The Cassegrain ADC for Keck 1
Preliminary Design Report
Version 2, Rev. 1.1
October 13, 2003

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1. Summary

This report contains the Preliminary Design for a Cassegrain Atmospheric Dispersion Corrector (ADC) for the Keck I telescope. This design is called to work over a wavelength range of 0.31—1.1-μm with full correction over zenith distances of 0-60°. While the ADC will operate over the 20-arcmin unvignetted field of view of the Cassegrain focus, its primary purpose is expected to provide dispersion correction for the Low-Resolution Imaging Spectrograph (LRIS), and the ADC design has been particularly studied with respect to this use.

At the Delta Conceptual Design Review (ΔCoDR; February 2003), the basic design adopted was the Linear ADC with prisms of high-grade fused silica. Within these constraints, there was little optical design work required. The performance of the system is largely determined by the dispersive properties of fused silica versus the atmosphere. The effect on image quality is negligible when the ADC is nulled; the effect is larger as the prisms separate due to a combination of lateral coma from the ADC and defocus introduced by the linear ADC design, but still meets performance criteria set by the Requirements Document.

The mechanical design has changed significantly from Conceptual Design. Rather than 3 lead screws turning synchronously to drive the prisms, we have adopted prism cells mounted on two linear bearings and driven by a single lead screw. This design is similar to that used by the CFHT secondary mirror. The primary concern about this design is whether it can hold the prisms to the required mechanical tolerances, but Finite Element Analysis (FEA) presented in this report confirms that the necessary stiffness will be achieved.

Electronics and software are seen as relatively simple, as this design includes only a single stage that moves as a function of telescope elevation. Some software modifications will be needed on the CARA side to provide appropriate focus and pointing corrections as functions of prism separation and physical rotator angle.

The overall schedule has slipped approximately six months over that presented at the ΔCoDR, representing about three months late start, one additional month to reach PDR, and about two months added for testing at the end of the project. The estimate budget has increased approximately 21% (23% of UCO/Lick costs), due to a combination of a slightly more expensive mechanical design, some unbudgeted shipping and tax costs, and additional unbudgeted requirements specified in the Requirements Document.

2. Introduction

This report documents the results of the Preliminary Design Study for an Atmospheric Dispersion Corrector for the Cassegrain Focus of the Keck 1 telescope. The Preliminary Design Study followed a Concept Design, which was reported in the Conceptual Design Report, October 31, 2002; and the Delta Conceptual Design Report, February 2, 2003. These reports can be found on the web at http://adc.ucolick.org/phase_a/index.htm.

The Preliminary Design Study started in June 2003.

Following a Preliminary Design Review, it is planned that the Detail Design Phase start, which will produce the fabrication level design of the ADC. The Fabrication and Test phase would follow after a Detail Design Review.

3. Specifications and Requirements

3.1 Preliminary Instrument Specifications

The Specifications for the ADC are detailed the Requirements for the Cassegrain ADC document version 1.3.2. Tables 5 and 6 of that document are inserted below (as Tables 1 and 2) to summarize the high level specifications. This document is available on the web at
http://adc.ucolick.org/prelim_design/workplan/Cassegrain_ADC_Requirements_1.3.2.pdf.

Table 1: Cassegrain ADC Typical Performance Requirements

Parameter	Min.	Typ.	Max.	Units	Notes
FOV	20	-	-	arcmin	1
Working zenith distance	0	-	60	degrees	2
Nominal design wavelength range	0.31	-	1.1	µm	3

Notes:
1. This is the diameter of the unvignetted FOV at the focal position for a Cassegrain instrument installed after the ADC in the tertiary tower of Keck I.
2. This is the range of telescope zenith distances for which correction of dispersion is desired.
3. The “nominal design wavelength range” defines the range of optical wavelengths for which the ADC design will be evaluated.

Table 2: Cassegrain ADC Goal Performance Requirements

Parameter	Goal	Min.	Max.	Units	Notes
Dispersion correction	<|0.05|	-	|0.1|	arcsec, RMS	1,2
Peak dispersion	<|0.06|	-	|0.2|	arcsec	1,3
Correction non-uniformity	<0.1	-	1	%, peak	4
Transmission	>95	90	-	%	5
Transmission non-uniformity	<0.05	-	0.1	%, peak	4
Effect on image quality	<0.5	-	0.6	FWHM, arcsec	6
Image quality non-uniformity	<10		40	%, peak	4
Ghost images	$<10^{-5}$	-	$<10^{-4}$	-	7
Differential Distortion	<0.08	-	<0.1	arcsec, RMS	8
Differential Rotation	<0.002	-	< 0.05	degrees	

Notes:
1. Dispersion is displacement of the image at a given wavelength with a wavelength of 0.45 μm as the reference; dispersions can therefore be positive or negative with respect to this wavelength.
2. For a zenith distance of 60 degrees over the full working wavelength range with no specific limit on the maximum distance between the prisms.
3. Peak value at any wavelength in the working wavelength range for a zenith distance of 60 degrees with no specific limit on the maximum distance between the prisms.
4. This is the peak variation over the full ADC FOV (20 arcmin).
5. This is the transmission over the correction wavelength range.
6. All zenith distances, all prism separations, all field points.
7. Intensity of the ghost image compared to the parent image at minimum prism separation.
8. In X and Y across the ADC FOV.

3.2 Compliance Matrix for Requirements

The Compliance Matrix for the specifications and requirements presented in the Requirements for the ADC document is Appendix 1 of this report.

4. Preliminary Design

4.1 Optical Design

The full optical design report is presented in Appendix 2. We copy the summary table here. There are no significant changes from Conceptual Design.

Prism opening angle	2.5°
Prism central thickness	45 mm
Prism clear aperture	1022.2 mm (min.) + 10 mm for safety
First prism offset	-22.1 mm (below center)
Minimum prism edge thickness	22 mm
First prism angle at outer surface	1.67°
First prism angle at inner surface	-0.83°
Minimum prism separation	20 mm
Maximum prism separation	1700 mm
Location in front of telescope focal surface	1695 mm – center of ADC 800 mm – min. distance (wrt 2nd prism)
Zenith distance for full correction	0 -- 60°
Prism Material	Fused Silica (Grade D suggested)
Coatings	MgF_2 + Sol-Gel
Expected Transmission	> 94%

4.1.1 Diameter of prisms

The minimum clear aperture is 1022.2 mm (dia.), to which we add 10 mm as a safety margin for either displacement of the final design forward in the tertiary tower, mechanical centering errors and/or flexure.

4.1.2 Vignetting

The clear aperture above produces no vignetting in the entire LRIS field (to a radius of 10.8 arcminutes from the telescope axis). The guider field is slightly vignetted over about 7%, with a maximum loss of ~25—30% in the extreme corner.

4.1.3 Thickness of the prisms

The center thickness is 45 mm, or 90 mm total thickness at all points. The ADC performance is very insensitive to the thickness.

4.1.4 Prism Angle

The adopted prism angle is 2.5 degree.

4.1.5 Prism Stroke

At the adopted prism angle, the ADC fully corrects at 60 degrees over the wavelength range 0.31–1.1 microns with a maximum prism separation of 1700 mm. The minimum separation should be 20 mm or less.

4.1.6 Throughput

The expected throughput is at or better than 94% over the entire range (see report).

4.1.7 Optical Material

As per the CoDR, fused silica is the optical material.

4.1.8 Homogeneity Specification

The ADC is fairly insensitive to index inhomogeneity, and we adopt Grade D as more than adequate. Athermalization effects are within tolerable limits (see Appendix 2).

4.1.9 Dispersion Correction Performance

The design ADC performance is set by the refractive index function of fused silica. At 60 degrees zenith distance, the maximum deviation is ±0.108″. Deviations scale directly with prism separation. At 72 degrees, the dispersion is roughly twice that at 60 degrees, so only half the dispersion is corrected.

4.1.10 Analysis of Expected Ghosting in Design ADC

Peak ghost intensity should be < 10-5 of the primary image if anti-reflection coatings perform as expected.

4.1.11 Anti-reflection Coating Specification

Sol-Gel + MgF2

4.1.12 Imaging Performance with and without LRIS

See report (Appendix 2).

4.2 Mechanical Design

With the acceptance of the Delta CoDR design review Keck authorized the preliminary design of the full aperture version of the ADC. This section presents the results of that mechanical design effort.

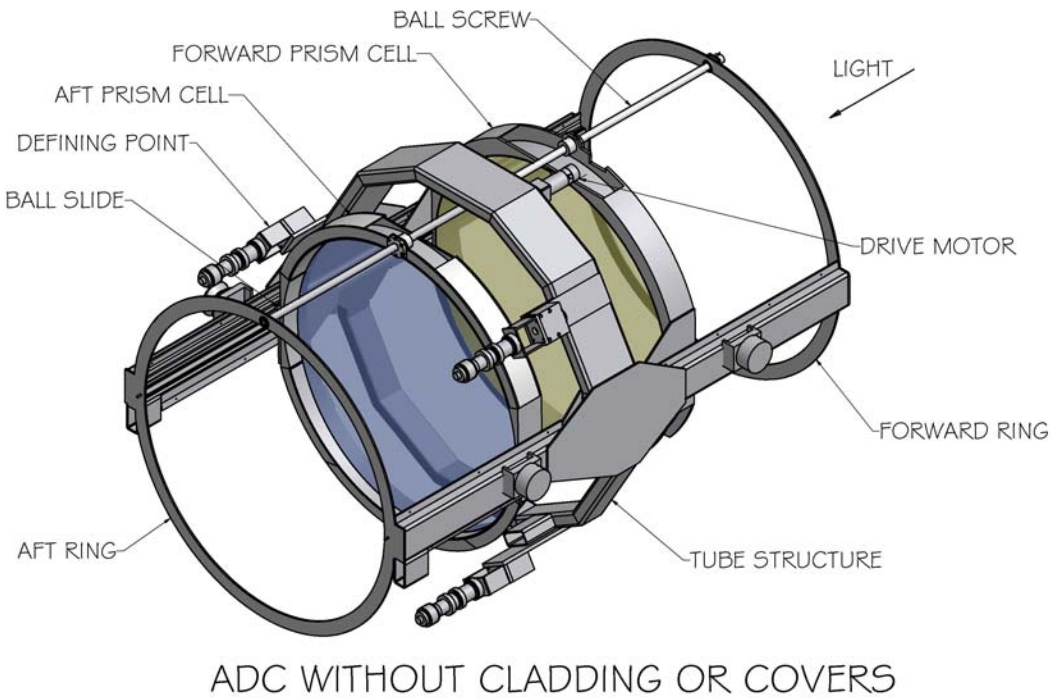

Figure 4.1

The Figure shows the current ADC without cladding or covers. As in the previous design the both prisms move toward and away from the center of the instrument, maintaining a constant center of gravity.

