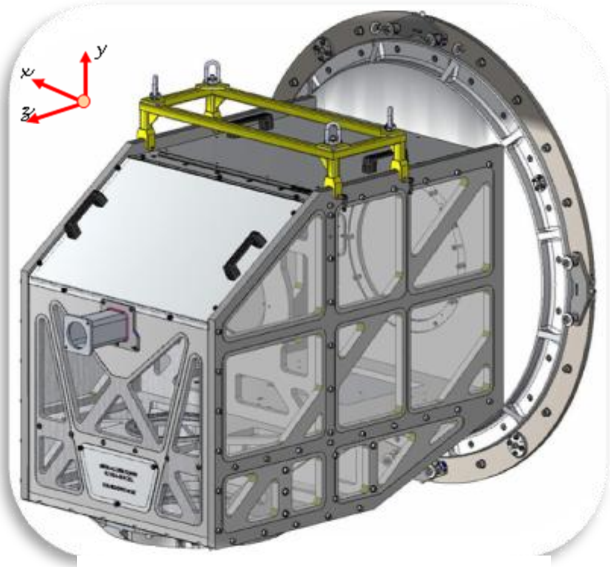

Figure 6 – NESSI instrument structure.

An instrument adapter ring is used to interface the structural support to the Nasmyth port of the MRO 2.4-meter Telescope. It has 1280mm outer diameter made of mild steel (as is the telescope structure), and has built-in horizontal and vertical rails to allow up to ±3mm of linear adjustments. These adjustments are needed to remove shear and tilt from the beam of light coming from the telescope.

A motorized environmental cover is installed at the front surface of the structural support (Figure 7). It provides a protective covering against dust coming from the outside environment and fingerprints/scratches to the field lens (during transportation or when the instrument is not in use). A DC-servo motor is used to drive the shutter. Manual actuation is possible in case of electrical failure. The motor can be replaced without the need to remove the instrument from the telescope.

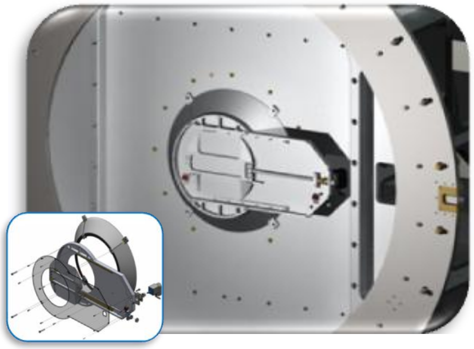

Figure 7 – NESSI environmental cover.

The major mechanical interfaces are defined for three NESSI components: - The instrument adapter ring which interfaces with the 2.4-meter Telescope and the structural support; - the structural support which interfaces with the adapter ring, warm-NESSI opto-mechanics and spectrograph; and - the spectrograph which interfaces with the structural support and the cold-NESSI opto-mechanics.

2.2 Warm NESSI opto-mechanics

The NESSI warm optical layout is presented in Figure 3. Elements that are in close proximity to one another are grouped together and installed in modules. These groupings of optics are represented within a dotted rectangle in Figure 3. They all have similar optical functions in the instrument and installing them in a single mount allows significant reduction of built-up tolerances between individual lenses. They also facilitate assembly and alignment checks in the lab by lens group (as a standard practice). Dimensions and positioning tolerances for warm optical elements are shown in Table 1.

Table 1: Dimension and tolerances of NESSI warm optics.

WARM OPTICAL GROUP	DIMENSION	MAXIMUM POSITION DEVIATION		
	Outer diameter [mm]	Error along optical axis - z [mm]	Decenter error xy plane [mm]	Tilt error xy plane [mm]
FIELD LENS 1	160.00±0.1	±0.40	±1.00	±0.20
RE-IMAGING LENS 1-2	130.00±0.1	±0.40	±1.00	±0.20
	130.00±0.1			
RE-IMAGING LENS 3-4	110.00±0.1	±0.40	±1.00	±0.20
	110.00±0.1			
BEAM-SPLITTER	20x100x150	Adjusted to steer light down to spectrograph		
AUTO-GUIDER 1-2	100.00±0.1	±0.40	±1.00	±0.20

It is also mechanically convenient to have a single mount to support these grouping of optical elements. The warm-NESSI opto-mechanics is then composed of a field lens support (FL-1), field de-rotator mechanism (K-mirror), re-imaging lens assembly (REI-L-1/2 and REI-L-3/4) which includes a beamsplitter support (BS-1), and the auto-guider assembly (AGR-L-1/2). An athermal design is used to match CTE between optical mounts and the structural support. The general purpose aluminum 6061-T6 alloy is largely used in this case.

The mechanical design philosophy applied in the design of the cells of all warm lenses (FL-1, REI-L-1/2, REI-L-3/4 and AGR-L-1/2) is build-to-print alignment [5]. This means that the performance of each lens group as assembled in its cell meet specification (assembly tolerances) without the need for any additional adjustment.

