GNAO Adaptive Optics Bench

Subsystem Specification Document
(aka L3 Reqs)

GNAO-AOS-SPE-002

Related PBS ID: 15.2

G.Sivo, W. Rambold, K. Tomasino-Reed

Document Acceptance and Release Notice

This document is a managed document. To identify changes, each page contains a release number and a page number. This document is authorized for release once all approvals have been obtained and logged in JIRA.

APPROVED:	*Signature on file* Manuel Lazo GNAO Project Manager and GNAO Project Acting Lead Systems Engineer	Date:	2021-09-30
APPROVED:	*Signature on file* Gaetano Sivo GNAO Principal Investigator	Date:	2021-09-30
APPROVED:	*Signature on file* Stephen Goodsell Project Director	Date:	2021-09-30

Change Record

Vers.	Date	Description	Change Request	Owner Name
0.1	2021-08-03	First draft for comment	N/A	W. Rambold
0.2	2021-08-31	Significant updates to draft	N/A	W. Rambold
0.3	2021-09-01	Significant updates to draft	N/A	W. Rambold
0.4	2021-09-07	Released for external review	N/A	W. Rambold
0.5	2021-09-13	Re-organized to move vendor derived requirements to Appendix A	N/A	W. Rambold
1.0	2021-09-14	Released for CCB approval	N/A	W. Rambold
2.0	2021-09-30	Released for CCB approval	N/A	W. Rambold

Table of Contents

1 Applicable Documents

Applicable Documents are those documents containing information that is considered binding in the context of this document. Unless otherwise specified, the latest version of the Applicable Document shall be used. In case of conflict between an Applicable Document and this document, this document shall take precedent.

	Document #	Title	Vers
[AD-01]	GNAO-SYS-SPE-002	GNAO System Specification Document (SSD)	2
[AD-02]	ICD 1.6/1.15.2.1	A&G Telescope Beam to GNAO AOB (aka as AO Fold ICD)	A
[AD-03]	ICD 1.15.2.1/1.6	AOB Corrected Beam to A&G Science Port	A
[AD-04]	IDD 1.15.2.1 to 1.15.2.3	GNAO AOB to GNAO AOS System Controller IDD	1
[AD-05]	IDD 1.15.2.1 to 1.15.2.2	GNAO AOB to GNAO RTC Controller	1
[AD-06]	ICD 1.5.3/1.15.2.1	Instrument Support Structure to GNAO Adaptive Optics Bench (GNAO-AOB)	A
[AD-07]	ICD 1.9/3.6	Science and Facility Instrument to ISS System Services	J
[AD-08]	INST-REQ-0001	Science and Facility Instruments Common Requirement Specifications	2
[AD-09]	ICD 1.9/5.0	Science and Facility Instruments to Transport, Observatory and Operational Environments	D
[AD-10]	N/A	Gemini Safety Policy & Organization	
[AD-11]	TBA	GNAO Adaptive Optics System Subsystem Specification Document	
[AD-12]	GNAO-MGT-005	GNAO Acronyms List	1

2 Reference Documents

Reference documents are those documents that are included for information purposes only. They may provide additional background or context, but are non-binding in the context of this document.

	Document #	Title	Vers
[RD-01]	TBA (In progress)	GNAO AOS Architecture Design Document (ADD)	TBA
[RD-02]	GNAO-SCI-REQ-001	GNAO Science Requirements Document	4
[RD-03]	GNAO-SCI-REQ-002	GNAO Operational Requirements Document	2
[RD-04]	GNAO-SYS-SIM-012	Simulations of the GNAO Narrow-field and Wide-field Modes	1.1

3 Scope

The scope of this document is limited to specifications for the GNAO Adaptive Optics Bench, a sub-component of the GNAO AOS Subsystem.

4 Purpose

This document describes the Adaptive Optics Bench for the Gemini North Adaptive Optics Facility, also referred to as "the Product" and provides the top-level requirements for its design and development.

5 Acronyms and Abbreviations

Acronyms used in this document are defined in GNAO Acronym List document [AD-12].

6 Terms and Definitions

The following terms have a specific meaning in the context of this specification:

"Full Width Half Maximum": The width of a line shape at half its maximum amplitude

"Goal": Something to try and achieve if at all possible. Not a mandatory requirement

"High-order Wavefront": Refers to all modes except tip/tilt and focus

"Input Beam": The beam delivered to GNAO by the AO Fold Mirror

"Laser Beacon": An artificial star created by energizing atoms in the sodium layer with a laser beam. Commonly referred to as a *Laser Guide Star*

"Low-order Wavefront": Refers to tip, tilt, and focus

"Narrow Field Mode": a system operating mode which provides enhanced image resolution over a 20 arc second by 20 arc second square area located in the center of the 2 arc minute field of view, with some level of improvement over the rest of the field

"Natural Guide Object": An astronomical object used as a reference to measure low order atmospheric disturbances which can not be detected using Laser Beacons. Commonly referred to as a *Natural Guide Star*

"Output Beam": The beam delivered by GNAO to the Science Fold Mirror

"*Performance Conditions*": The range of observing conditions (i.e. temperature, zenith angle), defined in this specification, over which performance is guaranteed during the course of one night (10 hours)

"*Performance FOV*": The field of view at the delivered focal plane over which all performance requirements must be met

"*Pointing Error*": The difference between the expected and achieved on sky position of a given object.

"*Pointing Precision*: The difference between achieved positions for repeated visits to the same sky position.