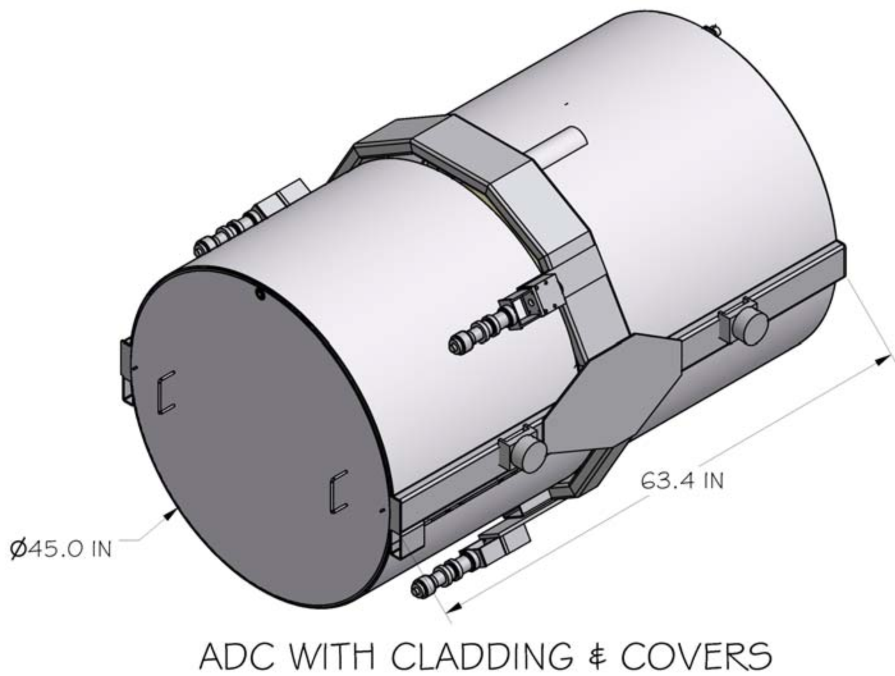

Figure 4.2

4.2.1 Changes from Delta CoDR

The design presented in the Delta CoDR had prism separation controlled by three lead screws that worked in unison to control separation and maintain perpendicularity of the prisms with the optical axis. There were ball slides to maintain lateral placement of the prisms. That design has been changed to a single ball screw to control separation, with the ball slides maintaining perpendicularity to the optic axis as well as lateral placement.

The structure has been modified to support the additional moment loads on the ball slides generated by the single ball screw at the edge of the optic. The ball slide supports are now rectangular tube. The flat plate that formed the center plane of the instrument has been replaced with a rectangular tube structure.

The prism mounting has been changed from a molded RTV design to a bolted design with three discrete pads at 120 degree spacing. There is sufficient clearance at the pads to allow for thermal variations. There is an alignment tab glued to each prism to maintain rotational alignment in the cell. The cell material has been changed from aluminum to steel to meet the thermal and stiffness requirements of the new design. The total travel has been increased from 1400 mm maximum separation to 1700 mm maximum separation to accommodate full correction to a zenith angle of 60 degrees.

4.2.2 Location, Weight and Mounting

The current weight of the instrument is 536 kg. We expect the final instrument weight to be below 550 kg. Since we are currently near the design limit, we expect to do some weight reduction work during detail design. The electronics enclosure will be mounted on the Nasmyth platform separately and will not exceed 100 kg.

The ADC location and vignetting are essentially the same as presented in the Delta CoDR for the full aperture design. The instrument will mount into the tertiary tower on defining points to be installed by Keck. The locations of these points have been agreed upon by Keck and Lick and are specified in the ICD. The Z position of the instrument is in front of LRIS and must clear the front hatch of LRIS. Keck is going to revise this hatch from a door to a sliding hatch. Final placement of the ADC on the Z axis, clearance with LRIS, and resulting prism diameter will be established after the modified hatch design is received from Keck.

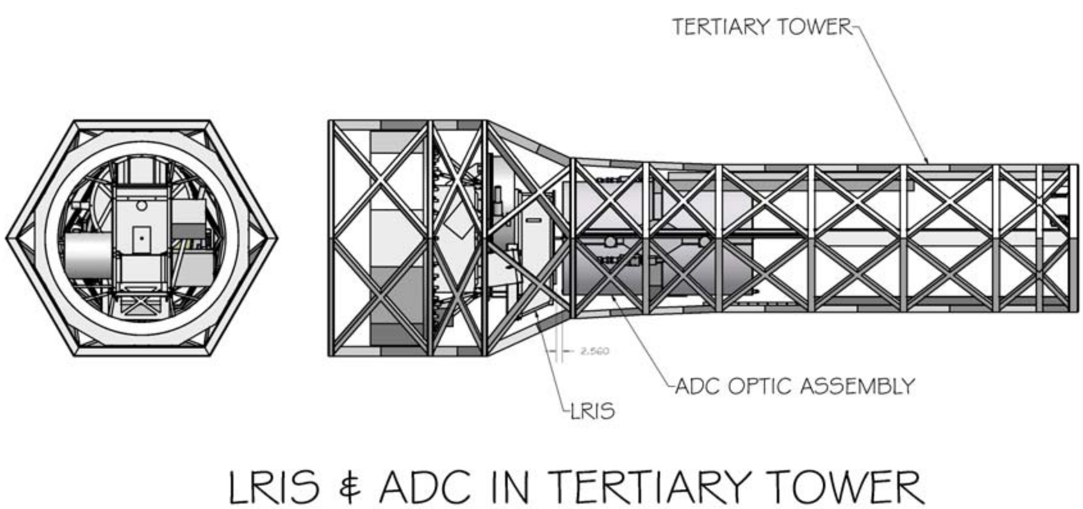

Figure 4.3

The instrument will be stored in and installed through the Cassegrain Transfer Module. The locations of the defining points have been chosen so that they do not interfere with the transfer module operation. The defining points are back (+Z) of the center of gravity of the instrument to clear the baffle deployment assemblies in the tertiary tower. When the transfer module is in use for other instruments the ADC will be stored on a jack stand permanently mounted on the Nasmyth deck.

Keck will supply a pin locking mechanism to hold the ADC in position in the transfer module when it is being moved.

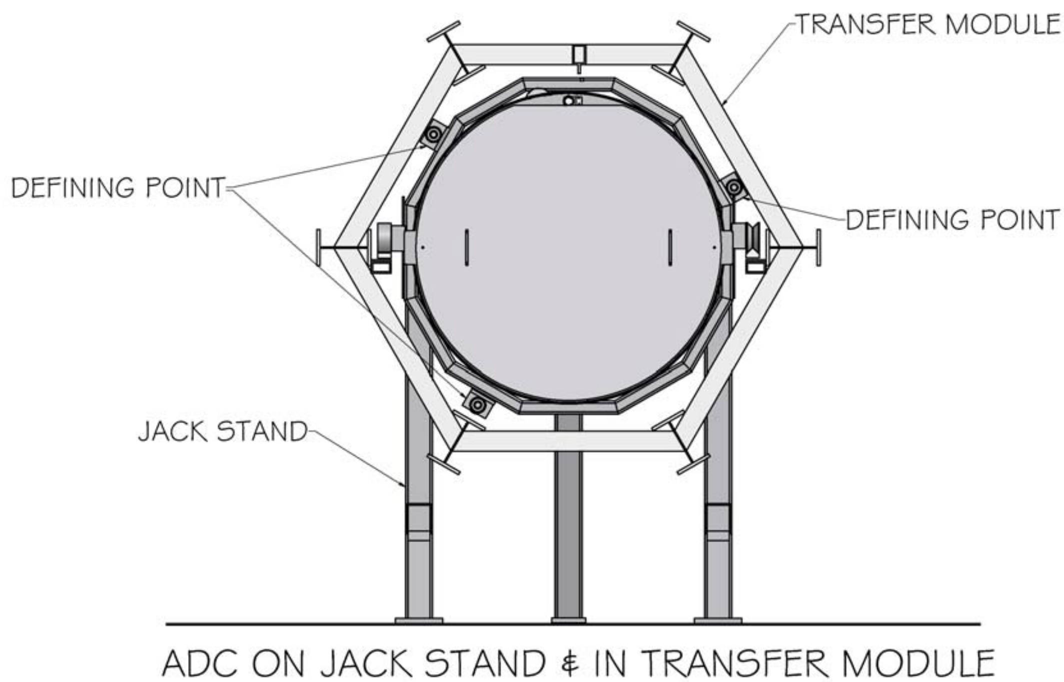

Figure 4.4

4.2.3 Cell Design

The prisms are mounted in steel cells with three radial and three axial constraints at 120 degrees. These constraints have adequate clearance to accommodate the temperature variation specified in the ICD. A radial clearance of 0.75 mm allows for 50 degree C cooling.