Lens mounts are designed to maintain the clear aperture of the lens (90% of lens diameter). Each lens mount is composed of a mounting cell, a G10 spacer whenever two or more elements are in the same cell (REI-L-1/2, REI-L-3/4 and AGR-L-1/2), an axial preload collar, a diaphragm spring, a retaining ring, a compliant pad and a preload spring. This will be shown in detail in the subsequent sections (field lens, re-imaging unit and auto-guider). The design of the mounting cell comprises two radial "hard pads" machined 120º apart and placed at the bottom of the cell, and one compliant radial constraint placed at the top (Figures 8, 12 and 13). The compliant pad and the preload spring (spring steel) are used to constrain the lens radially against the hard pads. Three axial pads are also machined 120º apart and the lens is constrained against them using an axial preload collar followed by a diaphragm spring (phosphoric brass) and a retaining ring. Both the axial pads and the axial preload collar have the radius of curvature of the lens machined on them for help centering and precisely de-spacing the lens inside the cell. Appropriate mechanical tolerances are enough to guarantee centering, tilt and de-spacing between optical elements in their cells.

Field lens and field de-rotator mechanism

Since NESSI is stationary to the fork of an alt-azimuth telescope, a field de-rotator is needed to compensate for the inherent image rotation. It is composed of a fixed field lens and a classical K-mirror which is allowed to rotate by a full ±170^0 (Figure 3) along the optical axis of the instrument.

The function of the field lens installed right before the K-mirror is to convert the f/# from f/8.856 to f/5.837. Figure 8 is the FL-1 general assembly as described earlier and the as-built mount.

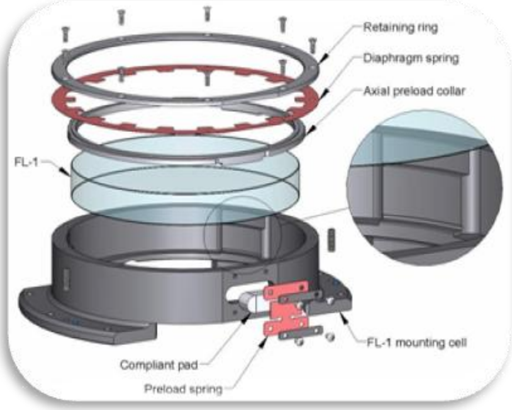

Figure 8 – NESSI field lens 1 assembly (FL-1).

The K-mirror is the only rotating part of the warm-NESSI opto-mechanics. It is a 3-mirror optical assembly (KM-1/2/3), configured as shown in Figure 3. It is motorized and controlled using a look-up table map to follow the alt-azimuth motion of the telescope. A Newport RV series precision rotation stage is used to drive the K-mirror assembly. Major characteristics that make these stages attractive for a K-mirror application are: monolithic design which ensures high structural stiffness, open-aperture for a moderate diameter beam of light to pass through the stage, high load capacity when operating vertically, small wobble which produces negligible beam wander, high absolute accuracy, high repeatability and small minimum incremental motion. Important specifications for model RV350HAT are shown in Table 2.

The K-mirror support assembly is mounted cantilever to the rotation stage. It is made of a substantial aluminum tube appropriately machined to interface at one end with the stage and internally with the mirror cells. Differential flexure is critical for the performance of the K-mirror assembly as a deviation of its optical rotating axis to the NESSI optical axis may result in an unacceptable drift of the image on the multi-object mask plane. Extensive FEA has allowed the design of a lightweight and stiff mount. For KM-1 and KM-3, an aluminum bridge creates a feasible interface with the mirror cell (Figure 9). A three-point flexure support is used to hold each mirror in place and allow adjustments in tip, tilt and piston. Pockets are machined on the rear surface of the Zerodur mirrors for light-weighting (Figure 9 - a 6:1 diameter to thickness is applied). This scheme requires three pads to be glued on the back of the mirrors, so safety pins are added in the design.

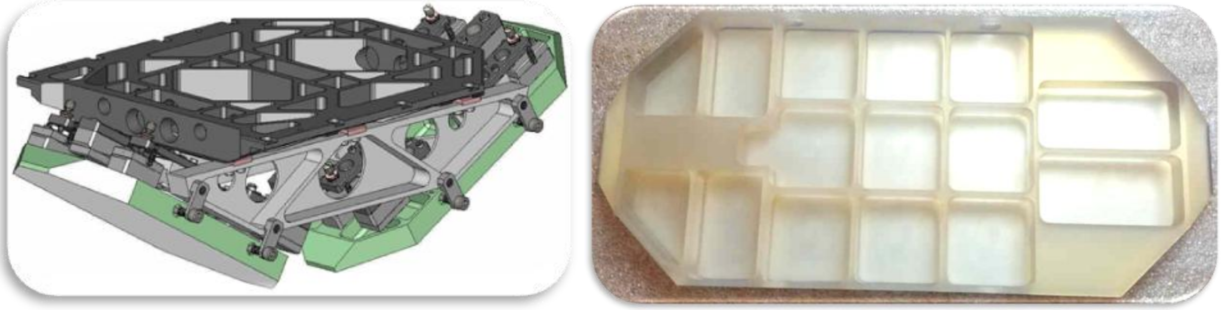

Figure 9 – NESSI KM-1/3 assembly and back of as-built mirror.

The KM-2 mirror cell is supported by an aluminum truss which minimizes mirror tilt induced by flexure and increases stiffness of the overall mount with minimum weight. The truss is an open frame which allows clearance for light to travel through it without vigneting (Figure 10). An aluminum bridge is also used to connect the truss to the aluminum tube. The KM-2 mirror is kinematically supported in its cell and tip, tilt and piston adjustments are made available.