"Reference Design": A conceptual design that contains the essential elements of the system which can be enhanced or modified by the designers, intended as a means of conveying information to the designers of a system.

"Shall": Mandatory requirement.

"Should": see Goal.

"Telemetry": The high-speed, real-time data published by the RTC to allow external systems to analyze system performance and create observational metadata.

"Verification": Confirmation, through the provision of objective evidence, that the specified requirements have been fulfilled. Verification methods include: Analysis; Demonstration; Inspection, and Test

"Wide Field Mode": a system operating mode which provides a measure of image resolution improvement over the full 2 arc minute circular field of view.

"Will": a fact or declaration of purpose.

7 Product Description

7.1 Context

The Adaptive Optics Bench (AOB) is a component of the GNAO Adaptive Optics Subsystem (AOS). Figure 7-1 below shows the context of the AOB within the larger GNAO Adaptive Optics system and identifies the interactions involved.

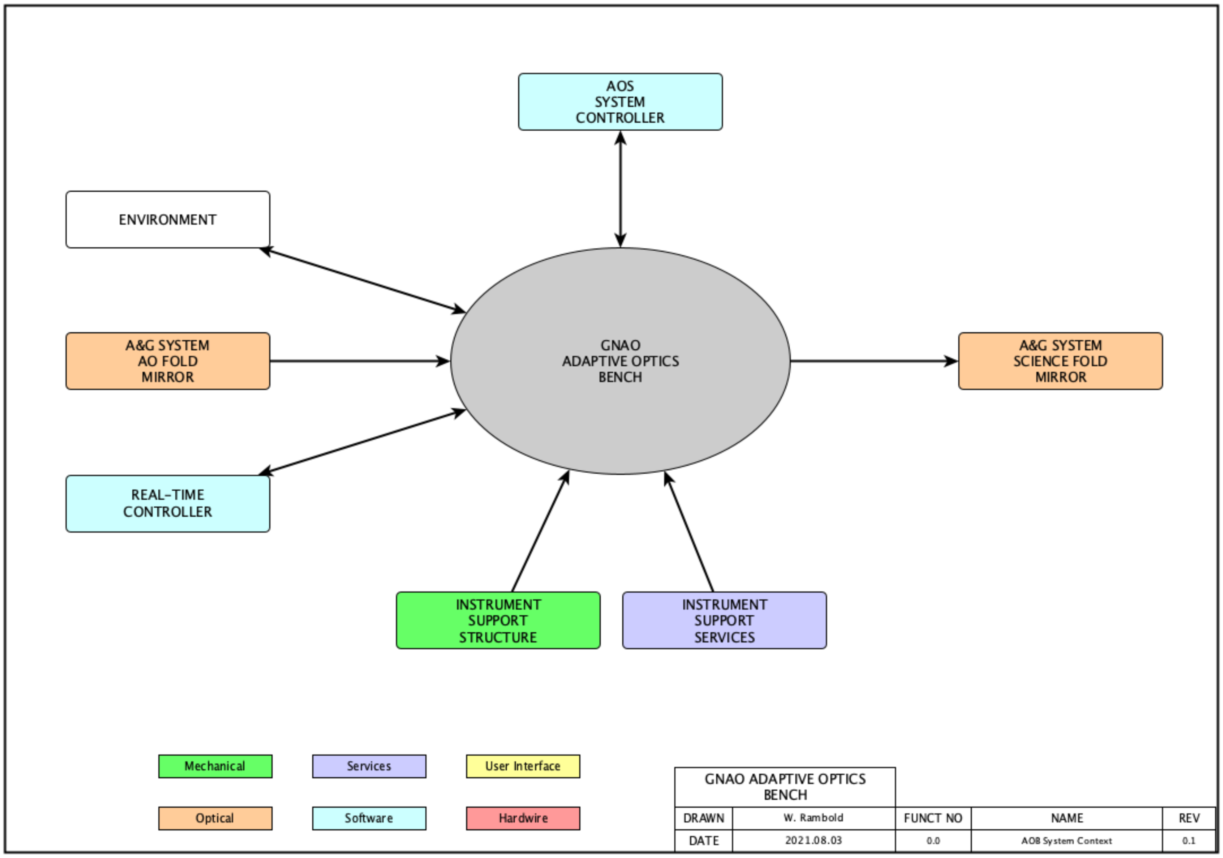

Figure 7-1 AOB System Context

AOS System Controller:
The AOB interacts with the AOS System Controller to receive low-level hardware device commands and send low-level hardware device status.

Environment:
The AOB must perform under the environmental conditions (temperature, humidity, wind, etc.) found at the Gemini North Telescope, as well as those it will be exposed to during transport to the telescope.

A&G AO Fold Mirror:
The AOB receives the uncorrected telescope beam from the Adaptive Optics Fold Mirror (the Telescope Beam), which is a component of the facility Acquisition and Guiding System.

Real-Time Controller:
The AOB relies on the Real Time Controller to analyze the wavefront and generate the appropriate adaptive optics corrections to cancel the sensed aberrations. The AOB sends raw pixels from the Wavefront Sensors to the RTC and receives AO component actuator positions from the RTC.

Instrument Support Structure:
The AOB physically mounts to the facility Instrument Support Structure, located under the mirror cell of the primary mirror of the telescope.

Instrument Support Services:
The AOB relies on the science and facility Instrument Support Services for electrical power, glycol cooling, dry air, and access to the facility network.