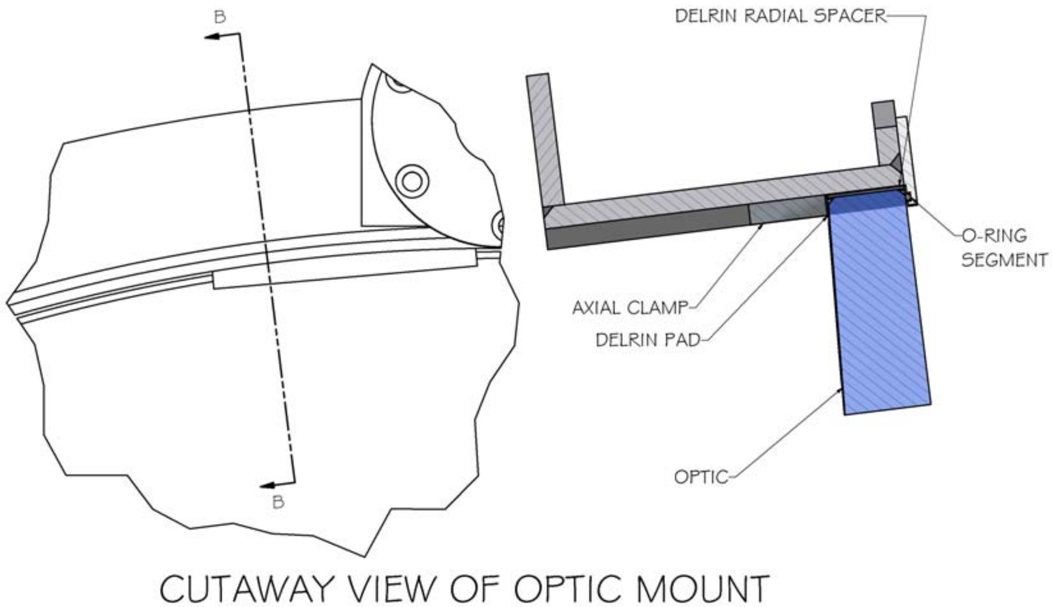

Figure 4.5

The section of o-ring provides some spring loading to hold the optic against the axial clamp. It is on the upper surface of each optic when pointed at the zenith. An index tab is glued to the optic and is restrained in a slot in the cell to control prism rotation in the cell.

The inner surfaces of the prisms are parallel to each other and tilted 0.83 degrees to the optical axis. The tilt is accomplished by mounting the ball slides at a 0.83-degree angle from axis of the cell. The ball slide mount pads are bolted onto the cell and also hold the index tab for the fiducal/limit sensors.

4.2.4 Structure

The stiffness requirements on the structure are greater with the single ball screw design than with the 3-ball screw design. These are met by making the base a rectangular tube structure. A finite element analysis of the entire structure has been preformed. The stresses are all within allowable levels for the materials used. The deflections of the prisms from desired locations have been predicted. The maximum tilt of a prism due to gravity is 1 mm across the diameter. The lowest modal frequency is 10 hertz.

The deflections predicted are all well within the requirements set forth in the optical design. The loads and stresses predicted are all within safe loads and stresses for the mechanisms and materials used.

4.2.5 Mechanisms

The moment load resulting from a single ball screw placed at the edge of the prism cell is taken by the ball slides. As a result, each cell will be supported by two ball slide assemblies, one on each side of the instrument. Each assembly has two slides that are separated by 7" centers to accept the moment. There are separate assemblies in the forward and aft ends of the instrument so that the slides can move past each other to get to the null position. We have identified and obtained quotes on slides from two manufacturers that meet the requirements.

The ball screw diameter is constrained partly by the manufacturers ability to manufacture one of adequate length. We have specified a 25 mm diameter screw and identified two manufacturers that can supply them. There will be separate screws in each half of the instrument. These will be constrained axially and radially by bearings at the ends near the center of the instrument. The other end will be constrained radially by a bearing. They will be coupled together by the timing belt pulley.

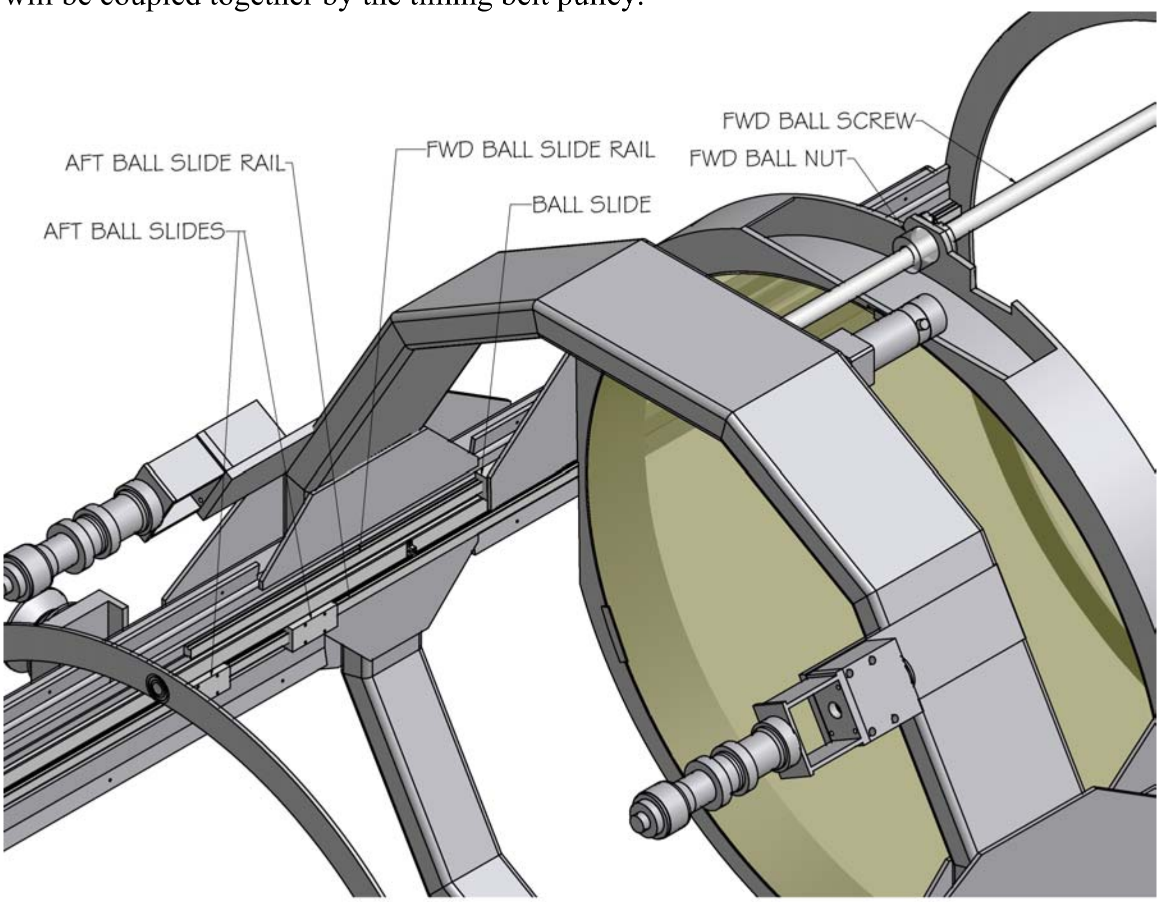

Figure 4.6 Shown without aft cell assembly or aft ball screw

The motor will be a Pitman, or equivalent, servo motor controlled by a Galil controller. A Bayside 10:1 gearbox will provide speed reduction and a timing belt will connect to the ball screw.

4.2.6 Structural Analysis

A finite element analysis of the entire structure has been run. This models the structural tubes as plate shell elements, parts of the prism cells as solids, and uses some beam elements to tie things together. The optics were represented as plate shell elements of a constant thickness equal to the average thickness of the prisms. They are held in the cells by x,y,z constraints at one point at each mounting pad. Since the pads are actually 3" long, this over-predicts the stresses; however, constraining at additional points introduces moments that are not representative of the actual mounting scheme. The cladding was not included in the analysis. The cladding is not expected to affect the structure, except for stiffening the end rings.

The coordinate axis for this analysis, with the instrument at the horizon is: z along the optical axis (+ in direction of light travel), y vertical (+ down), x horizontal (+ left when looking at back of instrument).

