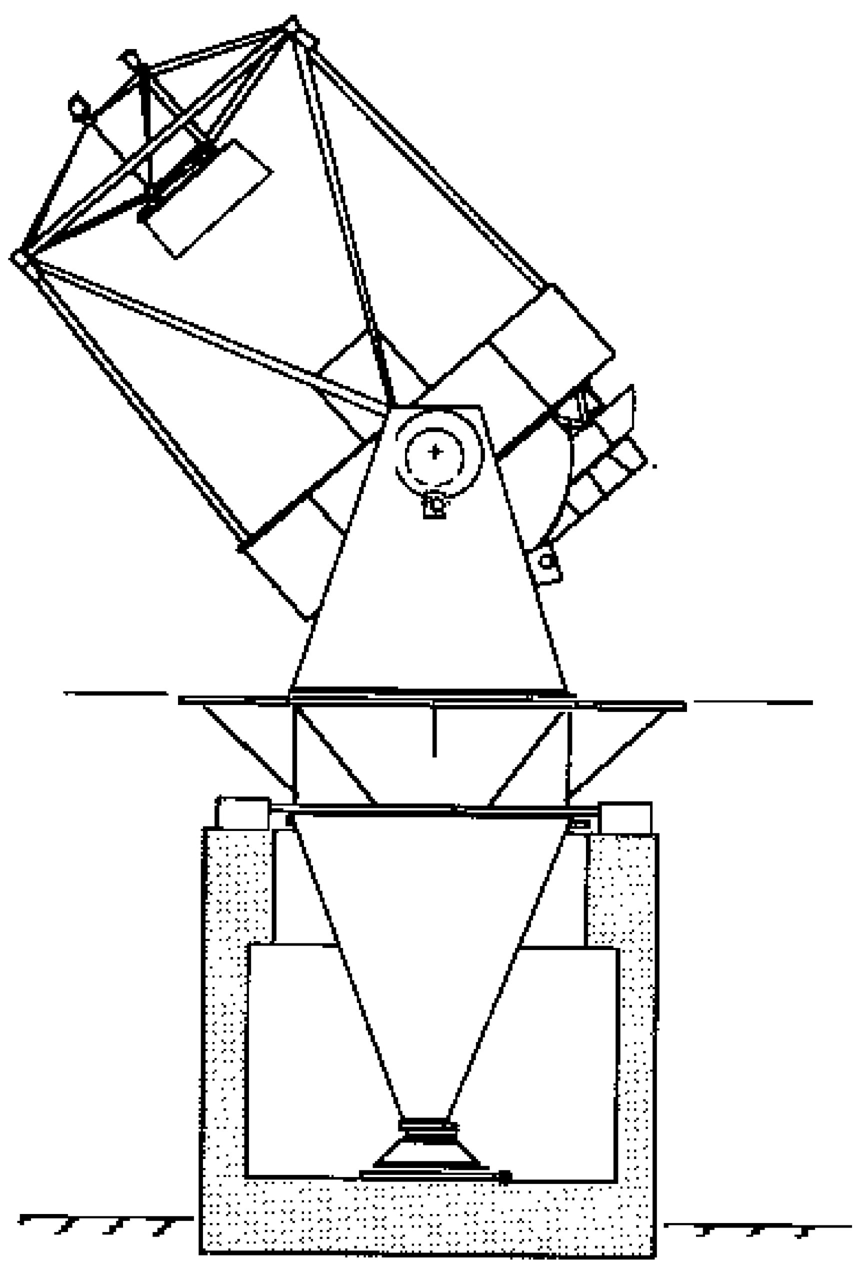
WISCONSIN
INDIANA
YALE
NOAO



3.5 METER TELESCOPE

# WIYN Operations Readiness Review: Review of Science & Technical Requirements

**WODC 02-38-01**

WIYN

# Operations Readiness Review

# Science and Technical Requirements

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# 1. About this Report

The purpose of this report is to review the Scientific and Technical Requirements for the WIYN 3.5 Meter Telescope (WODC 00-01-05, hereafter S&T document) versus the as-built telescope.

This report is organized such that the section numbers and topics correspond to those in the S&T document. In some cases, the content of the S&T document is summarized here (shown in italics). However, for completeness, the S&T document is needed in conjunction with this report.

In this report, a brief description for each scientific and technical requirement is given along with the specified requirement or goal. The as-built status is then reviewed along with the test procedure used, if applicable. In some cases, where the specification or goal was not met, the impact on operations is discussed and recommendations by the WIYN Project are presented.

A synopsis of the original specifications versus the as-built status is presented in a tabular form in Appendix A. For each section of the S&T document a description is listed along with the specifications and as-built status. The table also identifies if the requirement was a goal. The last column of the table shows the status of whether the specification was met or not.

All specifications where the as-built status is "unknown" as well as those that do not meet the requirements are summarized in Appendix B where a brief description is given along with recommendations and a list of action items.

# 2. General Considerations

## 2.1 Basic design

<u>Goal</u>: *Two additional foci are being planned for future expansion: a folded-cassegrain port on the top side of the optical support structure (OSS) and a modified-cassegrain focus immediately below the primary mirror. The beam will be directed to the folded-cassegrain focus by rotating the tertiary 90° about the primary optical axis from the Nasmyth positions. The tertiary will fold out of the way to allow the beam to reach the modified cassegrain focus. The initial design of the telescope will not include instrument rotators for these foci or the tertiary folding mechanism.*

This goal has been met because provisions were built into the telescope for future expansion at these ports. In addition, the tertiary fold mechanism has been installed and provides a clear aperture to the modified-cassegrain focus.

## 2.2 Operating modes

<u>Goal</u>: *A number of observing modes are planned. NOAO will be supporting survey and synoptic spectroscopic observations with service observing of queued programs. The universities will split their time between on-site and remote observing (Appendix A). Both groups require the ability to rapidly switch programs to adjust to changing seeing, transparency and moonlight. They will require the telescope to quickly and reliably acquire objects and to track accurately. The telescope and control system must be versatile enough to handle these requirements without undue demands on the skill level and learning curve for the operators and observers.*

This goal has been met as all member institutions frequently make use of the fast switch mode to address a variety of programs on a given night. However, the telescope pointing and tracking is not up to specification in some cases and may have an impact on certain types of programs. The status of the pointing and tracking is covered in the control system review given as a separate presentation.