Figure 10 – NESSI KM-2 truss assembly and back of as-built mirror.

Table 2: Technical specifications of the Newport RV350HAT.

Description	Specification
Travel range	±170º
Resolution	0.000035º
Minimum incremental motion	0.00075º
Uni-directional repeatability	0.0002º
Absolute accuracy	0.005º
Maximum speed	80º/s
Wobble	8μrad typical
Load capacity	6500N

Figure 11 is the general assembly of the de-rotator mechanism (exploded view) showing the field lens mount and the rotation stage. Mass balancing is almost achieved by design, so just a small counterweight is necessary.

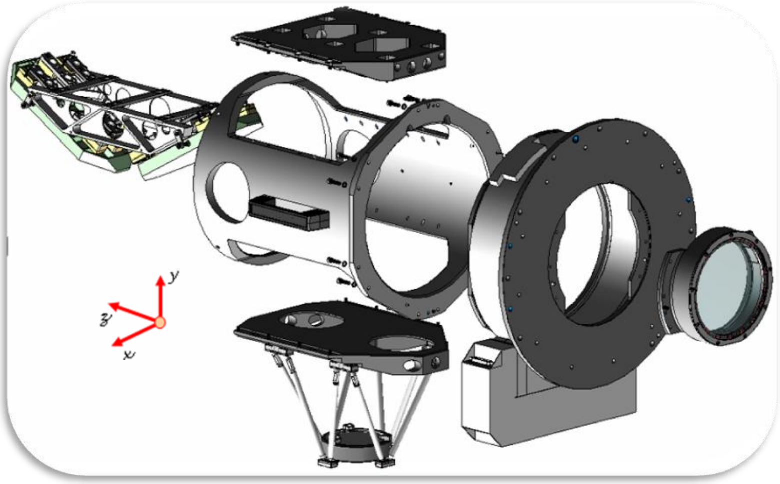

Figure 11 – NESSI field de-rotator - exploded view.

The de-rotator assembly was extensively analyzed to assess static displacement for different orientations. The differential flexure for a full 180° rotation was assessed for two critical orientations of the assembly, starting from 0° to 180° (maximum differential flexure is 2.97μm) and from 90° to 270° (maximum differential flexure is 4.96μm). Also, for any 60° rotation (translating to a four hour observation timescale), the maximum differential flexure between the two orientations is below 1.6μm. For any minimum incremental motion of the rotation stage (0.00075°), the maximum differential flexure is lower than 0.01μm. As the output beam of the K-mirror moves by 2α when the de-rotator rotates by an angle α, the flexure due to the minimum incremental motion produces a submicron spot motion on the mask plane, which is well within the requirements.

Also critical is the alignment and stability of alignment of the de-rotator. Two types of misalignments are considered. The first is a misalignment between the rotation axis of the RV350 stage with respect to the NESSI optical axis. This can be controlled to within specification by setting up appropriate fabrication/assembly tolerances. The second is a misalignment of KM-1/2/3 (any or all of the mirrors, but specially KM-3) together with a low stability of alignment. This results in an undesired drift of the image on the mask plane, so it is controlled to within specification by design of the mount and the application of an appropriate alignment technique.

Re-imaging unit

The major role of the NESSI re-imaging unit is to re-image the telescope focal plane on the multi-object mask inside the spectrograph. It is composed of two lens groupings (REI-L-1/2 and REI-L-3/4) and a dichroic beamsplitter (BS-1) placed between them. The same design configuration adopted for FL-1 is used in the opto-mechanical design of both lens grouping, as previously described. Figure 12 is the re-imaging lens 1 and 2 mount (REI-L-1/2). Figure 13 is the re-imaging lens 3 and 4 mount (REI-L-3/4).

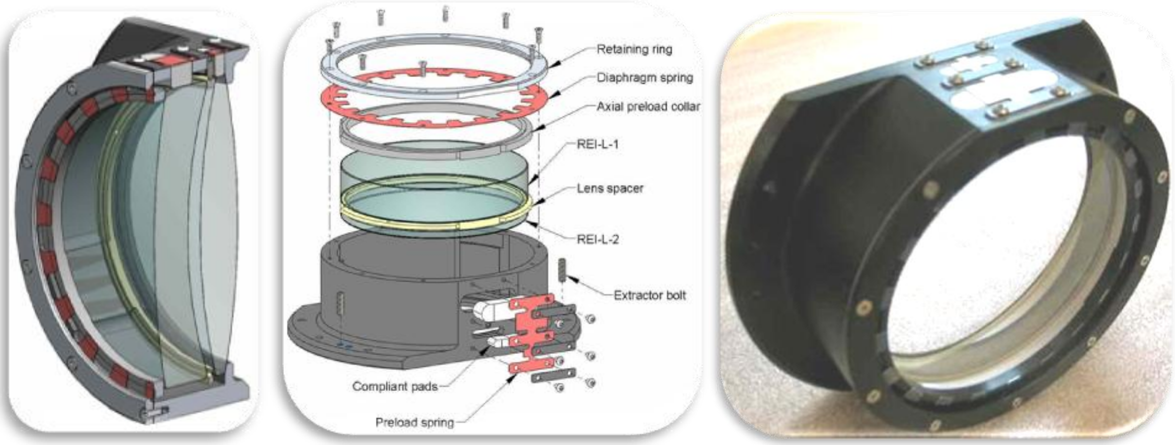

Figure 12 – NESSI re-imaging lens 1 and 2 – cut-away and exploded views, and as-built assembly.