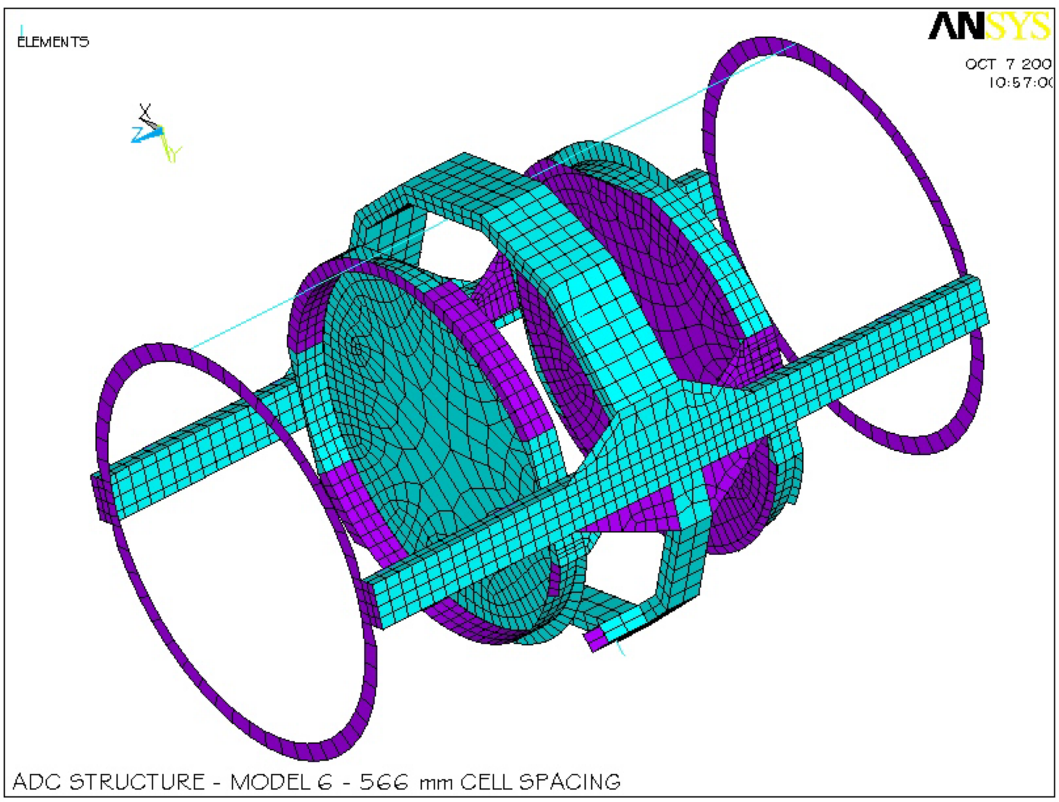

Figure 4.7

A modal analysis and various gravity loads were run. The gravity loadings were:

1) Instrument at zenith with full dispersion correction. This is a worst case, not an operating mode.
2) Instrument at zenith with null correction
3) Instrument at 30 degrees from zenith at the 30-degree correction, 568 mm prism separation.

4) Instrument at 60 degrees from zenith at full correction, 1700 mm prism separation.
5) Instrument at horizon at full correction. Full correction will be the normal observing mode from 60 degrees zenith distance to the limits of telescope travel.
6) An analysis was run with an arbitrary 10-pound load applied axially on the ball slides of one side of the optic only. This was to simulate friction on one set of slides. The loads and stresses were well within tolerances.

The modal frequencies less than 100 Hz are:

Table 4.1

MODE	FREQ	
1	10.187	End Ring
2	10.195	End Ring
3	10.662	Aft Cell
4	11.856	Forward Cell
5	18.867	
6	21.579	
7	24.592	
8	29.771	
9	29.812	
10	29.836	
11	29.908	
12	38.099	
13	42.538	
14	45.343	
15	45.459	
16	56.079	
17	61.495	
18	61.991	
19	63.415	
20	64.707	

The end rings will be stiffened in the process of completing the cladding design during the detail design phase. At the moment these show the largest deflections and result in the two lowest modal frequencies. Ignoring the two end ring modes, the third and fourth frequencies are theta y cell rotations as shown below. The third mode is the aft cell.

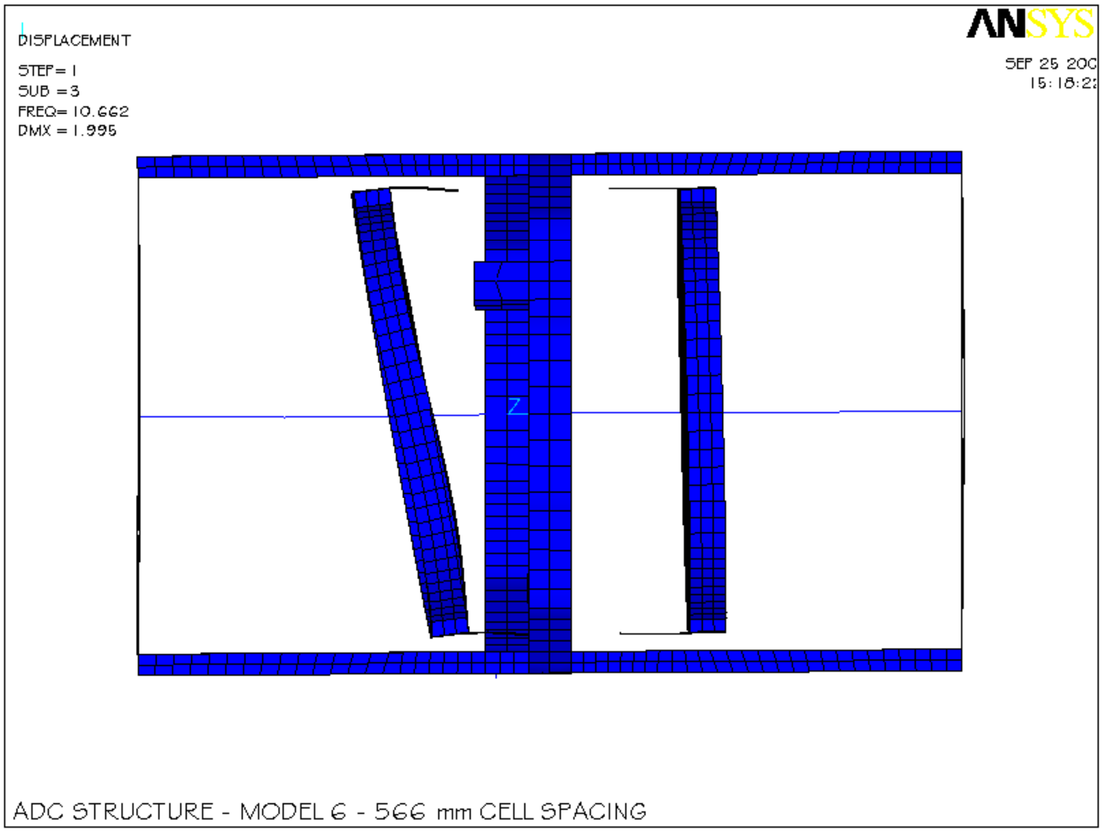

Figure 4.8 Mode #3, 10.7 hertz, theta y rotation of aft cell.

At 10.7 and 11.9 hertz these are adequately stiff; however, care will be taken during the detail design to be sure that they do not degrade.

The zenith gravity load with full correction gives the worse case deflection of the prisms. The largest deflection is a tilt of 1 mm across the diameter. This is a theta x rotation. These are both in the same direction; therefore the inner surfaces of the prisms stay nearly parallel. Their relative tilt is .25 mm across the diameter. The most stringent optical constraint is the relative tilt between the inner surfaces of the two optics. This shows up as ROTX and ROTY in the data presented. The optical tolerance is 0.2 degrees.

The deflections of the optics in several modes are provided below. They are all within the optical requirements.

The worst-case rotations and deflections of the center of the prisms are:

Table 4.2

FULL CORRECTION (1700 MM) AT ZENITH						
OPTIC CENTER	UX (mm)	UY (mm)	UZ (mm)	ROTX (deg)	ROTY (deg)	ROTZ (deg)
AFT OPTIC	0.06	-0.15	0.73	0.055	-0.005	-0.003
FWD OPTIC	-0.03	0.20	0.76	0.053	0.027	0.006
Difference	0.09	-0.36	-0.03	0.00	-0.03	-0.01

The deflections during operation at zenith are:

Table 4.3

10 MM CORRECTION AT ZENITH						
OPTIC CENTER	UX (mm)	UY (mm)	UZ (mm)	ROTX (deg)	ROTY (deg)	ROTZ (deg)
AFT OPTIC	-0.02	0.03	0.44	0.036	0.001	0.001
FWD OPTIC	0.00	0.01	0.52	0.039	0.008	0.002
Difference	0.01	-0.02	0.08	0.003	0.006	0.001

The deflections during operation at 30 degrees zenith angle are:

Table 4.4

566 MM CORRECTION AT 30 DEGREE ZENITH ANGLE						
OPTIC CENTER	UX (mm)	UY (mm)	UZ (mm)	ROTX (deg)	ROTY (deg)	ROTZ (deg)
AFT OPTIC	0.00	-0.01	0.57	0.043	0.004	-0.001
FWD OPTIC	-0.03	0.07	0.56	0.039	0.008	0.003
Difference	-0.03	0.09	-0.01	-0.003	0.004	0.005

The deflections during operation at 60 degrees zenith angle are:

Table 4.4

FULL CORRECTION (1700 MM) AT 60 DEGREE ZENITH ANGLE						
OPTIC CENTER	UX (mm)	UY (mm)	UZ (mm)	ROTX (deg)	ROTY (deg)	ROTZ (deg)
AFT OPTIC	0.05	-0.03	0.29	0.023	-0.001	-0.004
FWD OPTIC	-0.05	0.26	0.45	0.037	0.004	0.006
Difference	0.10	-0.29	-0.16	-0.014	-0.005	-0.011

The deflections of the optics at the horizon and full correction are:

Table 4.5

FULL CORRECTION (1700 MM) AT HORIZON						
OPTIC CENTER	UX (mm)	UY (mm)	UZ (mm)	ROTX (deg)	ROTY (deg)	ROTZ (deg)
AFT OPTIC	0.02	0.06	-0.05	-0.004	0.001	-0.002
FWD OPTIC	-0.02	0.17	0.12	0.013	-0.001	0.003
Difference	0.04	-0.11	-0.16	-0.017	0.002	-0.005

A finite element model of the optic constrained at 3 points similar to the current mounting scheme was run to predict stresses and deflections in the glass. Since these constraints are at points instead of spread out over the three-inch mounting pad, this is a conservative approach.