## 2.3 Maintenance & Reliability

Goal: *Two strong goals of the telescope and enclosure design are high reliability and low maintenance requirements to maximize the science return.*

Although the telescope and enclosure require low maintenance in general, there are specific areas that currently require a high level of maintenance.

The azimuth and altitude axes drive motors are leaking grease onto the drive disk surfaces. The friction drive encoders contact this same surface. The accumulation of the grease affects the encoder performance and thus the telescope pointing performance. As a result, it is necessary to clean the drive surfaces on a regular basis (currently on the order of once per week). We are presently working with the manufacturer of the drive system to determine the best course of action to eliminate the problem.

The high pressure brake system has been very unreliable. The original system used a gas booster to generate 400 PSI from a standard 100 PSI compressor. The gas booster would not operate properly at low temperatures despite attempts by the manufacturer to improve the design. A five-stage compressor was then installed on-site to generate the 400 PSI. However, moisture and oil buildup in the brake lines as a result of the five-stage compressor has required a high level of maintenance. Efforts are underway to improve the system reliability (i.e. install air dryer on intake), but a complete review of the system is needed to identify future upgrades.

A buildup of sand and grit occurs in the computer alcove of the control building. This grit accumulates on and around the computers and could potentially damage components. During windy conditions, the air carries a lot of sand and grit and apparently it builds up in the computer alcove because of a negative pressure produced from the ventilation systems. A review of the enclosure and ventilation systems is needed to determine a solution.

The primary mirror system (PMS) has required a high level of maintenance due to hydraulic fluid leaks in the actuators and coolant fluid leaks in the thermal system. In both cases, the system is being improved on an as-needed basis and should eventually require less maintenance.

The telescope pointing performance has required a high level of maintenance. The pointing performance has been unstable and frequent corrections to the pointing model are needed. The source(s) of the instability is unknown, but it is suspected that many factors contribute. The friction encoders exhibit slippage that occurs both gradually over the course of a night and sometimes suddenly during large slews. Performance of one of the encoders was improved through mechanical modifications to the mount, although some slippage still occurs. The other two encoders have not been modified to date. The encoders are sensitive to dirt and grease buildup on the drive disk surface and some improvements are needed to reduce the level of buildup. Some of the pointing instability may stem from active collimation. Efforts are underway to correct for known collimation induced pointing corrections outside of the pointing model and may help to simplify the model.

Computer crashes and hangs are a reliability concern as they generally impact operations more than any other technical problem. For the most part, the crashes occur randomly to all computer systems including the low-level systems and the Sun workstations. Hardware and software upgrades are being made to improve the reliability, but this problem will likely remain at some level due to the complexity of the control system.

## 2.4 Thermal design

Goal: *A number of strategies will be adopted to control thermally induced dome seeing. These include employing lightweight structures to minimize thermal mass, ventilating the telescope and enclosure to minimize the time it takes to come to thermal equilibrium, trapping and exhausting all sources of waste heat, and the use of special coatings to radiationally decouple sources exposed to the cold night sky.*

The goal of obtaining a good thermal environment for the telescope has been met as all strategies above have been implemented. To monitor the environment, the enclosure and telescope temperature data are logged nightly. In addition, a number of thermal surveys have been conducted using a 10 micron camera as well as surface probe measurements.

Active exhaust fans have been installed to draw air through the telescope structure, from the enclosure below the observing level, and from the utility room of the control building. The waste heat is exhausted approximately 40 meters downwind of the telescope enclosure.

Thermocouples have been installed throughout the telescope and enclosure to monitor the effectiveness of the ventilation system. The results show that the telescope and dome equilibrate with the outside air within 30 minutes of opening the dome and turning on the exhaust fans. The telescope and dome temperatures track the outside air to within two degrees during the course of a night.

Results of the thermal studies show that there are no major sources of heat that may compromise image quality with the exception of the OSSCS. The OSSCS is the control electronics for the optics support structure and is mounted on the center section of the telescope. The OSSCS contains many power supplies that generate enough heat to warm the center section of the telescope in that area and nearby vertical trusses by more than a degree Celsius above the surrounding structure when the active ventilation is turned off (during the day). In the evening, after the active ventilation is activated, a temperature gradient is introduced across the vertical truss structure as the "warmed" trusses equilibrate with the others. This may have the effect of introducing coma. We do experience a nightly coma variation during the first part of each night, although it has not been verified to be a result of the OSSCS. Currently, there is an improvement project planned to dump the waste heat from the OSSCS into the dome during the day. Other options, such as relocating heat producing components off the center section, will be evaluated for future upgrades to the system.

## 2.5 Active optics

<u>Goal</u>: *The telescope will employ an active optics system to keep the primary and secondary in alignment and in focus. Wavefront and focus sensors in the focal plane will provide input for making corrections in real-time. Active force actuators on the primary mirror axial supports will be provided as required to provide a level of correction for low spatial-frequency wavefront distortions to meet the image error budget for optical surfaces and supports.*

The goal of maintaining alignment and correcting wavefront has been met, but not in real-time. Instead, lookup-tables have been implemented for open-loop corrections and a wavefront correction technique is used for occasional optics tuning (closed-loop). Currently, the CCD imager is used for the closed-loop corrections and is somewhat inefficient (a typical correction takes approximately 30 minutes). Future upgrades in the IAS and in software will eliminate the need for using the CCD imager and will streamline the wavefront correction process.

Active force actuators have been provided per the specification and will be presented as a separate review.

A real-time focus correction is still under development as part of the IAS.

## 2.6 Safety

*Working at an observatory involves working around moving pieces of equipment often at night and from high platforms and ladders. All parts of the telescope and enclosure design will be subjected to and required to pass safety reviews.*

The as-built telescope and enclosure have been reviewed by the NOAO safety committee and all identified deficiencies have been addressed. All improvements and changes to the observatory are reviewed with the NOAO safety officer prior to implementation. Routine safety inspections are conducted on a yearly basis at the observatory by the NOAO Safety officer along with the Kitt Peak Safety Officer and others.