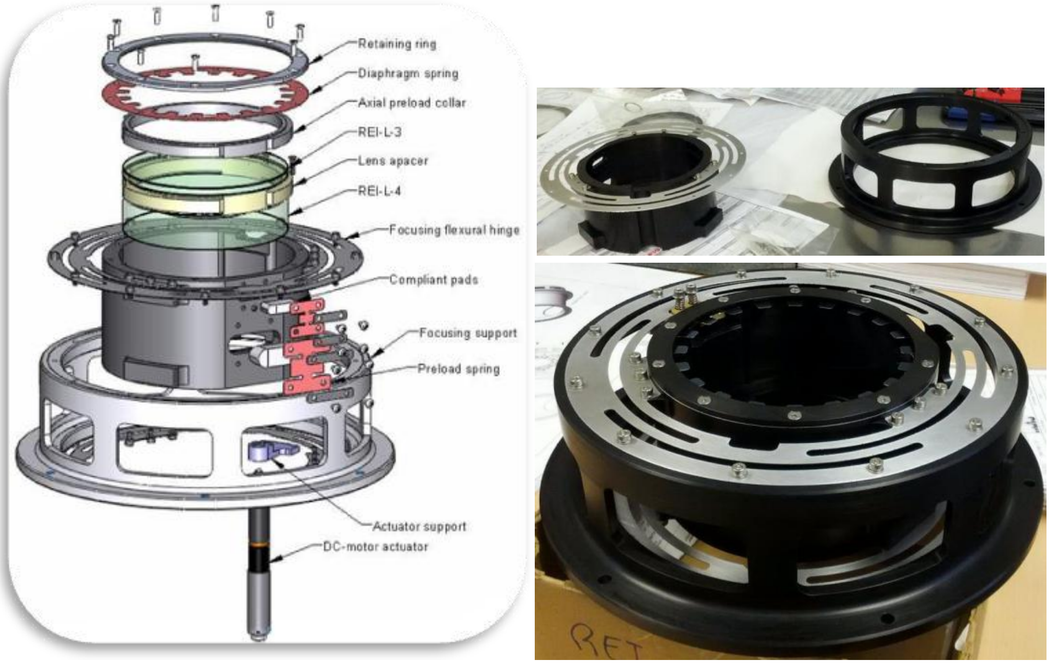

Figure 13 – NESSI re-imaging lens 3 and 4 - exploded view.

The secondary mirror of the 2.4-meter Telescope is used to set focus in between KM-1 and KM-2 (Figure 3). This gives some ability to focus the NESSI warm optics at the multi-object mask, but may not be sufficient when accounting for optical/mechanical fabrication and assembly errors throughout the instrument. A motorized focusing adjustment with a ±2mm of linear stroke along the NESSI optical axis is then required at the REI-L-3/4 mount (Figure 13). A pair of compliant ortho-planar springs (also called flexural hinge) is used to provide appropriate centering of REI-L-3/4 and quasi-linear focusing motion (a negligible inherent tilt is expected to be within the optical tolerance of the instrument). Each ortho-planar spring has all compliant links in the single plane with the linear motion out of that plane [6]. They are mounted parallel to one another. The mechanism designed has the advantage of delivering low noise, high positioning accuracy, zero friction and low backlash (given by the actuator system). It is low cost and of reduced size. The Thorlabs DC-servo actuator Z806 is adopted in the design. To use only one linear actuator, the focusing mechanism is assembled 3mm off its nominal position (zero deflection). The actuator then drives the lens mount (inner cylinder) to the nominal position by moving it 3mm and from that point on (home position) the optics can be moved linearly by ±2mm to find focus. Figure 14 is a cut-away view of the REI-L-3/4 focusing mechanism.

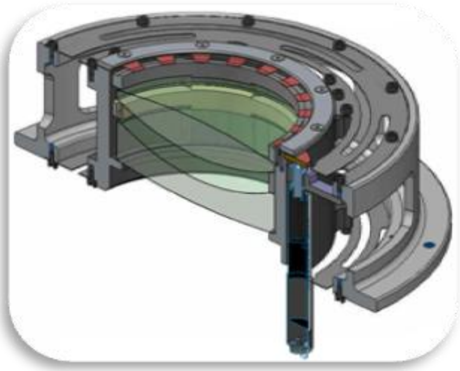

Figure 14 – REI-L-3/4 ortho-planar focusing mechanism.

An infrared-visible dichroic beamsplitter made of fused silica is located at a pupil image in between REI-L-1/2 and REI-L-3/4 to separate infrared light for science, and visible light for guiding. It is also used to shorten the length of the instrument so as to minimize overall flexure. Figure 15 is the BS-1 mount.