A&G System Science Fold Mirror:
The AOB delivers the corrected telescope beam to the Science Fold Mirror, which is a component of the telescope facility Acquisition and Guiding System

7.2 Functional Decomposition

This section presents the current level of AOB functional decomposition required to satisfy the AOS system requirements. The actual AOB functional decomposition will be done by the vendor, Figure 7-2 illustrates the core system functions and their functional interfaces, a brief description of each illustrated function follows below.

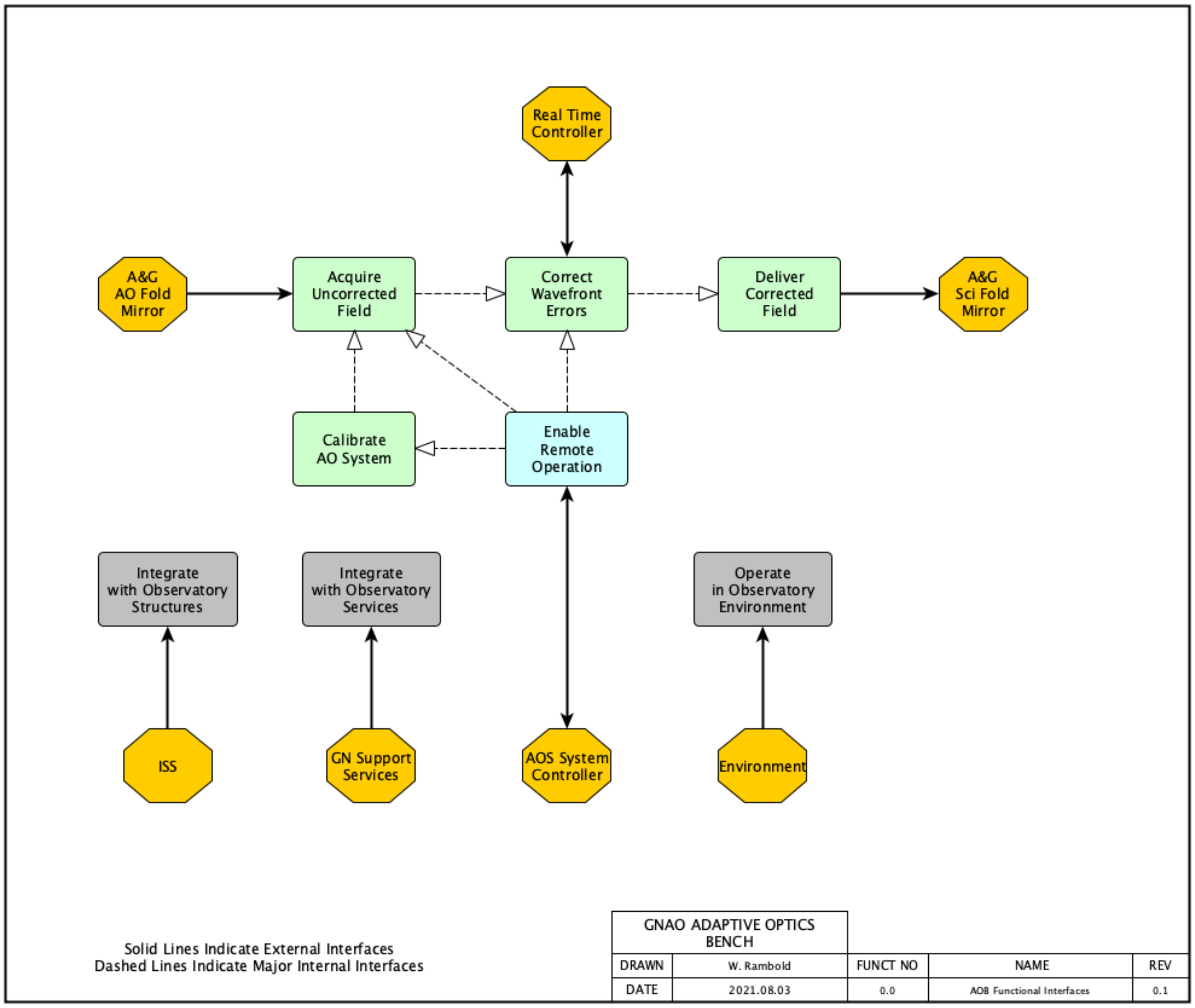

Figure 7-2 GNAO AOB Functional Decomposition and Interfaces

Acquire Uncorrected Field:

This provides the functionality of accepting either the uncorrected telescope beam from the AO fold mirror or a calibration beam from an internal calibration source and delivering it to the wavefront corrector.

Correct Wavefront Errors:
This provides the functionality required to sense and correct atmospheric and telescope induced aberrations in the incoming wavefront, and correct the aberrations in the science instrument as well (although not sensed)

Deliver Corrected Field:
This provides the functionality required to format the corrected telescope beam and deliver it to the Science Fold Mirror.

Calibrate System:
This provides the functionality required to calibrate the Adaptive Optics System.

Enable Remote Operation:
This provides the capability of operating all controllable hardware devices remotely.

Integrate with Observatory Structures:
This provides the functionality required to physically mount the AOB onto the Instrument Support Structure.

Integrate with Observatory Services:
This provides the functionality required to make use of the services provided by the Instrument Support Structure

Integrate with Observatory Environment:
This provides the capability of operating in the prevailing environmental conditions at Gemini North.

7.3 Physical Decomposition

Figure 7-3 shows a representative physical decomposition (solution) that would provide the required functionality, it is not intended as a prescriptive solution, this will be provided by the vendor.