# 3. Optical Design

## 3.1 Principal Optics

Refer to the table of Appendix A for a summary of these specifications. The specification for the conic constant of the secondary mirror was the only requirement not met. The secondary was accepted "as-is" and the telescope optics were re-spaced to correct for the different conic constant.

## 3.2 Specification of Foci

Minor changes were made to the optical design as needed to compensate for as-figured optics. In all cases, the optical quality exceeded the design specifications. Refer to the table of Appendix A for a summary of these specifications.

# 4. Image Size Budget

Goal: *The image size budget sets the imaging goals for the telescope and pre-allocates limits to the sources of image degradation to guide the design of the telescope and enclosure.*

The image budget for tracking has been evaluated independently as part of the control system review. The image budgets for the optical figuring were evaluated upon the acceptance of the optics from their respective manufacturers and in all cases surpassed their figuring specifications. The image budgets for alignment, thermal, support, and enclosure effects have not been determined independently. Instead, the delivered image quality (DIQ) of the telescope has been tracked over the past 18 months. The DIQ is measured each night of operations after performing a wavefront analysis. The DIQ is defined as the FWHM measured using the IRAF imexamine utility on 10 to 20 second CCD integrations through a Harris R filter.

Goal: *The image budget for narrow-field imaging is set by the requirement that the telescope and enclosure not degrade 0.7 arcsecond seeing by more than 0.1 arcsecond.*

The median DIQ is 0.8 arcseconds. The DIQ is 0.6 arcseconds or better 10% of the time and 0.7 arcseconds or better 25% of the time. The best DIQ measurement to date is 0.43 arcseconds.

Goal: *The image budget applies to zenith distances up to 60°. The telescope will operate at lower elevations as specified in a section 5. The contribution to image size from seeing grows as* $(\cos z)^{-3/5}$ *where z is the zenith distance. The image budgets for the telescope and enclosure are allowed to increase according to the same law thus keeping the relative contributions the same.*

Attempts were made to test this law by imaging a large sample of stars at varying zenith distances between 60° and 75° on a given night. Unfortunately, two attempts at this test gave inconclusive results due to non stable seeing conditions. Efforts to complete this test will continue during T&E blocks.

*The environmental conditions under which the image budget applies are: nighttime observing, wind speeds up to 10 m/sec. and outside air temperature gradients less than 0.5°C/hour. (10 m/sec. is approximately the 90 percentile wind speed on Kitt Peak).*

The DIQ results obtained include all environmental conditions where the dome is open. This includes wind speeds up to 22 m/s and temperature gradients on the order of 1°C/hour.

# 5. Telescope

## Axis Motion

Goal: *Axis motion in azimuth will be +/- 270° and in zenith angle will be 0.4° to 75° for observing and -2° to 90° for hard stops.*

The azimuth motion is per the specification. However, the altitude motion has no restrictions for zenith angles less than 0.4°. It is uncertain whether restrictions are needed (see blind spot tests) and should be determined so that warnings or limits can be applied if necessary.

## Zenith Blind Spot

Goal: *The zenith blind spot will be 0.8° diameter max.*

Two different tests were performed to evaluate the blind spot. The first test was to measure the servo errors for all telescope axes as an objects was tracked within 0.4° of zenith. The purpose of this test was to determine the minimum distance from the zenith that an object can be tracked without saturating the servos and to determine the degradation in servo error as a function of zenith distance. The tests involved tracking objects at various radii from zenith while acquiring 200 Hz servo data (open loop tracking). The results show that the servo data appears to be more dependent on azimuth position than on the tracking speed. The telescope was able to track within 0.2° of zenith without any apparent degradation in servo error.

The second test was to take several five minute exposures tracking near zenith while autoguiding and compare to images obtained away from zenith to determine if any image deterioration was evident near zenith. This test would also allow NIR rotation to be evaluated for signs of error. Unfortunately, a bug in the guider code was introducing an incorrect guider offset as the meridian was approached which resulted in a several arcsecond image smear in the E-W direction. Some of the smear could be a result of poor tracking performance. This test will have to be repeated once the source of the guider bug is eliminated and the tracking performance improved.

Another potential source of image smear near zenith could be flexure in the instruments. Further tests will be necessary to determine the stability of the guide probe stages as well as the imager-FSA interface.

Conclusion: The servo error data indicate that the telescope is capable of tracking within 0.2° of zenith. However, a combination of tracking and pointing errors coupled with a guide software bug prevented a conclusive test. Once these problems have been corrected, the blind spot tests will be repeated.

## Slewing

Goal: *The maximum slew rate will be 5°/sec with a slew ramp of 1°/sec$^2$. The settling time after a slew will be 10 seconds maximum. The track to track time will be 100 seconds maximum for < 360° azimuth rotation and 20 seconds maximum for < 10° offset and < 10° azimuth.*

The major component affecting the settling time after a slew is the update rate of the active optics. We define the settling time as the interval from the moment the displayed position error goes to zero to the moment the star appears to be visibly settled. To measure this, stars were monitored on the acquisition TV using a guide probe and motion was timed with a stopwatch. Settling time was measured for large elevation slews between zenith angles of 10° and 70°. The slews were initiated only after the active support was stable and the timing was done for slews in both directions. Eight measurements were made (four in each direction) and the settling times obtained ranged from 55 seconds to 75 seconds. The settling time did not exhibit any motion direction dependence. Major upgrades to the primary mirror support system would be required to reduce the settling time. It is therefore recommended that this specification be accepted as is.

The conditions under which slew tests were performed were with no additional loads due to wind, unbalance, and friction. Reduction in performance as a function of these loads was beyond the scope of this test and could be determined mathematically if desired.

The slew rate and slew ramp were evaluated by capturing servo error data every 5 ms while performing slews at various accelerations and velocities to determine under what conditions saturation occurs. The limiting acceleration may be a matter of judgment, but the criterion used is that the demand should not saturate more than once for each change in acceleration.

Values of 0.5°/sec$^2$ and 3°/sec are currently adopted as default parameters because they were the maximum values for which an acceptably brief saturation occurred. The maximum acceleration depends slightly on maximum velocity because of the speed dependence of friction, but the main reason for limiting the velocity is because of the larger time required for acceleration. There isn't much to be gained by increasing the velocity limit, because it would only be reached for very large slews, and it increases the risk of damage, since it also takes longer (and further) for the servos to decelerate the telescope. The adopted values do not meet the design goal specification and have the effect of increasing the track to track and offsetting times.