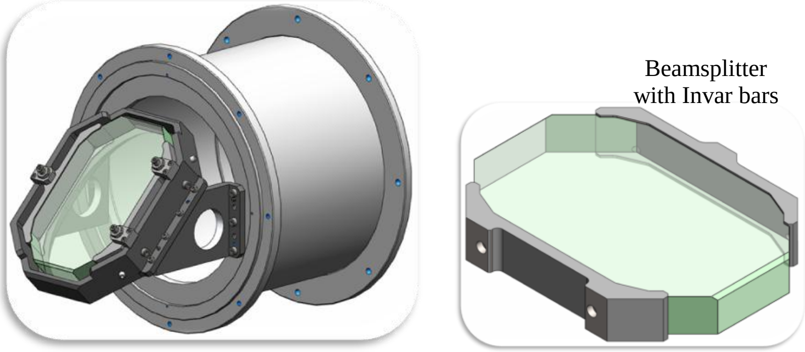

Figure 15 – BS-1 mount.

The two long-sides of a beamsplitter are glued to Invar reinforcement bars to minimize unwanted distortions at their ends and corners due to the mounting scheme using three kinematic points. Three axial adjustment bolts are placed against three preloaded compliant constraints to provide fine adjustment in tip, tilt and piston. Radial constraint is achieved using two hard and two compliant points (spring plungers). An aluminum tube is used to support the beamsplitter cell. This provides high stiffness at low weight. Dowel pins are used for precision mounting of the assembly.

Auto-guider

An auto-guider is used as a sensor to allow appropriate closed-loop guiding of the telescope mount. It can also be used as an acquisition camera to facilitate telescope pointing. It is composed of an achromatic doublet and a detector (ML4710 from Finger Lakes Instrumentation), and operates in the visible (optimized for 700-900nm).

The same design configuration adopted for FL-1 and the NESSI re-imaging optics is used in the opto-mechanical design of the auto-guider imaging optics (Figure 16). A motorized focusing adjustment with ±2mm of linear stroke is also required. Thus, the same compliant ortho-planar spring previously described is used together with the same driving scheme for pistoning the lens mount.

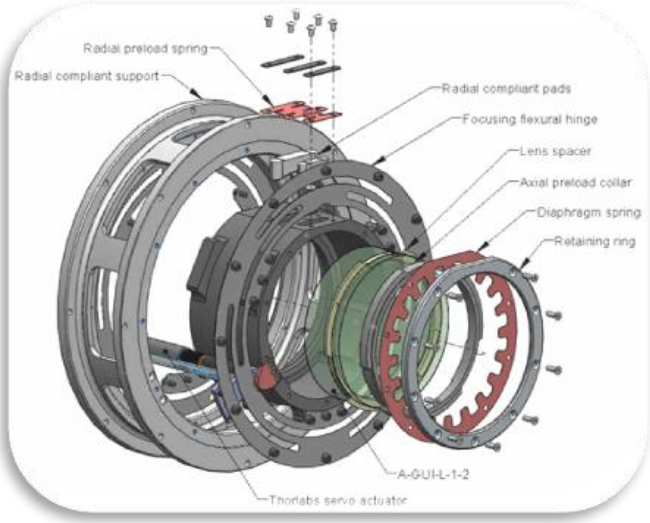

Figure 16 – Auto-guider focusing mechanism - exploded view.

The auto-guider focusing mechanism is attached to an aluminum tube which, by its turn, is attached to the BS-1 mount (Figure 17). Appropriate mechanical tolerances are enough to guarantee centering, tilt and de-spacing of the imaging optics to within acceptable levels. The auto-guider camera is assembled independently at the rear surface of the structural support (Figure 17). No fine adjustment is required.

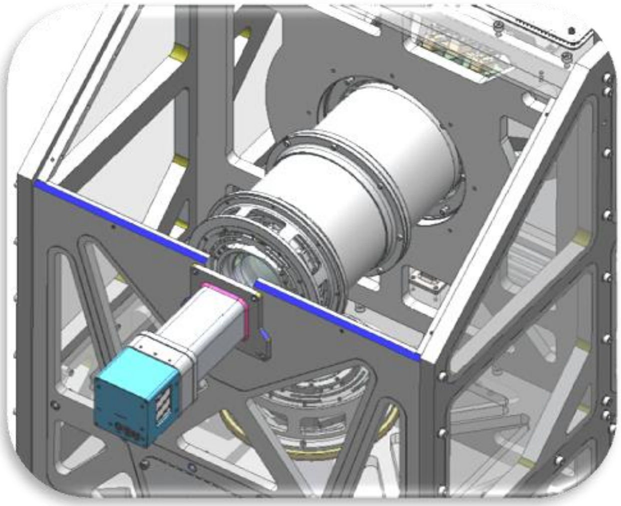

Figure 17 – Auto-guider assembled in the structural support.

2.3 Cold NESSI opto-mechanics

The main role of the NESSI spectrograph is to select a target and calibrator objects in the field, spectrally disperse light and sense the dispersed spots on the detector [1]. For the spectrograph to operate appropriately in the infrared, the optics and detector have to be enclosed inside a cryogenic environment, i.e. a Dewar, with vacuum and temperature provided by LN2 at 77K. It is composed of a Dewar which includes a cryostat, LN2 reservoir and fittings, cold plate, getter, vapor/radiation shields and vacuum gauge, multi-object mask wheel, collimator, filter wheel, Lyot stop, grism wheel, camera, field flattener and detector (Figure 4). As discussed for the warm optics, elements that are in close proximity to one another can be grouped together and installed in modules. These groups are represented within blue dotted rectangles in Figure 4. Dimensions and positioning tolerances are shown in Table 3.