The stresses in the aft optic at the zenith are:

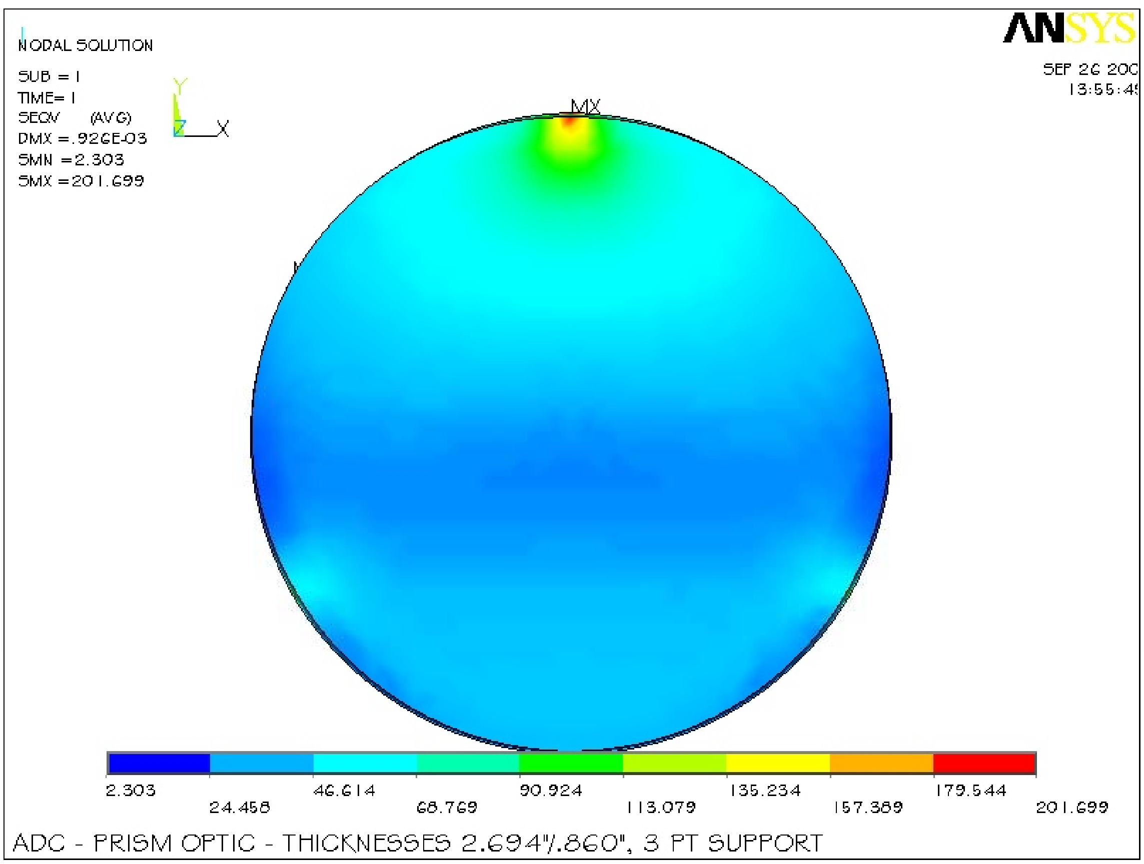

Figure 4.9

The stresses in the forward optic at the zenith are:

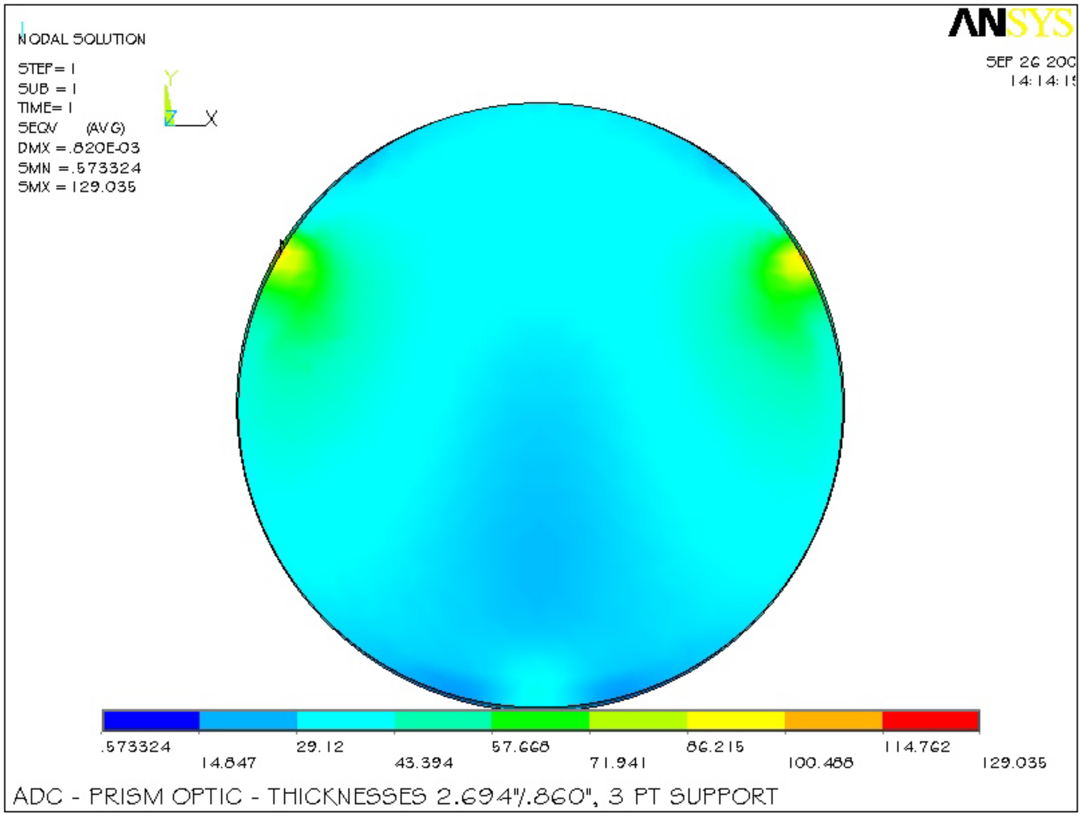

Figure 4.10

Deflection of the aft optic due to gravity, looking at zenith:

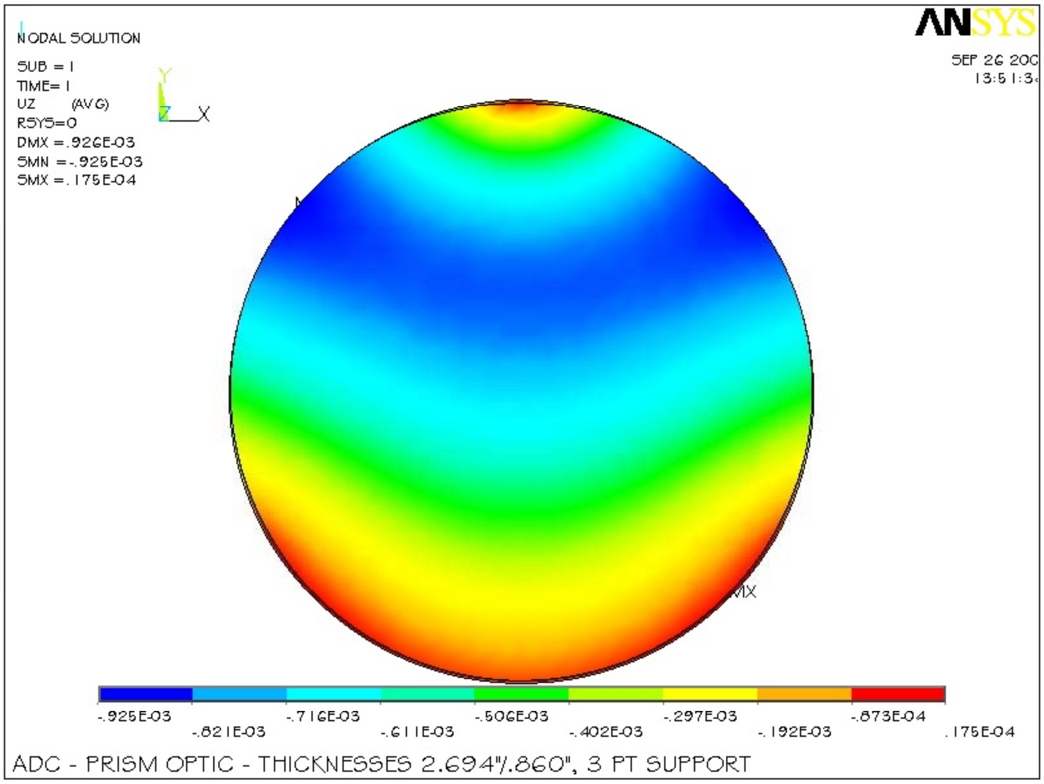

Figure 4.11

Deflection of the forward optic due to gravity, looking at zenith:

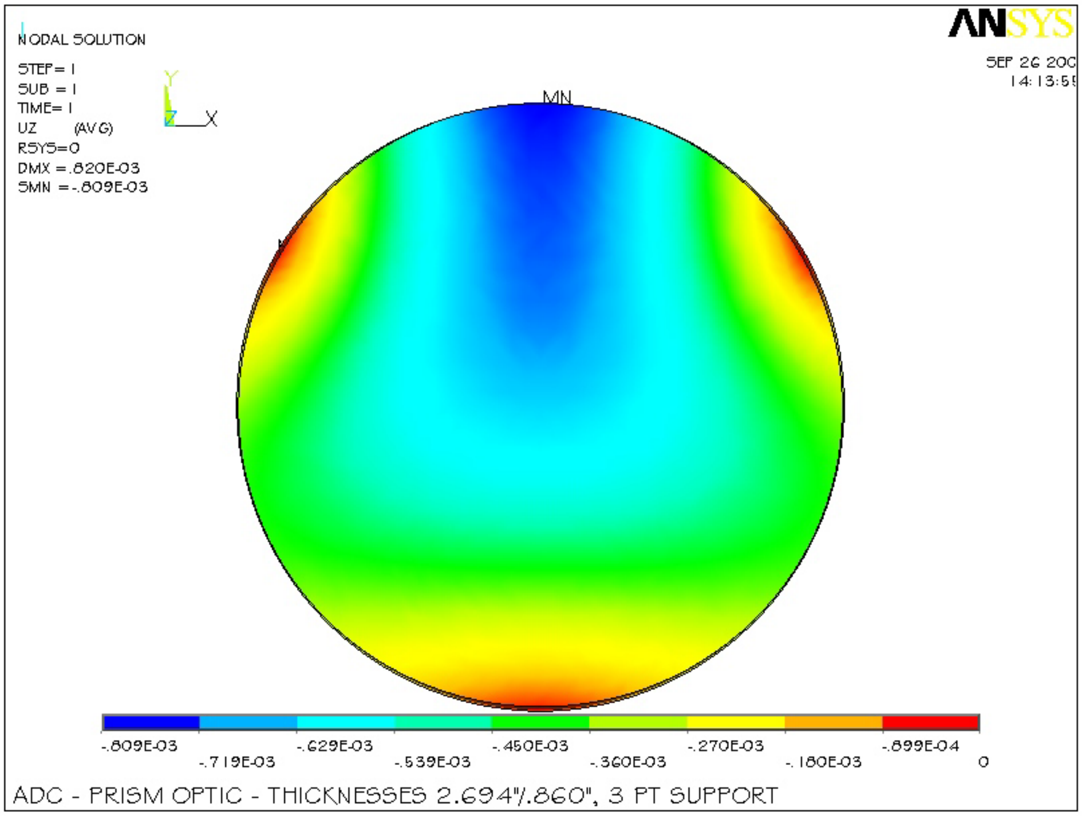

Figure 4.12

Stresses in steel looking at zenith with 1700 mm correction are:

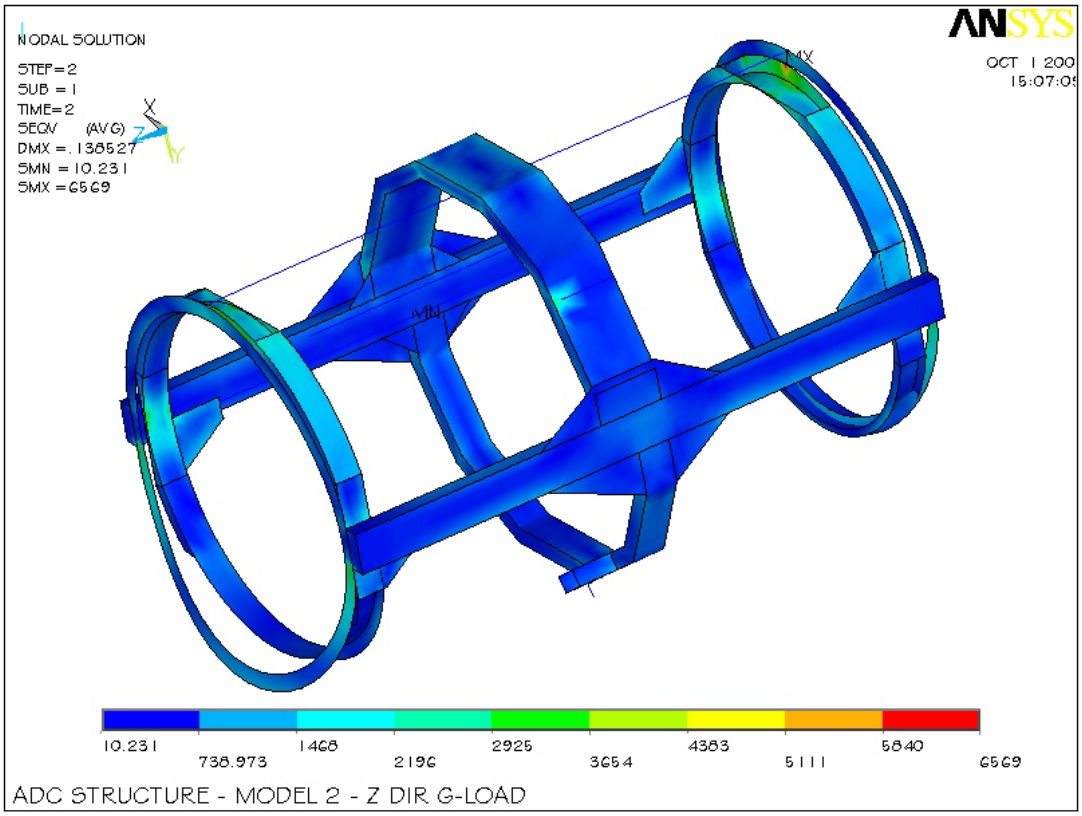

Figure 4.13

The high stresses at the connection of the ball screw to the cells are an artifact of the analysis. These are still well below the yield stress of mild steel (35,000 psi).

4.2.7 Mechanical Performance

The maximum travel rate for an individual prism will be 20 mm/sec. This allows the correction adjustment of the ADC to keep up with the telescope slew rate at 60 degrees zenith distance. The maximum separation of the inner surfaces of the prisms is 1700 mm and the minimum separation is 10 mm.

The positional accuracy is limited by flexure of the instrument. The positional deflections due to gravity are presented in the structural analysis.

Maximum power to the motor is expected to be 10 W. This will be dissipated by the motor and the mechanical components of the instrument. We do not expect this to be significant. This is less than the 50 W maximum specified in the requirements document.

4.2.8 Encoder, Fiducal, and Limit Locations, Mounting and Logic

A rotary encoder will be installed on the front of the instrument, keyed to the ball screw. This will be used by the software to determine that the drive system is functioning properly. The fiducals and limits will be Hall effect sensors that are mounted along the ball slide support tube between the ball slides on one side of the instrument.

The fiducal will be closer to one end of travel, in the maximum correction direction, than the length of the index tab. When the instrument powers up, if the fiducal is blocked by the tab the cell will move toward the center of the instrument, otherwise it will move outward. A complete description of the logic and wiring is provided in drawing EL-3610.

4.2.9 Electronic Enclosures

We plan to package the electronics in two MENA Type 4 enclosures mounted close together and coupled with a large nipple. One will contain the electronics and the other the breakers and disconnects. The two boxes selected are Hoffman # CSD363020 for the electronics and # A1212CHNF for the beakers.These will be mounted on the HIRES Nasmyth platform and will connect to the ADC through the elevation cable wrap. They will be connectorized so that they can be moved to the Nasmyth deck to operate the ADC when it is parked there. Wheels will be installed to move the assembly.

4.2.10 Jack Stand Design

The jack stand will mount permanently on the Nasmyth deck behind the module handler for the transfer module. It has two long forks that extend under the ball slide support tubes for the aft optic, and dowels that key into the support tubes. These lift the ADC free of the rails in the transfer module by pivoting upward. The pivot is actuated manually with an acme screw.

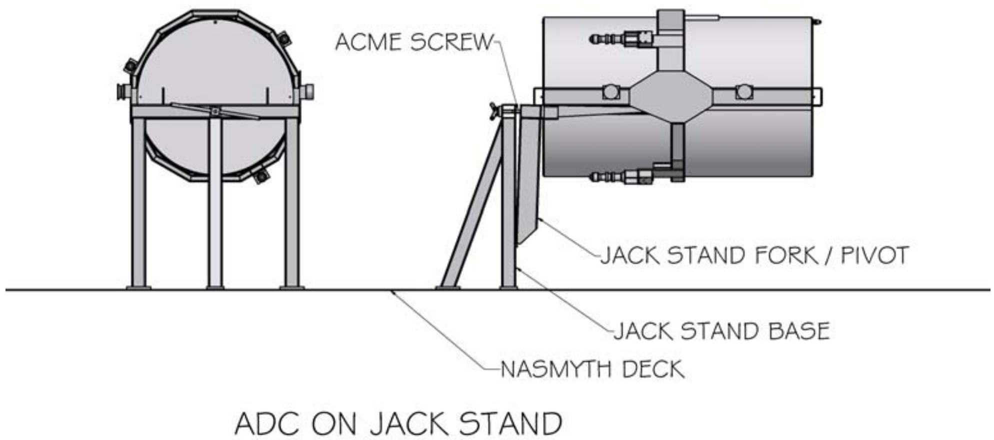

Figure 4.14

Figure 4.15

4.2.11 Testing at Santa Cruz

We plan to construct a test stand and environmental chamber and test the operation of the ADC through the gravity changes from zenith to the horizon. The defining points will be removed and the ADC will be mounted to the test stand with bolted blocks for these tests.

This stand may be used during the assembly and will be available to Keck after our testing.

Some of these tests will be conducted at 0 degrees C. These will be with dummy optics that weigh the same as the real ones.

4.2.12 Assembly and Part Drawings: PDF Files (Appendix 3)

4.3 Electrical Design

The control electronics for the Keck Cassegrain ADC will consist of a control computer and an electronics enclosure located at the Cassegrain focus. The electronics will provide for the drive and safety of the ADC prisms. The control computer will communicate with the stand-alone Galil servomotor controller, located in the electronics enclosure, via an ethernet connection. See Keck ADC Block Diagram, Appendix 4.