The servo tests revealed that a prototype acceleration/velocity feedback circuit on the elevation axis, that was installed to improve disturbance rejection, effectively acts as a jerk limiter preventing the servo amps from saturating. This allows running the elevation axis at speeds and accelerations considerably higher than the present settings.

Conclusion: Installation of the acceleration/velocity feedback allows the telescope to meet the slewing requirements. Therefore, the circuit should be packaged, spared, documented, and installed on both azimuth and altitude axes. Once this is done higher slew limits can be implemented. The effect of greater slew velocities on the telescope pointing performance will have to be evaluated as encoder tests indicate a degradation in performance occurs with higher velocities.

## Pointing Accuracy

Goal: *Pointing offsets ≤ 1 degree will be accurate to less than 0.2 arcseconds RMS, pointing offsets > 1 degree will be accurate to ≤ 1 arcsecond RMS, pointing offsets > 10 degrees will be accurate to ≤ 2 arcsecond RMS.*

The pointing accuracy of the as-built telescope will be covered as part of the control system review.

## Track rates

Goal: *The maximum track rate will be 0.5°/sec with a track ramp of 0.1°/sec$^2$ maximum.*

5 millisecond servo data were obtained while objects were tracked crossing the meridian near zenith (to maximize azimuth motion) and objects rising due east (to maximize elevation motion). In addition, tests were conducted where telescope slews were initiated with the slew parameters reset to the values above. In all cases the telescope met the goal.

## Tracking Accuracy

Goal: *Open loop tracking will be accurate to ≤ 0.10 arcseconds RMS for 2 minutes, and < 0.5 arcseconds RMS for 15 minutes. Closed Loop (Guided) tracking will be accurate to ≤ 0.10 arcseconds RMS for one hour.*

The tracking accuracy of the as-built telescope will be covered as part of the control system review.

# 6. Telescope Equipment

## 6.1 Baffles

Goal: *Baffles will be provided at the secondary and tertiary mirrors and on the altitude axis near the edge of the primary mirror to eliminate lines-of-sight from the focal plane to the night sky or inside of the dome. The baffles will introduce a maximum obscuration of 16.7%.*

All baffles have been installed as described above. The obscuration due to the baffles is 17.1% as determined with a ray trace program. This is the minimum obscuration possible for a one degree field.

## 6.2 Instrument Rotators

Requirement: *Instrument rotators will be provided on both Nasmyth foci with a rotation range of 360°.*

The instrument rotator range is -180° to +179.999°. The +179.999° limit is not a mechanical restriction. It is a software restriction where a position command of +180° causes the rotator to unwrap (i.e. go to -180°). This is likely a minor software bug.

Goal: *The rotation rate will be -5°/sec. to +5°/sec with a ramp rate of -1°/sec² to +1°/sec².*

The slew rate and slew ramp were evaluated by capturing 5 ms servo error data while performing slews at various acceleration limits and velocity limits to determine under what conditions saturation occurs. The results show that the instrument rotators can be slewed at the specified goal with no saturation evident. The slew parameters for the rotators are currently set to rates of 3°/sec and ramps of 0.5°/sec to be consistent with the main telescope axes slew parameters.

Goal: *The accuracy will be ≤ 5 arcseconds.*

One test for accuracy was to track an object at field center while obtaining centroid data to establish a common-mode baseline. An object was then tracked at the edge of the same field while obtaining centroid data for comparison to the baseline. The test was repeated several times at different parts of the sky. The data for this test has been obtained, but has not been evaluated. Although we do not have quantitative results, the qualitative impression is that the accuracy is quite good.

Another test was to clamp a bar to the rotator so that it contacted a dial indicator. The rotator was then moved 30 degrees away and returned. The dial indicator readings were recorded each time. The measurement was repeated ten times for both CW and CCW motions. Measurements were also checked for 180° motions. The results showed that the displacement was less than two arcseconds.

## 6.3 Instrument Adapter

The goals for the Instrument Adapter Subsystem (IAS) will be covered as part of a separate review.

## 6.4 Tertiary Rotator

Goal: *The tertiary rotator will be remotely actuated and will have a time to beam switch of less than 1 minute.*

The amount of time it takes for the tertiary rotator to move between the Nasmyth instrument ports was measure moving in both directions using a stopwatch. The time to switch from the MOS port to the WIYN Port is 70 seconds and the time to switch from the WIYN port to the MOS port is 38 seconds. The rotation does not currently meet the specification in the CW direction, but adjustments are available to increase the motor speed.

Goal: *The repeatability will be < 4 arcseconds.*

To test the repeatability, a guide camera was placed on-axis at both Nasmyth instrument ports and a star was tracked while switching back and forth between the ports. Each time a port was switched the star position was marked on the acquisition TV screen. After switching to each port seven times, the maximum spread in the datapoints was determined by commanding fixed offsets to the telescope to reproduce the maximum point spread. Using this technique, we measured the maximum point spread to be 8 arcseconds for the MOS port and 10 arcseconds for the WIYN port. As major revisions to the mechanics of the rotator would be needed to improve the repeatability and since no major drawbacks have been experienced to date, we recommend that this specification be accepted as is.

Goal: *The accuracy will be <30 arcseconds.*

This accuracy was established at the time of optics installation and has not been verified since. The accuracy will be checked as part of the collimation process needed after aluminization of the optics (scheduled for later this year).

## 6.5 Primary Mirror Cover

Requirement: *The primary mirror cover will seal the primary mirror against dust when closed. It will be designed such that it will protect against blunt impacts of up to 20 kg-m/s and present minimal cross section for wind shake.*

The mirror cover is a bi-folding type that minimizes its cross sectional surface and provides baffling for the Nasmyth instrument ports. A rubber seal is present at all interfaces to provide a dust seal when closed. The mirror cover material is one inch thick aluminum with honeycomb cells for lightweighting. The blunt impact specification has not been verified.