Table 3: Dimension and tolerances of NESSI cold optics.

OPTICAL GROUP	DIMENSION	MAXIMUM POSITION DEVIATION		
	OUTER DIAMETER [mm]	ERROR ALONG OPTICAL AXIS - Z [mm]	DECENTER ERROR XY PLANE [mm]	TILT ERROR XY PLANE [mm]
FIELD LENS 2	**60.00±0.1**	**±0.40**	**±0.25**	**±0.20**
COLLIMATOR LENS 1-5	**60.00±0.1**	**±0.05**	**±0.05**	**±0.025 or 0.01°**
	68.00±0.1			
	82.00±0.1			
	80.00±0.1			
	70.00±0.1			
FILTERS	**60.00±0.1**	**±0.40**	**±1.00**	**±0.20**
CAMERA LENS 1-6 and FIELD FLATTNER	**68.00±0.1**	**±0.05**	**±0.05**	**±0.025 or 0.01°**
	66.00±0.1			
	72.50±0.1			
	78.00±0.1			
	90.00±0.1			
	66.50±0.1			
	56.00±0.1			

An athermal design is used to match CTE between optical mounts, cryostat and the structural support. The general purpose aluminum 6061-T6 alloy is largely used as for the warm-NESSI opto-mechanics. Thermal stability is crucial for parts that play a key role in the global alignment of the spectrograph or in the support of an optical element. It means that these parts should perform as designed and hold critical dimensional tolerances as set for room temperature at 293.15K (fabrication, assembly and preliminary alignment) and at 77K (final alignment and operation). This can be achieved by setting up appropriate heat treatment and stress relief for the raw material prior to final machining.

Design, construction and testing of the Dewar, multi-object mask wheel, filter wheel, Lyot stop, grism wheel, and detector mount was outsourced to Universal Cryogenics in Tucson. Outer dimensions are ø508mm by 970mm length. The total weight is 140kg, including optics and about 11.8 liters of LN2. Driving motors for the internal wheels are placed outside for ease of maintenance. Required hold time is 36 hours. Figure 18 is a global view of the spectrograph.

Design and construction of the collimator assembly, camera assembly, interface plate used to connect the spectrograph to the NESSI structural support, and handling/integrating cart is responsibility of the MRO engineers. All these sub-assemblies are now under fabrication.

The opto-mechanical design philosophy applied in the design of the cells of all cold lenses (FL-2, COL-L-1/5, CAM-L-1/6 and FF-1) is build-to-print alignment [5]. This means that the performance of each lens and lens group as assembled meet specification without the need for any additional adjustment.

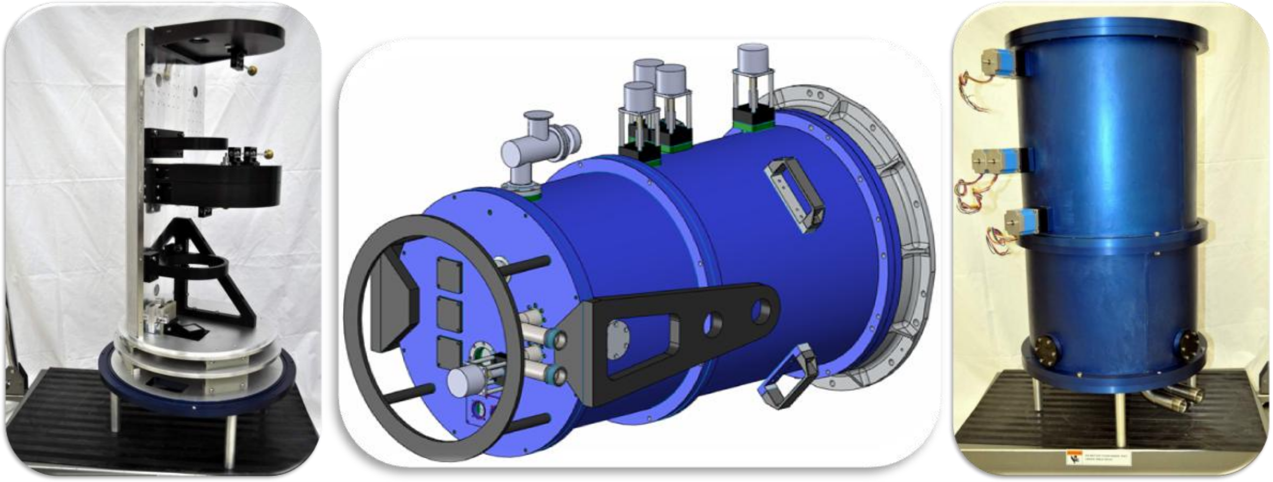

Figure 18 – Global view and as-built NESSI Dewar spectrograph.