4.3.1 Control Computer

The control ("target") computer has been determined by the UCO/Lick and Keck software groups to be a standard Keck Solaris computer. There are no special hardware requirements.

4.3.2 Electronics Enclosure

The electronic enclosure will be a commercial box that will hold all of the control electronics. The box will include connections for coolant, AC power, observatory E-Stop, and communications. The box will include a second electrical box with a hinged cover that will contain the circuit breakers, over temperature shutdown relay circuit, local/remote operation switch, and manual pushbuttons to run the stage locally. Other items found in the enclosure include the standalone Galil servomotor controller, a terminal server (if used), a power control/distribution box, the servomotor power supply, a limit interlock/interconnect box, the Protheus flow switch, a fan control box, and the cooling fans/heat exchanger. In addition, the enclosure will include a series of connectors for the servomotor, the stage limits, the servomotor encoder, and the auxiliary encoder. Lastly, the enclosure will have a prominently displayed E-Stop switch.

4.3.3 Communications

Communications to and from the ADC control electronics will be performed over a Ethernet connection. A standard CAT-5 connection will bring the Ethernet into the enclosure where it will either connect to the Galil controller or a small Ethernet hub. Internal to the enclosure communications paths will be in place to the Galil controller and the Pulizzi power controller.

4.3.4 AC Power

The AC power will enter the electronics enclosure via a 7-pin Bendix SP02E-22-96P connector. The Observatory will provide AC power via a mating 7-pin Bendix SP06E-22-96-SR cable-end connector. Though the Observatory provides both "clean" and "dirty" power, the instrument will make use of only the "clean" circuit. Power will then be wired into a Carlingswitch AA2-B0-24-610-181-C 10A circuit breaker. Because the ADC is a relatively small instrument, there will only be the one breaker. The breaker will feed the instrument's over-temperature protection circuit. This circuit will remove AC power if the temperature inside the electronics enclosure exceeds 80° F (26.7° C). The AC power is then fed into the Pulizzi AC power controller from which it is distributed to the various components of the control system

4.3.5 Stage Wiring

Stage wiring will consist of four components. The motor power will be wired with a shielded, twisted pair cable using a 4-pin connector. The servo motor encoder will be wired with a shielded, twisted pair cable and a 10-pin connector. The stage limits, primary, and secondary, along with a home fiducial, will be wired with a shielded, twisted pair cable using an 8-pin connector. The auxiliary encoder will be wired with a shielded, twisted pair cable and a 12-pin connector. In all cases, the shielding will be electrically tied to the metal of the electronics enclosure. We will also provide an emergency stop-motion control at both the stage and the electronics enclosure.

4.3.6 Cooling

The cooling system for the electronics enclosure will consist of a heat exchanger and two cooling fans. Temperature in the enclosure will be maintained at about 5° C. The cooling loop will consist of a semiconductor sensor and the cooling fans. The Galil will actively monitor the temperature inside the box and turn the fans off and on to maintain a temperature within a range of ±3° C.

4.3.7 Observatory E-Stop

As per the DEIMOS instrument, an E-Stop relay will be included on the ADC instrument. The operation of the E-Stop relay will be that if the E-Stop voltage is removed, the power to the servo motor will be removed. This will be accomplished by running both connections to the motor through contacts on the relay. A signal will also be sent to the Galil to inform the software of the condition. The connector that will be provided for the E-stop circuit is a KPT02E12-3P. This will mate with the Observatory-supplied PT06E-12-3S-SR cable-end connector. The 120V AC signal will operate a Potter & Brumfield KUP-11A55-120 relay. One set of contacts on the relay will interrupt drive power to the servo motor and another set of contacts will be wired into the Galil controller to inform the software that the instrument has been locked out by the Observatory E-Stop.

4.3.8 Local Operation

Local operation of the ADC stage will be accommodated through the use of a local/remote toggle switch and a pair of pushbuttons to run the stage in either direction.

4.3.9 Documentation

The electronics documentation for the ADC will consist of complete set of schematics and wiring diagrams. Each schematic will also be accompanied by a short write-up/circuit description in the form of a HTML page. The documentation will be delivered as two complete hard-copy sets in binders and two CD-ROMs with both the original PCAD drawings and PDF files.

4.4 Software

4.4.1 ADC hardware

The ADC software has to carry out just a few simple functions: controlling the separation of the prisms, monitoring coolant flow, and turning the fans on or off as needed.

The prism separation will be driven by a servo motor under the control of a Galil DMC 2200 motion controller. The DMC-2200 is a standalone unit, with communications taking place over serial and/or 100Base-T Ethernet lines; the ADC will use Ethernet.

The process that communicates with the Galil is the ADC "dispatcher." The dispatcher will monitor DCS demands, implement the ADC keyword service, and send motion control commands to the Galil. The dispatcher plus the code that runs on the Galil (as described below) combine to form the target software, which is the application suite that implements the ADC keyword service and motion control system.

The ADC target computer is the primary computer on which the target software runs, and can be a standard Keck Sun computer. The target software's demands for CPU use and I/O are very low, so there is no performance requirement that this be a standalone computer reserved for ADC: it is perfectly reasonable to run the target software on a computer that also has other, non-ADC tasks.

The telescope OA will interact with the ADC through a DCS GUI control row ("host software," in the requirements document), running on the "host computer." The control row will be similar to an instrument rotator control row, and the software interface will be analogous to a rotator interface: DCS shall provide keywords to tell the ADC to INIT/STBY/HALT, and to provide status and error feedback.

The target software will constantly monitor the following:

- prism separation;

- prism velocity;
- coarse load encoder;
- limit switches;
- coolant flow status;
- E-stop input;
- remote/local control switch;
- electronics enclosure temperature;
- motor interlock.

At all times, the target software will control the following:

- fans (on or off)
- over-temperature power cutoff

When the remote/local switch is in "local" mode:
The 24V motor power supply is switched away from the Galil and is under the control of pushbuttons at the telescope: the Galil and hence the target software can monitor but not control the prisms.

When the remote/local switch is in "remote" mode:
The target software has normal control over the 24V power supply.

4.4.2 DCS Software

The DCS keyword service will be modified by CARA to provide the following keywords, which are closely analogous to the rotator-control keywords described in KSD 46, section 3.5:

- ADCINIT/ADCSTBY/ADCHALT plus complements;
- ADCSTAT, ADCSTST, ADCERRS, ADCERVL
- ADCMODE (tracking, fixed value, or halted)
- ADCDEST (contains the desired prism separation)
- ADCPOSN (to report the current prism separation)
- ADCSRVER (servo error: ADCPOSN - ADCDEST)

We have not yet decided if DCS will compute the correct ADC prism separation when in tracking mode, or if the ADC target software will compute the separation. If ADC computes the separation, then the DCS keyword ADCDEST should be writable, so that the ADC can inform DCS of the desired separation. On the other hand, if DCS computes the prism separation, then it will need to have two additional writable keywords, WAVELO and WAVEHI, to specify the bandpass for which the dispersion correction should be optimized.

For planning purposes, this document assumes that the ADC target software will compute the separation, and write its value to ADCDEST.

4.4.3 Target Software

Most of the target software resides on the target computer, mainly because the Galil control language is very primitive, and much harder to maintain and update than any modern language code running on the target computer. However, since networks are subject to disruption, it is important to operate any safety-critical software on the Galil itself. Local-control mode must be operable when the network is not available, so any local-control software must also run on the Galil.

A. Galil Software

The Galil supports up to eight independent threads of code. One thread will be devoted to monitoring the network connection to the dispatcher. If the connection should fail when the ADC is in remote-control mode, then the thread will bring all motion to a stop and set an output bit to indicate the failure.

The following threads of code will run on the Galil at all times:

- The network-monitor thread will keep track of both the Galil's own built-in variable that monitors the state of TCP connections, and a timer that will be periodically re-initialized by the dispatcher. If either the Galil variable indicates an error or the timer expires, the monitor thread will infer that the dispatcher is unable to communicate with the Galil. The nominal timer value will be one second.

  There is no special local-control software to run on the Galil, because the local-mode switch will disconnect the Galil from motor control: the Galil is unable to control the motors and therefore can take no safety actions.

- The temperature thread will monitor the electronics enclosure temperature. It will control the fans and over-temperature switch. Should the temperature should exceed a safety threshold, power to the motor and electronics will be cut off.

- The coarse load monitor will compare the coarse load encoder to the motor encoder position. Should they disagree, motion will be stopped. Note that this will not have any effect during local-mode operation.

B. Dispatcher Software

The dispatcher has the following functions:

- monitor DCS keywords ADCINIT, ADCSTBY, ADCHALT;
- provide feedback to the DCS GUI's ADC control row through the new DCS keywords ADCSTAT, ADCSTST, ADCERRS, ADCERVL;
- provide feedback through the new DCS keywords ADCMODE, ADCDEST, ADCPOSN, ADCSRVER;
- provide an ADC keyword service to control all ADC functions and monitor ADC status;
- control the ADC hardware via the Galil.

It will be implemented as a multi-threaded process, with the following threads:

- Galil I/O: this thread manages all Galil I/O, multiplexing the requests from the motion control thread and the Galil status thread. This thread's rate is driven by requests from other threads.

- Galil status: this thread monitors the Galil status and updates corresponding dispatcher state variables. It periodically re-initializes the Galil timer thread. It broadcasts ADC keyword changes at 1-Hz intervals. All data needed for ADC keywords are collected here. This thread will run at about 10 Hz, to ensure that it updates the Galil timer sufficiently rapidly and that it collects data sufficiently quickly that a human will not notice any latency due to this thread's timing.