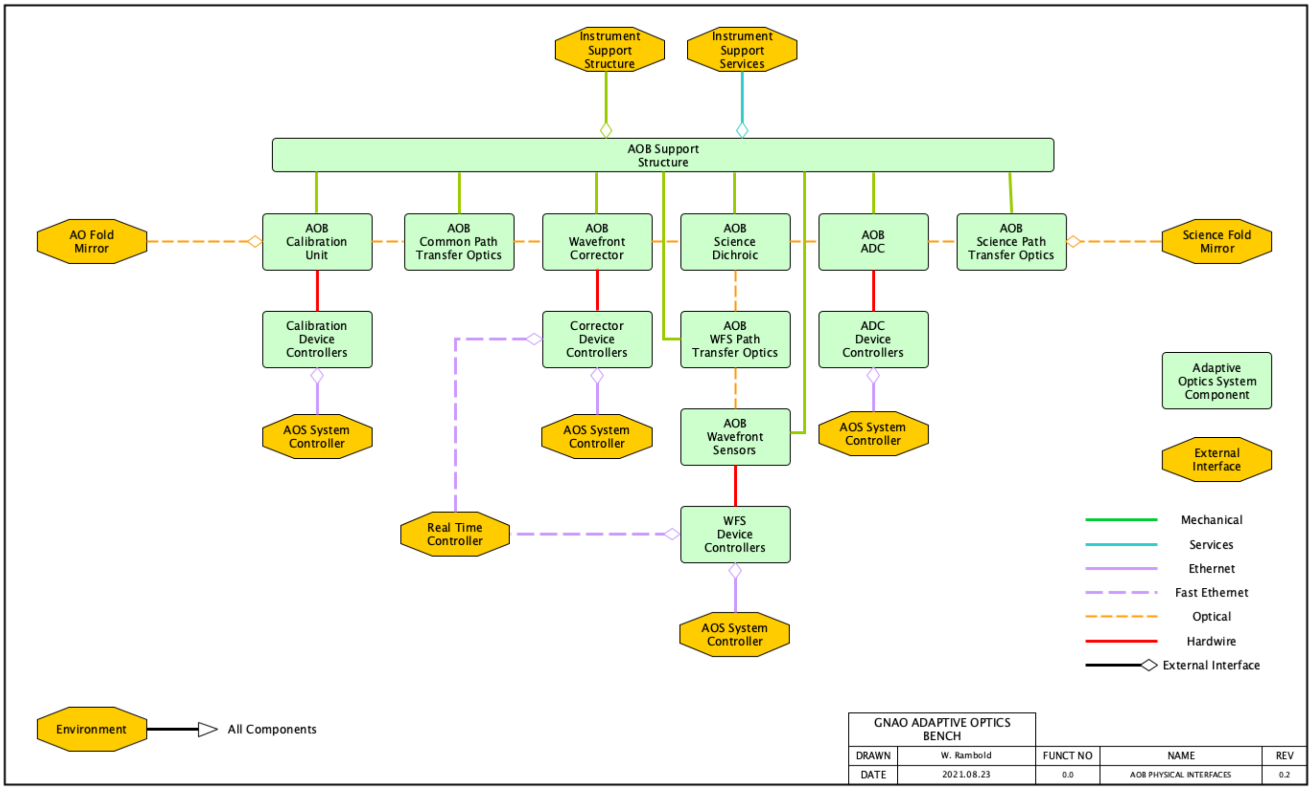

Figure 7-3 GNAO AOS Physical Decomposition

AOB Support Structure:

The AOB Support Structure attaches to the AO port of the ISS and provides a stable mounting platform for all of the opto-mechanical components and wavefront sensors. It also represents any thermal enclosures required to house the AOB and associated device control electronics.

AOB Calibration Unit:

The Calibration Unit provides various light sources required for internal calibration of the AOB. It also includes any mechanisms required to remotely insert and remove the calibration sources from the input beam.

AOB Wavefront Corrector:

The Wavefront Corrector provides all of the Adaptive Optics hardware components (such as Deformable Mirrors) required to correct low order and high order aberrations in the beam delivered by the telescope.

AOB Science Dichroic:
The Science Dichroic separates the wavelengths being sent to the output beam and the wavelengths being sent to the wavefront sensors. This separation is necessary so the wavefront sensors can access the whole field without obscuring parts of the image and operate continuously during an observation.

AOB ADC:
The ADC corrects for optical dispersion introduced by the atmosphere. This correction is applied to the output beam only, it does not affect the wavefront sensor beam. Since this correction is not always required the ADC can be remotely removed if necessary.

AOB Wavefront Sensors:
The Wavefront Sensors sample the residual low-order and high-order wavefront error, what remains after the corrections have been applied by the Wavefront Corrector. In this decomposition, the Wavefront Sensors also include any mechanisms required to select the Natural Guide Stars or Laser Beacons (Laser Guide Stars) and direct the light to the wavefront sensors.

AOB Transfer Optics:
The Transfer Optics represent the optical elements required to complete the optical path within the AOB. The transfer optics form three distinct light paths:

- *Common Path Transfer Optics:* Represents all of the optics required to transfer the input beam (telescope or calibration) to the Science Dichroic, including the wavefront correcting optics.
- *Science Path Transfer Optics:* Represents all of the optics required to transfer the science light from the Science Dichroic to the A&G Science Fold Mirror (the Output Beam).
- *WFS Path Transfer Optics:* Represents all of the optics required to transfer the wavefront sensing light from the Science Dichroic to the various Wavefront Sensors.