The same spring finger lens cell design [5,7] is adopted for all cold lenses. Assembly tolerances are mostly concentrated on centering, tilt and de-spacing of each individual lens, lens grouping and between collimator/camera assemblies, and are carefully checked at room temperature and 77K operating temperature. Each lens mount is composed of a spring finger lens cell, G10 axial preload collar, diaphragm spring, retaining ring and a G10 restrain cooling ring (Figure 19). The spring finger lens cell has a titanium liner used to break the thermal-path from the cold plate to the lens and, consequently, minimize high thermal gradient during cool-down cycles. The spring fingers are used to radially constrain the lens at room temperature (light pre-load) and control the force applied to the lens due to contraction at cryogenic temperature (without producing stresses over the limit of the lens material). The lens is axially constrained in the cell by using a G10 preload collar followed by a diaphragm spring and a retaining ring.

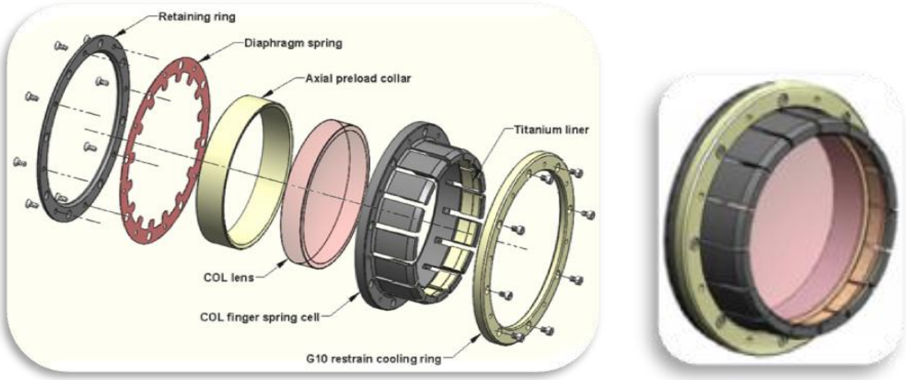

Figure 19 – Spring finger lens mount.

Individual lens cells are mounted on precision machined barrels for spacing and centering at both room and cryogenic temperatures. Baffling for scattered light is included wherever space is available inside the barrels. Figure 20 is a cut-away view of the collimator assembly. Figure 21 is a cut-away view of the camera assembly. The collimator and camera barrels are assembled on angle brackets precisely mounted on the cold plate of the spectrograph. Figure 22 are as-built collimator and camera lenses.

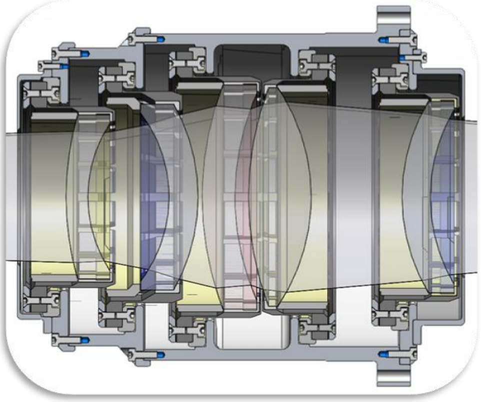

Figure 20 – Cut-away view of collimator assembly.

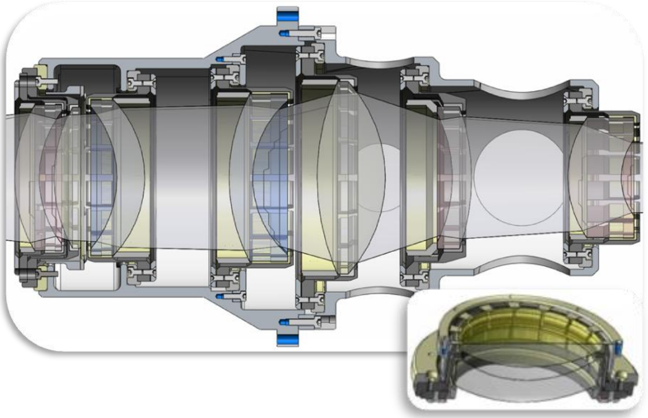

Figure 21 – Cut-away view of camera assembly.

Figure 22 – Collimator and camera lenses.

A general assembly of NESSI mounted on the Nasmyth port of the telescope is shown in Figure 23.

Figure 23 – The NESSI assembly on the 2.4-meter Telescope.

2.4 Handling and testing equipment

A general purpose handling and testing cart is designed for servicing all MRO-owned instruments (Figure 24), including NESSI. It enables these instruments to be mounted, integrated, aligned and extensively tested in the lab (sub-system level testing and fully populated testing), as well as facilitate assembly, handling and servicing of subassemblies at the telescope site. It is essentially made of 80mm aluminum profiles and an aluminum interface plate to mount the instruments. It also features a frontal frame and two off-the-shelf breadboards for mounting of laser and alignment hardware. The base frame is V-open at the rear end to allow approach and installation of the Dewar spectrograph. Instrument polyurethane casters are used for dampening vibrations to a specified level. The external dimensions are 1910mm long, 2370mm height and 1455mm wide.

Figure 24 – NESSI handling and testing cart.

The handling cart has two sets of mounting holes to allow NESSI to be mounted with or without the instrument adapter ring. Other handling and testing equipments are designed to facilitate installation of opto-mechanical sub-systems, optical alignment and testing of NESSI at subassembly level.