- Motion control thread: all motion of the motor is driven by this thread. It runs a PID control loop that sends position demands to the Galil. If the motor should be stopped, this is the thread that monitors the stop request, and sends the stop commands to the Galil.

  Control thread update rate: when tracking, the motor will be moving at a typical rate of 0.067 mm/sec, or about 400 motor counts/sec. The requirements document specifies a "typical" error limit of 0.1% of full range, or about 0.9 mm. A tighter constraint comes from the software limits, which will be placed about 1 mm from the limit switches. Allowing 0.5 mm stopping distance, we need to detect the software limits within 0.5 mm of reaching them, or within 7.5 sec at track speed. (Slew speed does not matter, because we will not accept a slew request that is beyond a software limit.) Conclusion: a 1-Hz update rate is nearly an order of magnitude safety margin.

- DCS monitor: this thread will monitor the INIT/STBY/HALT keywords. When one of these keywords changes, the request is forwarded to the request thread for handling. Update rate: as requested by DCS.

- DCS updates: a separate thread to update the DCS status keywords. It may be necessary to implement this as a distinct co-process (as was done for the DEIMOS rotation controller) rather than a thread, so that the updates can be handled separately from the monitoring. Alternatively, we might choose to merge this thread with the DCS monitor thread. Update rate: 2 Hz.

- Traffic daemon communications: this thread will manage communications with the traffic daemon, through which all ADC keyword messages travel. All incoming requests are received by this thread and are handed to the request thread for processing. Update rate: driven by requests from others; normally 1 Hz, the broadcast rate.

- Request thread: all KTL reads and writes are handled here, as are motion changes required by the INIT/STBY/HALT DCS keywords. KTL reads are handled directly. Motion requests are passed to the motion control thread; other KTL writes are handled directly. Update rate: driven by requests from others.

Overall, the software is very low-load: the Galil status thread will request approximately 250 bytes of data every 100 ms, and will write approximately 20 bytes to the Galil every 100 ms. Other threads run at typically 1 Hz updates. By comparison, the DEIMOS control system, running on a 900 MHz Pentium P3, is able to update Galil status at 500 Hz and runs its PID loop at 20 Hz. We anticipate the ADC software will present at most a few percent load on the I/O channels and CPU of any modern computer.

4.4.4 Traffic Daemon

The ADC service will be implemented using the MUSIC message method; therefore, a "traffic" daemon must run for the MUSIC messages. The traffic daemon will run on the target computer.

4.4.5 ADC keyword service

The ADC keyword service will implement the following keywords:

SEPMM (r/w) Separation between prisms, in mm (real).
SEPUM (r/w) Separation between prisms, in microns (int).
SEPENC (r/w) Separation between prisms, in motor encoder counts (int).
SEPTRG (r) Target separation between prisms, in motor encoder counts (int).
SEPENCCO (r/w) Separation between prisms, coarse load encoder counts (int).
SEPVELUM (r/w) Velocity of prism separation, in microns/sec (real).
SEPVELMM (r/w) Velocity of prism separation, in mm/sec (real).
SEPVELEN (r/w) Velocity of prism separation, motor encoder cts/sec (int).

ADCEL (r/w) Elevation for which ADC is correcting, in deg (real).
WAVELO (r/w) Lower wavelength of optimal ADC correction, in Angstroms (real).
WAVEHI (r/w) Upper wavelength of optimal ADC correction, in Angstroms (real).

TORQUE (r) Torque of separation motor (real).

SRVERRUM (r) Servo tracking error when ADCMODE=TRACK, microns (int).
SRVERRMM (r) Servo tracking error when ADCMODE=TRACK, mm (real).

ADCMODE (r/w) Overall ADC mode:
Values are:
1. MANUAL: prism separation is controlled by modifying the ADCEL or SEPxxx keywords.

2. TRACK: prism separation is automatically set to correct the dispersion according to the current telescope elevation.
3. HALT: ADC ignores all motion commands. It changes out of this state upon receiving ADCINIT=true from DCS, or when the ADCMODE is explicitly modified.

ADCLCK (r/w) Software lockout. Must be set to "unlocked" in order to enable MANUAL-mode commands.

MOTORPWR (r) boolean: indicates if motor power is servo-controlled.

ESTOP (r) boolean: indicates if E-stop switch is engaged.

ADCLIM (r) Limit switch status.

ADCSTA (r) Overall ADC status (Halted, Calibrating, Slewing, Tracking, etc.)

ADCSWSTA (r) ADC software status (software health keyword; values TBD.)

ADCCLOCK (r) Most recent Galil sample number. Acts as a "heartbeat" keyword.

ADCCAL (r/w) Home all motors, or report state of same.

CONTROL (r) State of local/remote switch.

TEMPR (r) Temperature, raw volts.
TEMPC (r) Temperature, Celsius.
COOLFLOW (r) boolean value indicating if coolant flow is OK.
FAN (r/w) Fan's off/on state.

4.4.6 Graphical User Interfaces

A modest graphical user interface (GUI) will be supplied with the ADC target software. Although the Requirements document does not call for a GUI, we will provide a simple one for engineering purposes. The GUI will be written using Tcl/Tk, and will have keyword communication using the "Ktcl" KTL extension.

The GUI will have three modes:

1. Engineering mode (the default), which will provide display and control over most or all of the ADC service's keywords.
2. OA (observing assistant) mode, which will have a subset of ADC and possibly DCS keywords that are useful to an telescope OA.
3. Observer mode, which will have a subset of keywords that are useful to an observer.

4.4.7 Start/Stop Scripts

Standard start/stop/status scripts will be supplied. They will follow the conventions that have been established for other instruments, e.g.:

```
% adc start daemons
% adc start gui
% adc status daemons
```

4.4.8 Observer Planning Tools

At the Delta CoDR, the review committee recommended that observer planning tools be descoped, but with the statement that they could be reconsidered in the future. We have not included them here. A simple scaling factor to prism separation (based on the wavelength range of interest) may be included in the GUI. We are able to provide planning tools, if desired.

4.5 Interface with K1 Telescope and CARA facilities

The current version of the ICD for this project is available on the web at http://adc.ucolick.org/prelim_design/workplan/Cassegrain_ADC_Interface_1.2.pdf

5. Detail Design Phase Work Plan

The draft work plan for the next phase of the project development is attached as Appendix 5. This work plan would become part of the contract between CARA and Lick for this phase of the work, as the plan for the Preliminary Design was part of the contract for the current phase of the work.

6. Project Schedule

The project schedule is attached as Appendix 6.

As was the case at the CoD phase, the plan is to purchase the optics at the start of the Detailed Design Phase in order to shorten the overall project schedule. Even doing this, completion of the optics is on the critical path for the project.

The current milestones for the project are presented below and compared to the milestones planned at the CoDR:

Milestones		Milestones from the CoDR
Start of Preliminary Design	Jun 2/03	Mar 11/03
PDR	Oct 15/03	Jun 9/03
Start of Detailed Design	Dec 15/03	Jul 7/03

Order Optical Material	Dec 15/03	Jul 10/03
Detailed Design Review	Mar 9/04	Sept 3/03
Start of Fabrication	Apr 6/04	Sept 25/03
Pre-ship Review	Feb 1/05	Aug 3/04
First Light	Mar 29/05	Sept 28/04

The change in when we might expect to see first light is largely due to an increase to the testing schedule and the fact that the PD studies started later than originally planned.

7. Project Budget

The current estimate to complete the project is $1,059,991. The project budget is attached Appendix 7.

The cost estimate to complete has increased by about 23%, or by $160,000 from what was estimated at the time of the CoD for the work that would be done by Lick Observatory. The detail of this increase in shown in Appendix 8. A spending profile in graph form appears as Appendix 9.

8. Preliminary Design Report Revision History

Draft Revision 1	11 September 2003
Draft Revision 1.3	23 September 2003
Draft Revision 1.4	26 September 2003
Draft Revision 1.5	26 September 2003
Draft Revision 1.6	29 September 2003
Final Report Version 2, Rev. 1.0	6 October, 2003
Final Report Version 2, Rev. 1.1	13 October, 2003

9. References

Koo, David C., David Cowley, and Lee Laiterman. *Conceptual Design (Phase A) Report for an Atmospheric Dispersion Corrector for the Low Resolution Imaging Spectrograph (LRIS)*. Santa Cruz, California: UCO/Lick Observatory, University of California Santa Cruz, October 31, 2002

Koo, David, Drew Phillips, Lee Laiterman, Vernon Wallace, David Cowley and Sean Adkins. *Atmospheric Dispersion Corrector for the Low Resolution Imaging Spectrograph Delta Conceptual Design Report*. Waimea, Hawaii: W.M. Keck Observatory, February 2, 2003

Cowley, David. *ADC – Preliminary Design Phase Project Plan: Revision 1.2*. Santa Cruz, California: UCO/Lick Observatory, University of California Santa Cruz, May 14, 2003

Adkins, Sean. Draft Requirements For the Cassegrain ADC, Version 1.3 Waimea, Hawaii: W.M. Keck Observatory, September, 2003

Adkins, Sean. *Draft Interface Control Document For the Cassegrain ADC*, Version 1.1. Waimea, Hawaii: W.M. Keck Observatory, July 25, 2003

Appendices:

1. **Compliance Matrix**
2. **Optical Design Report**
3. **Mechanical Drawings**
4. **Electronic Drawings**
5. **Detailed Design Work Plan**
6. **Schedule**
7. **Budget**
8. **Budget Details**
9. **Expected Spending Profile**