Hardware Device Controllers:
The Hardware Device Controllers provide low-level control of all controllable devices (motors, wavefront sensors, etc). This includes the controller itself and all cabling required to interface it to the device being controlled. In most cases this will be the control hardware provided by the device manufacturer. The AOB only provides the means to remotely control these devices; the appropriate motor positions, wavefront sensor parameters, etc. will be provided by the AOS System Controller.

- *Calibration Device Controllers:* Provide remote control of the calibration light sources and the insertion/removal mechanism.
- *Corrector Device Controllers:* Provide remote control of the AO optics in the Wavefront Corrector and receive an actuator position stream directly from the Real Time Controller (RTC).
- *WFS Device Controllers:* Provide remote control and synchronization of the WFS camera controllers and pixel streams sent directly to the RTC. Also control any devices required to select the Natural Guide Stars or Laser Beacons and direct them to the various wavefront sensors.
- *ADC Device Controllers:* Provide remote control of the Atmospheric Dispersion Correction optics and the insertion/removal mechanism.

7.4 AOB Control Integration

How the AOB components (a purely representational view) integrate into the overall GNAO control scheme is shown in Figure 7-4 below.

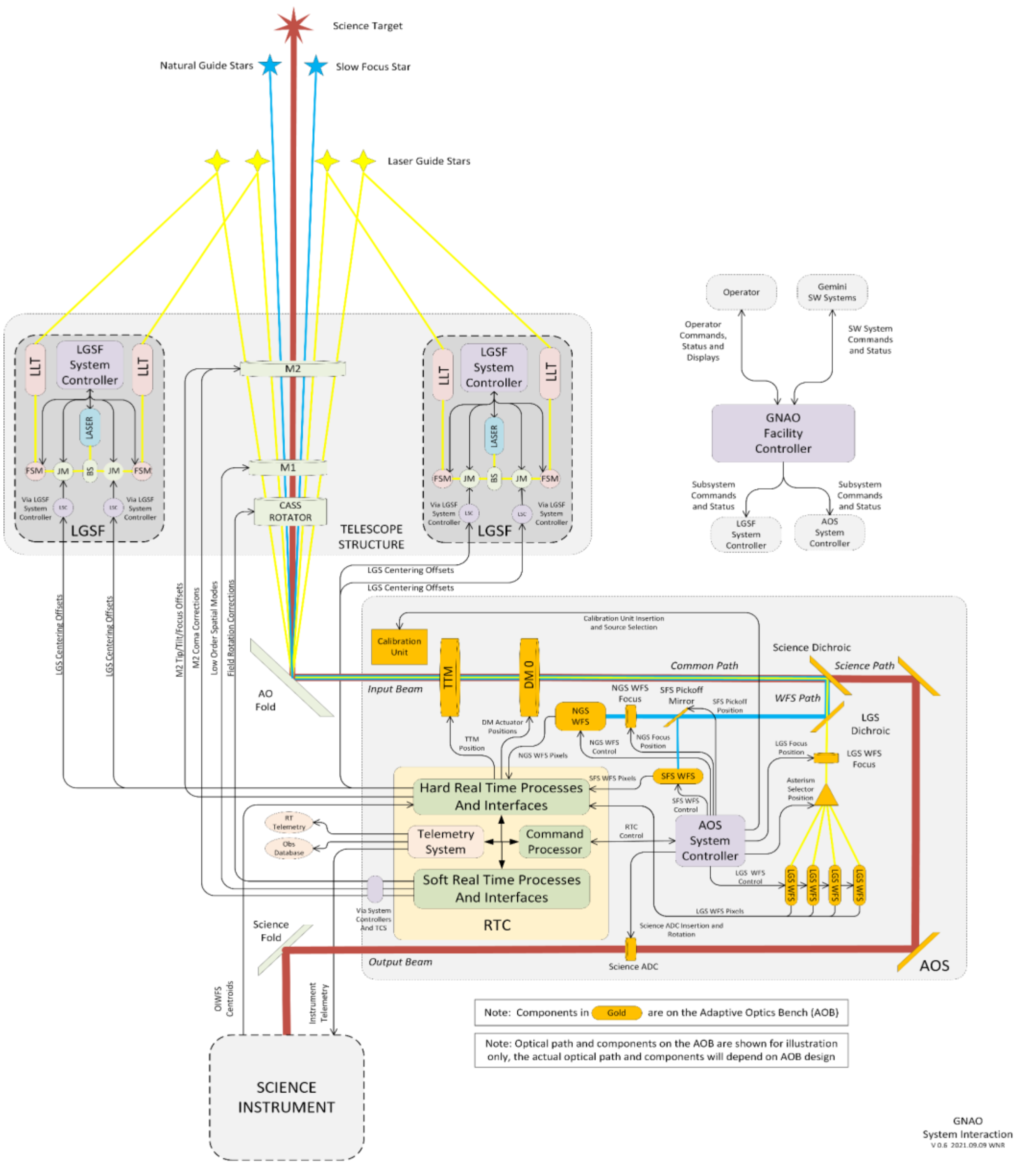

Figure 7-4 GNAO AOB System Control Integration

7.5 Correction Modes

To satisfy all of the Science Cases GNAO must have two modes of AO correction: a Wide Field (Ground Layer Adaptive Optics) mode which provides improved correction over the full field of view delivered to the instrument, and a Narrow Field (Laser Tomography Adaptive Optics) mode which provides an enhanced level of correction over a smaller field of view, shown in Figure 7-5.