3. MECHANICAL ASSEMBLY, INTEGRATION AND VERIFICATION

The NESSI mechanical AIV is defined as the process in the life-cycle of the project beginning with the assembly of all finished parts and ending with the verification of the mechanical system performance at a subsystem level. Overall, the NESSI mechanical AIV involves three sequential planning parts. The main purpose for the <u>assembly planning</u> is to list the activities which indicate how parts and sub-assemblies, or any combination thereof, should be put together to perform a specific function and capable of disassembly prior to integration. The main purpose for the integration planning is to list the activities which indicates how major components of the subsystem should be put together to form a suitably larger unit prior to performance verification. Both assembly and integration are planned with a focus on completing within a defined schedule and with an efficient use of resources. Finally, verification planning will allow for the full assessment of functional efficiency and performance to be undertaken with lowest risk and cost. The verification planning should provide confidence that each subsystem has met its performance requirements. Dependencies between major activities or sub-activities are also covered in such planning.

For the definition of an appropriate mechanical AIV scope of work, a set of high-level deliverables were first identified together with its associated mechanical AIV activities, this been carried out for each subsystem. The goal was to define and arrange a list of activities and sub-activities, preparation tasks and high-level deliverables in order to accomplish the mechanical AIV. This resulted in a list of engineering tasks needed to complete each subsystem on time, on budget and meeting all specification requirements. Preparation tasks are defined as independent engineering activities, not specifically part of the subsystem work package which nevertheless must be executed on an appropriate schedule. The sub-activities are generally sized to be small enough to allow precise estimation of resources (cost, schedule, and physical resources), execution and monitoring.

The NESSI mechanical AIV also incorporates a project plan where each sub-activity is broken down into a sequence of lower-level tasks. Each of these tasks is associated with a Description or a Work Definition Task Sheet (WDTS). These are numbered as a subset of the WBS, following the MRO numbering system, and list full details and dependencies of the task to be carried out. Each Description provides a brief explanation of the hardware being delivered, as well as the technical interfaces and related documentation. Each WDTS provides a final level of technical details as information on the name/WBS of the task, requirements, the task input/output, the task duration, resources, required equipment & facilities, applicable documents, task procedure and any special notes. Sub-activities that contain tasks with a significant level of complexity and/or are safety critical must have their procedures documented to an appropriate level of detail to ensure risk mitigation. All estimates on schedule and task duration also incorporate contingencies.

The verification planning includes activities at the fabrication shop, the campus (Workman lab) and the telescope site.

Activities at the fabrication shop include:

- Full metrology for tolerance assessment of mechanical parts and subassemblies;
- Verification of squareness of instrument structure;
- Check that lens cells and spacers match the as-built optics;
- Check that interferences and mounting fit are according to built-to-print approach; and
- First level static flexure and vibration testing in a subsystem level.

Activities on the campus include:

- Check of de-rotator mechanical alignment, static flexure, resonant frequencies and stability;
- Check optical cells on support structure built-up;
- Check interface and functionality of environmental cover;
- Check REI-L-3/4 and auto-guider focusing stages;
- Check interface and alignment of spectrograph;
- Have all dowel and locating pins installed; and
- Check repeatability of optical mounts and mechanisms.

NESSI global AIV and commissioning start after mechanical AIV is completed.

4. RISK ASSESSMENT

Mechanical engineering risks are mostly identified as technical and schedule risks. They are shown in Table 4.

Table 4: Risk assessment for the NESSI mechanical design.

Risk	Mitigation Strategy	Impact
Lack of detailed technical information on the performance of the 2.4m Tel.	Site visits and engineering time for proper assessment. Assessment before start of construction.	Medium
Lack of systems engineering	Built-in expertise within team members.	Low
Optics fabrication does not meet spec	Proper measurement by Vendor. Rework on spacers for each grouping cell.	Low
Structural support flexure greater than modeled	Pre-tests with dummy mass (static and dynamic) with subsequent stiffening.	Medium
De-rotator flexure and wobbling greater than modeled	Improvement of design and FEA.	High
Envelope and weight restrictions don't match needs (trucks, cranes, doors, elevators)	Rigorous flow-down of requirement with appropriate check before hand.	Low
Mechanical interfaces with spectrograph not properly defined	Interface control documents for structural support to spectrograph mount flange, optics cells to cold plate and array support to cold plate.	High
High fabrication cost	In-house fabrication for non-critical parts (NMT machine shop). Extensive discussion with Vendors for clear understanding of design and fabrication requirements. Get quotes in advance. Outsource where cost effective.	High
General problems during integration	Systems engineering and extensive lab testing.	High
Misalignment and/or not enough provision for alignment	Built-to-print methodology and modular design. Backup plan for alignment procedure.	Medium

5. CONCLUSION

NESSI: the **N**ew Mexico Tech **E**xtrasolar **S**pectroscopic **S**urvey **I**nstrument is designed to accomplish scientific missions from the ground what has only been accomplished prior to 2009 using space-based platforms. It is characterized by its modularity, compactness, stability of alignment and low cost. A suitable opto-mechanical design was carried out to guarantee proper optical performance with no damage for the lenses. An appropriate AIV plan is devised to help deliver the instrument on time and within an available tight budget. NESSI is completely under fabrication and testing in the lab. It is scheduled to be commissioned on the MRO 2.4-meter Telescope by early 2013.

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