## 6.6 Flat Field

Goal: *A screen and illuminating lamps covering the full aperture of the telescope for calibrating the instrumental response over the full field of view. The screen will be mounted on the inside sloping panels of the dome oriented so that it may be viewed normal to the optical axis of the telescope. Two banks of flat field lamps will be provided: a high intensity set for quick exposures and a continuum set with color balance filters.*

A screen was fabricated using left-over panels from the dome. The screen is mounted on the inside sloping surface of the dome 90 degrees from the shutter opening. A bank of four high intensity and four color balanced lamps have been installed on the vertical trusses of the telescope. Tests show that the high intensity lamps provide a very good flat field. The color balanced lamps have not been tested for flatfielding because of difficulties in finding lamps with satisfactory illumination patterns (the lamp beams are too narrow).

# 7. Instrument Mounting & Weights

Refer to the table of Appendix A for a summary of these specifications.

# 8. Instrument Support

## 8.1 Nasmyth Instruments

Goal: *Provide services for instrument support at each Nasmyth focus.*

The MOS fork tine has the following available:

| | |
|---|---|
| UPS power: | 120 VAC, 15 amp. |
| Dirty power: | 120 VAC, 15 amp. |
| Control lines: | two serial lines with DB-25 connectors |

The WIYN fork tine has the following available:

| | |
|---|---|
| UPS power: | 120 VAC, 15 amp. |
| Dirty power: | 120 VAC, 15 amp. |
| Dry filtered N2: | two ports with 10 cfh flow gauges |

The IAS interface panel has the following available from the computer room.

| | |
|---|---|
| Control lines: | two serial lines with DB-9 connectors |
| Data lines: | four RG-59U coax lines |
| Optical fibers: | six lines with ST-type connectors |
| Power/control: | 12-cond., 16AWG cable with Burndy connectors |
| Video acquisition: | 3 channels (two coax, one 19-cond. gain control each) |

## 8.2 Spectrograph Laboratory

Goal: *Two stations will be provided for stationary spectrographs. The first will be occupied by the MOS. The other will be available for future instruments.*

The Bench Spectrograph Room (BSR) for the MOS has the following available:

| | |
|---|---|
| UPS power: | 120 VAC, 15 amp. |
| Dirty power: | 120 VAC, 15 amp. |
| Control lines: | as required |
| Video control: | as required |
| Dry filtered N2: | two ports that share a 10 cfh flow gauge |

Compressed air: 100 PSI regulated down to 40 PSI
Remote alarm sensors:
$O_2$ depletion.
Interconnected smoke detector.

Fiberoptic feed to spectrograph room:
Cableway for four 100 optical fiber cables in four 2" diameter armored flex-conduits.

The Auxiliary Spectrograph Room (ASR) has the following available:
UPS power: 120 VAC, 15 amp.
Dirty power: 120 VAC, 15 amp.
Dry filtered N2: one port with a 10 cfh flow gauge
Remote alarm sensors:
$O_2$ depletion.
Interconnected smoke detector.

A cableway into the ASR is available and services will be installed on an as-needed basis.

# 9. Facility Instruments

## 9.1 Hydra

Goal: *Robot for positioning fiber optics in the focal plane of the MOS port. Hydra will mount directly to the instrument rotator and place its focal plane at the appropriate position as specified in section 7. The fibers will pipe light to a spectrograph off the telescope. Means will be provided for acquiring the field and for sensing guide errors, field rotation and focus errors. An alignment camera with the ability to simultaneously view the superimposed images of the fiber and program object will provide a check of fiber positioning.*

The Hydra instrument will be covered as part of a separate review.

## 9.2 Multi-Object Spectrograph (MOS)

Goal: *Bench mounted multi-object spectrograph for use with the Hydra. MOS will include a selection of gratings and cameras to cover various spectral resolutions and wavelength ranges. Commonly used functions that will be automated include collimator focus, grating tilt and camera focus. The spectrograph entrance aperture will be large enough to accommodate the output of all the active fibers in a fiber cable with adequate separation of adjacent spectra on the detector. Remote post slit viewing will be provided to verify fiber positioning.*

The MOS will be covered as part of a separate review.

## 9.3 CCD Imager

Goal: *Wide-field CCD imager for use on the WIYN Port. The imager will mount on the Instrument Adapter with its focal plane appropriately spaced as specified in Section 7. The probes in the Instrument Adapter will be used for field acquisition and guiding. A shutter, automated filter wheel and a selection of broadband filters will be provided with the instrument.*

The CCD Imager is covered as part of a separate review.

## 10. Enclosure

Requirement: *Dome rotation will have an unlimited azimuth range.*

This requirement has been met.

Goal: *Dome rotation will have a slew rate of -4°/sec. to +4°/sec.*

The slew rate was measured to be 1.73°/sec. The inverter frequency is set at 100Hz, but the maximum value attained by the inverters is 75Hz. Both inverter and software parameters have been verified to be correct. Further investigation is needed to determine what is limiting the slew rate.

Goal: *Dome will have a track rate of -0.5°/sec. to +0.5°/sec.*

This requirement has been met.

Goal: *Dome will have a slew ramp of 0.75°/sec.$^2$*

The slew ramp is currently set to 0.17°/sec. This value was selected to minimize wear on the dome drive tires. We recommend that this parameter be accepted as is since it has a relatively low impact on dome slew times.

Goal: *Dome will have a tracking accuracy of 0.5°.*

The dome tracking accuracy is set through the user interface. The current value used is 0.5° as per the specification.

Requirement: *Dome shutters will provide an unobstructed width opening of 4.3 m.*

This specification was revised during construction as different opening widths were incorporated for "observing" and "servicing". The unobstructed "observing" opening is 4.09 m and the "servicing" opening is greater than five meters. A 0.5° tracking accuracy of the dome requires a minimum opening of 3.63 meters for observing. We therefore recommend that this specification be accepted as is.

Requirement: *The shutters will provide an unvignetted horizon limit of 15° altitude maximum and an unvignetted zenith limit of 92° altitude minimum.*

The enclosure was designed to this specification, but has not been verified. This should be checked during an upcoming T&E block.

Goal: *The time-to-open/close the dome shutters will be 45 seconds maximum.*

The actual open/close time for the shutters is 120 seconds including a 10-15 second alarm before any motion begins. We recommend that this be accepted as is since it does not adversely affect operations.