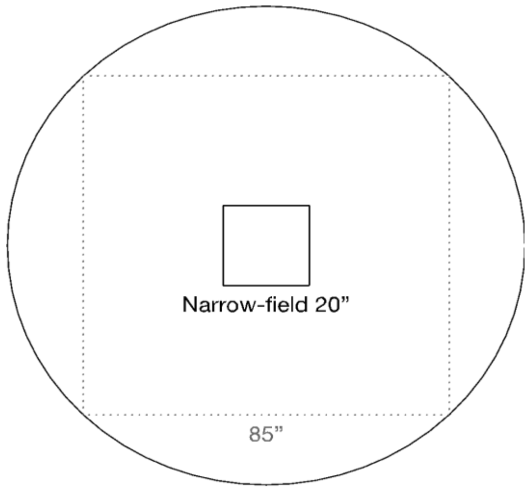

Figure 7-5 Wide Field Mode and Narrow Field Mode Fields of View (FOV)

Each mode will have a unique Laser Beacon configuration, optimized for the respective Performance Field of View, as shown in Figure 7-6 below. It will be necessary for the AOB to sense the incoming wavefront from both configurations.

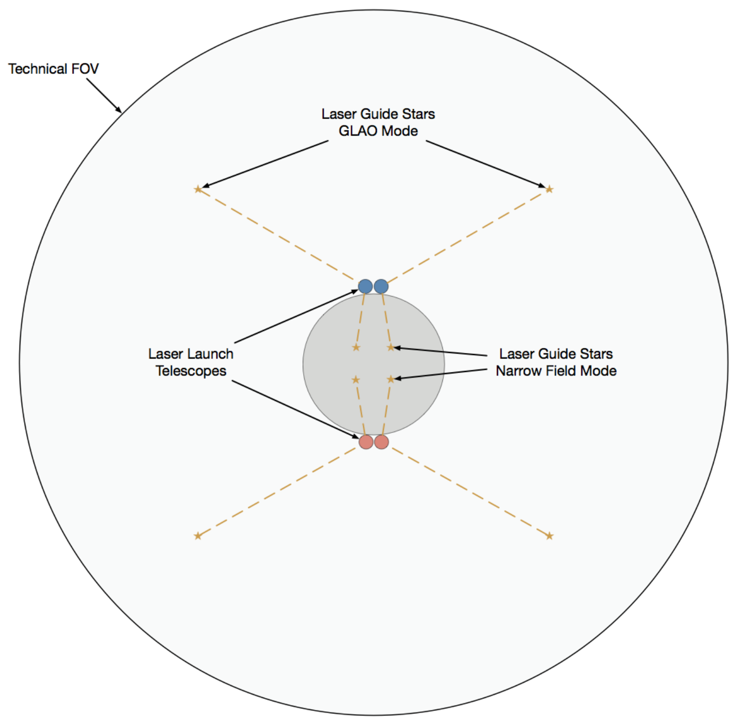

Figure 6-5 GNAO Laser Beacon (Guide Star) Configurations

8 Requirement Decomposition Process

This specification for the AOB requirements was created as an outcome of the overall GNAO system requirements decomposition and design process as shown in Figure 8-1 below.