## 11. Servicing & Maintenance

Refer the table in Appendix A for a summary of the servicing and maintenance times.

# 12. Site & Environmental

## 12.1 Operating Conditions

Requirement: *The conditions for operating the telescope with the enclosure shutters and windows open will be peak wind gusts of 60 mph, temperatures between 0°F and 100°F, and non-condensing humidities of 98%.*

The telescope will breakaway (lose servo control) during wind gusts above 40 mph if pointed into the wind. Therefore, operation is restricted to downwind only during these conditions (which occur statistically five nights per year). The existing drive system may allow the drive motor current to be increased on the altitude axis (where most breakaways occur). We recommend that this possibility be reviewed and implemented, if possible.

The telescope has been operated at temperatures below 0°F and near 100°F as well as in high humidity conditions without visible adverse effects.

## 12.2 Survival Requirements

Requirement: *The earthquake specification will be UBC Zone 2. The worst case weather conditions with the dome parked and the shutters and windows closed will be peak wind speeds of 150 mph and a snow load of 24 inches.*

These survival requirements were included in the design specifications for both the telescope and enclosure, but have not been verified. The maximum wind speed experienced at the site to date is on the order of 100 mph. There has been no appreciable snowfall since the construction of the WIYN facility.

# Appendix A: Summary of Scientific and Technical Requirements

| Sec# | Description | Specification | As-built | Goal? | Met Spec? |
|---|---|---|---|---|---|
| **2** | **General Considerations** | | | | |
| 2.1 | Tertiary rotator | allow access to fcass port | completed | G | yes |
| | Tertiary fold | allow access to mcass port | completed | G | yes |
| 2.2 | Operating modes | rapid program switching | | G | yes |
| 2.3 | Maint. & reliability | maximize science return | on-going effort | G | unknown |
| 2.4 | Thermal design | minimize dome seeing | | G | yes |
| 2.5 | Active optics | auto-alignment | covered in PMS review | G | N/A |
| | Active optics | auto-focus | covered in IAS review | G | N/A |
| 2.6 | Safety | pass safety reviews | | | yes |
| **3.1** | **Principal Optics** | | | | |
| | M1 shape | concave hyperboloid | concave hyperboloid | | yes |
| | M1 diameter | 3.5 meter | 3.4989 meter | | yes |
| | M1 Focal ratio | f/1.75 | 1.7505 | | yes |
| | M1 central hole dia. | 0.96 meter | 0.9652 meter | | yes |
| | M1 rad. of curv. | 12.250 meter | 12.2535 meter | | yes |
| | M1 conic constant | -1.070833 | -1.0708 | | yes |
| | M2 shape | convex hyperboloid | convex hyperboloid | | yes |
| | M2 Diameter | 1.2 meter | 1.2 meter | | yes |
| | M2 rad. of curv. | 5.332 meter | 5.332 | | yes |
| | M2 conic constant | -3.731667 | -3.74 | | no |
| | M3 Shape | Plano, quasi-elliptical | Plano, quasi-elliptical | | yes |
| | M3 major dia. | 1.10 meter | 1.10 meter | | yes |
| | M3 minor dia. | 0.77 meter | 0.77 meter | | yes |
| **3.2** | **Specification of Foci** | | | | |
| | Focal ratio | f/6.3 | f/6.289 | | yes |
| | Plate Scale | 9.36 arcsec/mm | 9.375 arcsec/mm | | yes |
| | Bare R-C without corrector | | | | |
| | Field of view | 15 arcminute | | | yes |
| | Linear field | 96 mm | not verified | | unknown |
| | Field rad. of curv. | 2.11 meter | 2.11 meter | | yes |
| | Dist. to exit pupil | 8.5 meter | not verified | | unknown |

| Sec# | Description | Specification | As-built | Goal? | Met Spec? |
|---|---|---|---|---|---|
| **3.2** | **Specification of Foci (cont'd)** | | | | |
| | MOS port with corrector | | | | |
| | Corrector | doublet, spher. surf., AR | | G | yes |
| | Field of view | 1 degree | 1 degree unvignetted | | yes |
| | Linear field | 385 mm | covered in Hydra review | | N/A |
| | Wavelength range | 3300 A - 1.5 um | covered in Hydra review | G | N/A |
| | Field rad. of curv. | 5.51 meter | covered in Hydra review | G | N/A |
| | Broadband foc. tol. | 0.5 for 0.1 arcsec enlarg. | covered in Hydra review | | N/A |
| | Dist to exit pupil | 7.3 meter | not verified | G | unknown |
| | WIYN port with corrector | | | | |
| | Corrector | 4-element ADC, AR coat | not yet implemented | G | TBD |
| | Field of view | 30 arcminute | not yet implemented | | TBD |
| | Linear field | 192 mm | not yet implemented | | TBD |
| | Wavelength range | 3500 A - 1.1 um | not yet implemented | G | TBD |
| | Field curvature | Plano | not yet implemented | | TBD |
| | Broadband foc. tol. | 0.5 for 0.1 arcsec enlarg. | not yet implemented | | TBD |
| | Folded Cassegrain port | | not implemented | G | TBD |
| | Same as bare R-C | | not implemented | G | TBD |
| | Modified Cassegrain port | | | | |
| | Focal reducer | two mirror | not yet complete | G | TBD |
| | Focal ratio | f/13 - f/13.5 | not yet complete | G | TBD |
| | Nominal FOV | 6 arcminute diameter | not yet complete | G | TBD |
| | Linear FOV | 82 mm nominal | not yet complete | G | TBD |
| | Focus behind M1 | 114 cm nominal | not yet complete | G | TBD |
| **4** | **Image Size Budget** | | | | |
| | Narrow field | 0.40 arcseconds | 0.43 arcsec (best to date) | G | unknown |
| | Wide field | 0.52 arcseconds | | G | unknown |