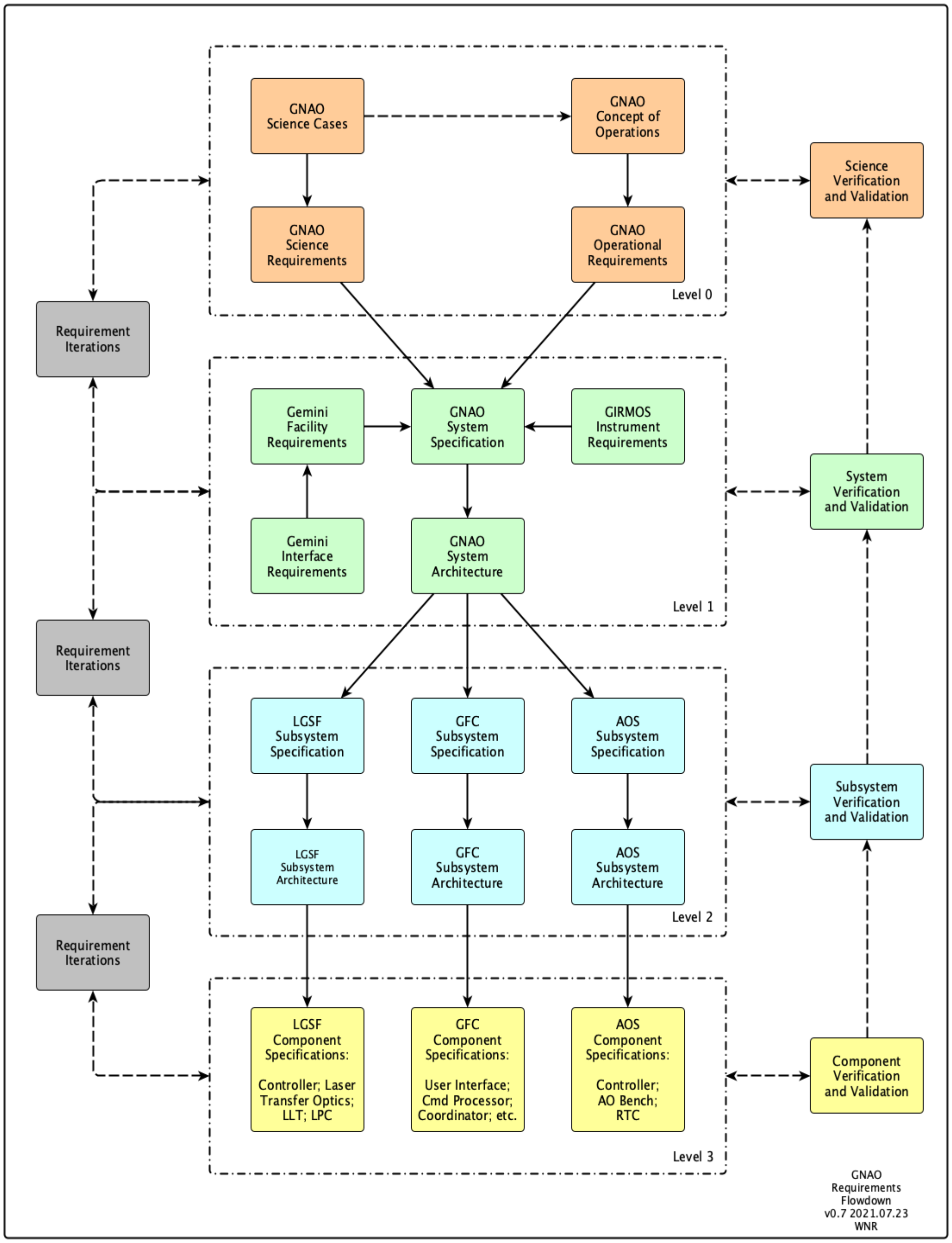

Figure 8-1 GNAO Requirements Decomposition Process

Level 0 Requirements

Level 0 Requirements codify the GNAO stakeholder's expectations for how the system will perform. Level 0 requirements will be verified and validated during system commissioning.

Level 0 requirements are documented in the GNAO Science Requirements [RD-02] and Operations Requirements [RD-03] Documents.

Level 1 Requirements

Level 1 Requirements are the top-level requirements for the System. Level 1 requirements are inherited or derived via budgets and models from the GNAO Level 0 requirements, the GIRMOS Level 1 requirements, and Gemini Facility/Interface Requirements. They specify and constrain the system to be developed to satisfy the user's and facility's expectations. Level 1 requirements are validated and verified once all of the subsystems have been delivered and integrated at the telescope.

Level 1 requirements are documented in the GNAO System Specification Document [AD-01], which collates and codifies these requirements to drive the system design process.

Level 2 Requirements

The System design process generates an architecture of cooperating subsystems which together will satisfy the overall system requirements. Level 2 Requirements are the driving requirements for each of these subsystems, and are either derived directly from L1 system requirements or allocated across subsystems via system budgets and simulations. Level 2 requirements are verified and validated once all of the subsystem components have been delivered and integrated, before the subsystem is integrated into the subsystem.

A Subsystem Specification Document is created for each subsystem. These documents codify the Level 2 requirements needed to drive the subsystem design process. The GNAO Adaptive Optics System Subsystem Specification [AD-11] is the primary source of AOB requirements.

Level 3 Requirements

Level 3 Requirements are the driving requirements for each major component of a subsystem. These requirements are derived or allocated through the design process down to the lowest level components (Level 4+). Level 3 requirements are normally verified and validated during the Factory Acceptance Test stage of the major GNAO components.

This document contains the Level 3 requirements for the Adaptive Optics Bench.

9 AOB Top-Level Requirements

Temp ID	[REQ-L3-AOB-1]
Name	**Improve Image Resolution**
Requirement	The AOB shall sense, and apply corrections for, atmospheric and telescope induced blurring.
Rationale	Key science cases for both GIRMOS and GNAO require an improved image resolution
Note	This function is performed with the aid of the Real Time Controller. The level of resolution improvement will depend on the area over which corrections are made.
Derivation	Derived from REQ-L2-AOS-001 (improve image resolution)
Verification	Demonstration [OAT]

Temp ID	[REQ-L3-AOB-2]
Name	**Support Wavefront Correction Modes**
Requirement	The AOB shall support both the Wide Field Mode (Wide Field Mode FOV 2' diameter) and Narrow Field Mode (Narrow Field Mode FOV 20" square, centered in the Wide Field FOV) of GNAO system operation.
Rationale	Enhanced improvement over a smaller field of view is required for some science cases.
Note	For the AOB, this requires that different constellations of Laser Guide Beacons be directed to the high order wavefront sensors.
Derivation	Derived from REQ-L2-AOS-010 (define AO correction modes)
Verification	Demonstration [OAT]