| Sec# | Description | Specification | As-built | Goal? | Met Spec? |
|---|---|---|---|---|---|
| **5** | **Telescope** | | | | |
| | Az. motion | +/- 270 degrees | +/- 270 deg. | G | yes |
| | Alt. motion (observe) | 0.4 d < zenith ang < 75 d | 0 d < zenith ang < 75 d | G | yes |
| | Alt. motion (limits) | -2 deg. and 90 deg. | -2 deg. and 90 deg. | G | yes |
| | Zenith blind spot | 0.8 deg. dia. max | unable to determine | G | unknown |
| | Slew rate | 5 deg./sec max. | 3 deg./sec | G | no |
| | Slew ramp | 1 deg./sec^2 | 0.5 deg./sec^2 | G | no |
| | Settling time | 10 seconds max. | 55 to 75 sec. | G | no |
| | Track to track time | 100 sec max, < 360 deg az | 126 sec. | G | no |
| | Track to track time | 20 sec max, < 10 deg offset | < 10 sec. | G | yes |
| | Track to track time | 20 sec max, < 10 deg az | < 10 sec. | G | yes |
| | Pointing accuracy: | | | | |
| | offsets < 1 deg. | < 0.2 arcseconds RMS | covered in CS review | G | N/A |
| | offsets > 1 deg. | < 1 arcsecond RMS | covered in CS review | G | N/A |
| | offsets > 10 deg. | < 2 arcseconds RMS | covered in CS review | G | N/A |
| | Maximum track rate | 0.5 deg./ sec | > 0.5 deg./ sec | G | yes |
| | Track ramp | 0.1 deg./sec^2 max. | > 0.1 deg./sec^2 max. | G | yes |
| | Tracking accuracy: | | | | |
| | Open loop - 2 min. | < 0.1 arcsec RMS | covered in CS review | G | N/A |
| | Open loop - 15 min. | < 0.5 arcsec RMS | covered in CS review | G | N/A |
| | Closed loop - 1 hour | < 0.1 arcsec RMS | covered in CS review | G | N/A |
| **6** | **Telescope Equipment** | | | | |
| 6.1 | Baffle obscuration | 16.7% max. | 17.10% | G | no |
| 6.2 | Nasmyth Instrument Rotators | | | | |
| | Availability | both Nasmyth foci | | | yes |
| | Rotation range | 360 deg. | -180 deg to 179.9999 deg | | no |
| | Rotation rate | -5 deg/sec to +5 deg/sec | -5 deg/sec to +5 deg/sec | G | yes |
| | Ramp rate | -1 deg/sec to +1 deg/sec | -1 deg/sec to +1 deg/sec | G | yes |
| | Accuracy | < 5 arcsec | < 2 arcsec | | yes |

| Sec# | Description | Specification | As-built | Goal? | Met Spec? |
|---|---|---|---|---|---|
| **6** | **Telescope Equipment (cont'd)** | | | | |
| 6.3 | Instrument Adapter | | covered in IAS review | G | N/A |
| 6.4 | Tertiary Rotator | | | | |
| | Time to beam switch | < 1 min. | 38 sec CCW, 70 sec CW | G | no |
| | Repeatability | < 4 arcsec. | 7 arcsec RMS | G | no |
| | Accuracy | < 30 arcsec. | not verified | G | unknown |
| 6.5 | Primary mirror cover | | | | |
| | Dust seal | | rubber seal throughout | | yes |
| | Impact protection | 20 kg-m/s max. | not verified | | unknown |
| | Cross section | minimize for windshake | bi-fold design | | yes |
| 6.6 | Flat field | provide screen & lamps | completed | G | yes |
| **7** | **Instrument Mounting & Weights** | | | | |
| | MOS port: | | | | |
| | Mounting surface | rotator | rotator | G | yes |
| | Back focus distance | 533.4 +/- 0.6 mm | 525.6 (best focus) | G | no |
| | Instrument weight | 1000 kg max. | shop tested | G | yes |
| | Cantilever moment | 3000 N-m max. | shop tested | G | yes |
| | Instrument envelope | 2.5 m L x 2.0 m D | shop tested | G | yes |
| | Imbalance about axis | 150 N-m max. | shop tested | G | yes |
| | WIYN Port: | | | | |
| | Mounting surface | instrument adapter | instrument adapter | G | yes |
| | Back focus distance | 127 +/- 0.6 mm | optics spaced to meet | G | yes |
| | Instrument weight | 600 kg max. | shop tested | G | yes |
| | Cantilever moment | 2500 N-m max. | shop tested | G | yes |
| | Instrument envelope | 2.0 m L x 2.0 m D | shop tested | G | yes |
| | Imbalance about axis | 30 N-m max. | shop tested | G | yes |
| | Folded Cassegrain Port: | | | | |
| | Mounting surface | flange on OSS | flange on OSS | G | yes |
| | Back focus distance | 977.9 +/- 0.6 mm | not verified | G | unknown |
| | Instrument weight | 400 kg max. | not verified | G | unknown |
| | Cantilever moment | 2000 N-m max. | not verified | G | unknown |

| Sec# | Description | Specification | As-built | Goal? | Met Spec? |
|---|---|---|---|---|---|
| **7** | **Instrument Mounting & Weights (cont'd)** | | | | |
| | Modified Cassegrain Port: | | | | |
| | Mtg. surface (S) | flange on mirror cell | flange on mirror cell | G | yes |
| | Back focus distance | 1941.8 +/- 0.6 mm | not verified | G | unknown |
| | Dist. to S from el axis | 1233.17 mm | not verified | G | unknown |
| | Instrument weight | 175 kg max. | not verified | G | unknown |
| | Cantilever moment | 400 N-m max | not verified | G | unknown |
| **8** | **Instrument Support** | | | | |
| 8.1 | Services for Nasmyth instruments | | complete | G | yes |
| 8.2 | Services for specrograph labs | | complete | G | yes |
| **9** | **Facility Instruments** | | | | |
| 9.1 | Hydra | | separate review | G | N/A |
| 9.2 | Multi-object spectrograph | | separate review | G | N/A |
| 9.3 | CCD Imager | | separate review | G | N/A |
| **10** | **Enclosure** | | | | |
| | Dome rotation range | unlimited | unlimited | | yes |
| | Slew rate | -4 deg/sec to +4 deg/sec | +/-1.73 deg/sec | G | no |
| | Track rate | -0.5 deg/sec to +0.5 deg/sec | +/- 0.5 deg/sec | G | yes |
| | Slew ramp | 0.75 deg/sec^2 | 0.17 deg/sec^2 | G | no |
| | Tracking accuracy | 0.5 degrees | 0.5 deg | G | yes |
| | Shutter opening | 4.3 meter | > 5 meter (service) | | yes |
| | Shutter horiz. limit | 15 deg. alt. max. | not verified | | unknown |
| | Shutter zenith limit | 92 deg. alt. min. | not verified | | unknown |
| | Open/close times | 45 sec. max. | 120 sec. | G | no |
| **11** | **Servicing and Maintenance** | | | | |
| | M1 remove/install | 7 hours | TBD | | maybe |
| | M2 remove/install | 2 hours | < 2 hours | | yes |
| | M3 remove/install | 3 hours | < 2 hours | | yes |
| | M2 baffle rem./inst. | | N/A | | N/A |
| | Mount WIYN instr. | 2 hours | < 2 hours | | yes |

| Sec# | Description | Specification | As-built | Goal? | Met Spec? |
|---|---|---|---|---|---|
| **11** | **Servicing and Maintenance (cont'd)** | | | | |
| | Dome truck/drive | 4 hours | estimate 4 hours | | yes |
| | Dome shutter drive | 7 hours | estimate 4 hours | | yes |
| | Telescope encoders | 1 hour | estimate 2 hours min. | | no |
| | Telescope drives | 2 hours | estimate 2 hours min. | | no |
| **12** | **Site & Environmental** | | | | |
| 12.1 | Operating Conditions | | | | |
| | Peak wind gusts | 60 mph | breakaways above 40 mph | | no |
| | Temperature | 0 deg F to 100 deg F | operated in -5 to 95 deg F | | yes |
| | Humidity | 98% | operated at 98% | | yes |
| 12.2 | Survival requirements | | | | |
| | Earthquake | UBC Zone 2 | not verified | | unknown |
| | Peak wind speed | 150 mph | 100 mph max to date | | unknown |
| | Snow load | 24 inches | not verified | | unknown |

# Appendix B: Action Items

## Action Items

Following is a listing of the items that require actions because they do not meet the specifications outlined in the Scientific and Technical Requirements Documents.

Section 2.3 Maintenance and Reliability:

| | |
|---|---|
| Grease buildup on drive surfaces | Action: Work with manufacturer to develop course of action. |
| High pressure brake system | Action: Implement air dryer, review complete system. |
| Grit buildup in computer alcove | Action: Review control building ventilation, determine fix. |
| Primary mirror system leaks | Action: Improve reliability on an as-needed basis. |
| Telescope pointing is unstable | Action: Continue evaluation, implement collimation pointing corrections. |
| Frequent computer crashes | Action: Upgrade hardware and software where feasible. |

Section 2.4 Thermal Design:

| | |
|---|---|
| Local heating due to OSSCS | Action: Short term - Dump waste heat into dome during day.<br>Long term - Move heat producing components off OSS. |

Section 3.1 Principal Optics:

| | |
|---|---|
| M2 conic constant | No action: the optics were re-space to accommodate |

Section 3.2 Specification of Foci:

| | |
|---|---|
| Bare R-C linear field has not been verified | No action. |
| Bare R-C dist. to exit pupil not verified | No action. |
| MOS port dist. to exit pupil not verified | No action. |
| WIYN port parameters not verified | Action: Verify after ADC installation. |
| F-cass port parameters not verified | Action: Verify when port is implemented. |
| M-cass port parameters not verified | Action: Verify when port is implemented. |

Section 4 Image Size Budget:

| | |
|---|---|
| Image budget size has not been verified | Action: Accept telescope as is, continue to compile DIQ statistics. |
| Image size versus cosine law not tested | Action: Attempt to measure during T&E time. |

Section 5 Telescope:

| | |
|---|---|
| No restrictions for zenith angles < 0.4° | Action: Determine actual limits, implement warning or limit in software. |
| Unable to determine zenith blind spot size | Action: Correct software bug, improve tracking, determine limits. |
| Slew settling time greater than spec. | Recommend to accept as is. |
| Slewing rate and ramp less than spec. | Action: Package, spare, and document acc/vel feedback circuit.<br>Install acc/vel feedback on azimuth axis.<br>Evaluate pointing with higher slew parameters. |

Section 6.1 Baffles:

| | |
|---|---|
| Obscuration is greater than spec. | Recommend to accept as is. |

Section 6.2 Instrument Rotators:

| | |
|---|---|
| Rotation range has unknown limit | Action: Determine cause of +179.999° limit. |
| On-sky accuracy has not been verified | Action: Evaluate edge-of-field centroid test data. |

Section 6.4 Tertiary Rotator:

| | |
|---|---|
| Time to beam switch is greater than spec. | Action: Adjust speed settings for CW motion. |
| Repeatability is greater than spec. | Recommend to accept as is. |
| Accuracy has not been verified | Action: Check during collimation after optics aluminization. |

Section 6.5 Primary Mirror Cover:

| | |
|---|---|
| Impact protection has not been verified | Recommend to accept as is. |

Section 7 Instrument Mounting and Weights

| | |
|---|---|
| MOS port back focus dist. out of spec. | No action: Chosen for best focus. |
| F-cass port parameters not verified | Action: Defer until development of this port. |
| M-cass port parameters not verified | Action: Verify as part of re-imager evaluation. |

Section 10 Enclosure:

| | |
|---|---|
| Dome rotation slew rate less than spec. | Action: Investigate 75Hz inverter limit, set to 100 Hz. |
| Dome rotation slew ramp less than spec. | Recommend to accept lower limit to reduce tire wear. |
| Dome shutter opening less than spec. | Recommend to accept as is since no impact. |
| Dome shutter horizon and zenith limits not verified | Action: Determine during T&E time. |
| Shutter open/close times greater than spec. | Recommend to accept as is since no impact. |

Section 11 Servicing and Maintenance

| | |
|---|---|
| Time to replace encoders greater than spec. | No action. |
| Time to replace drives greater than spec. | No action. |

Section 12.1 Operating Conditions:

| | |
|---|---|
| High wind telescope breakaways | Action: Review feasibility of increased motor current. |

| | |
|---|---|
| Section 12.2 Survival Requirements: | No action: cannot verify |