<table>
<tr><td>Temp ID</td><td>[REQ-L3-AOB-3]</td></tr>
<tr><td>Name</td><td>Wide Field Mode Image Quality</td></tr>
<tr><td>Requirement</td><td>The AOB shall enable,
● with GNAO in Wide Field mode;
● with a minimum of 60% sky coverage at the galactic pole;
● under median turbulence conditions;
● on average across the full 2’ Wide Field FOV;
● measured at the instrument (imager) focal plane;
a delivered image FWHM of less than:
<table>
<tr><th>Band</th><th>FWHM at 50° ZA</th></tr>
<tr><td>K-band (2.2 µm)</td><td>120 mas</td></tr>
<tr><td>H-band (1.65 µm)</td><td>150 mas</td></tr>
<tr><td>J-band (1.25 µm)</td><td>200 mas</td></tr>
</table></td></tr>
<tr><td>Rationale</td><td>This requirement provides the image quality needed for driving science cases.</td></tr>
<tr><td>Note</td><td>This is the overall system image quality requirement; it must be decomposed to derive the AOB performance requirements.
This requirement assumes the following atmospheric and telescope contributions, as defined in [RD-04]:
● telescope vibrations causing a tip-tilt error of 12 milliarcseconds (TBC)
● Gemini telescope secondary mirror (M2) print-through effect
● Mauna Kea atmospheric conditions
Imager potential top-level parameters:
● Pixel scale 21mas
● detector HAWAII-4RG
● 85”x85” FoV
● Imager wavelength 0.83 - 2.4µm
● Wavefront Error (WFE RMS) < 100 nm (goal < 65 nm)</td></tr>
<tr><td>Derivation</td><td>Inherited from REQ-L2-AOS-005 (wide field mode IQ)</td></tr>
<tr><td>Verification</td><td>Demonstration [OAT]</td></tr>
</table>

<table>
<tr><td>Temp ID</td><td>[REQ-L3-AOB-4]</td></tr>
<tr><td>Name</td><td>Narrow Field Mode Image Quality</td></tr>
<tr><td>Requirement</td><td>The AOB shall enable,

with GNAO in Narrow Field mode;
with a minimum of 60% sky coverage at the galactic pole;
under median turbulence conditions;
on average across the central 20” x 20” Narrow Field FOV;
measured at the instrument (imager) focal plane;

a delivered Strehl ratio greater than:
<table>
<tr><th>Band</th><th>Strehl at 25° ZA</th><th>Strehl at 50° ZA</th></tr>
<tr><td>K-band (2.2 μm)</td><td>35%</td><td>20%</td></tr>
<tr><td>H-band (1.65 μm)</td><td>20%</td><td>10%</td></tr>
<tr><td>J-band (1.25 μm)</td><td>10%</td><td>5%</td></tr>
</table>
</td></tr>
<tr><td>Rationale</td><td>This requirement provides the image quality needed for driving science cases.</td></tr>
<tr><td>Note</td><td>This is the overall system image quality requirement; it must be decomposed to derive the AOB performance requirements.
This requirement assumes the following atmospheric and telescope contributions, as defined in [RD-04]:

telescope vibrations causing a tip-tilt error of 12 milliarcseconds (TBC)
Gemini telescope secondary mirror (M2) print-through effect
Mauna Kea atmospheric conditions

Imager potential top-level parameters:

Pixel scale 21mas
detector HAWAII-4RG
85”x85” FoV
Imager wavelength 0.83 - 2.4μm
Wavefront Error (WFE RMS) < 100 nm (goal < 65 nm)

</td></tr>
<tr><td>Derivation</td><td>Inherited from REQ-L2-AOS-006 (narrow field IQ)</td></tr>
<tr><td>Verification</td><td>Demonstration [OAT]</td></tr>
</table>

<table>
<tr><td>Temp ID</td><td>[REQ-L3-AOB-5]</td></tr>
<tr><td>Name</td><td>Narrow Field Mode Image Quality with a single On-axis NGS</td></tr>
<tr><td>Requirement</td><td>The AOB shall enable,
• with GNAO in Narrow Field mode;
• under median turbulence conditions;
• with one on-axis Natural Guide Star of 12th magnitude in the R band;
• on average across the central 20” x 20” Narrow Field FOV;
• measured at the instrument (imager) focal plane;
a delivered Strehl ratio greater than:
<table>
<tr><th>Band</th><th>Strehl at 25° ZA</th><th>Strehl at 50° ZA</th></tr>
<tr><td>K-band (2.2 µm)</td><td>60%</td><td>45%</td></tr>
<tr><td>H-band (1.65 µm)</td><td>45%</td><td>25%</td></tr>
<tr><td>J-band (1.25 µm)</td><td>25%</td><td>10%</td></tr>
</table></td></tr>
<tr><td>Rationale</td><td>This requirement provides the image quality needed for driving science cases.</td></tr>
<tr><td>Note</td><td>This is the overall system image quality requirement; it must be decomposed to derive the AOB performance requirements.
This requirement assumes the following atmospheric and telescope contributions, as defined in [RD-04]:
• telescope vibrations causing a tip-tilt error of 12 milliarcseconds (TBC)
• Gemini telescope secondary mirror (M2) print-through effect
• Mauna Kea atmospheric conditions
Imager potential top level parameters:
• Pixel scale 21mas
• detector HAWAII-4RG
• 85”x85” FoV
• Imager wavelength 0.83 - 2.4µm
• Wavefront Error (WFE RMS) < 100 nm (goal < 65 nm)</td></tr>
<tr><td>Derivation</td><td>Inherited from REQ-L2-007-TBA (on axis mode IQ)</td></tr>
<tr><td>Verification</td><td>Demonstration [OAT]</td></tr>
</table>

<table>
<tr><td>Temp ID</td><td>[REQ-L3-AOB-6]</td></tr>
<tr><td>Name</td><td>Wide Field Mode Sensitivity</td></tr>
<tr><td>Requirement</td><td>The AOB shall enable,
with GNAO in Wide Field mode;
under photometric conditions;
under median turbulence conditions;
per hour of on-source integration time;
measured at the instrument (imager) focal plane;
a delivered 5-sigma point source sensitivity of at least:
<table><tr><th>Filter</th><th>Sensitivity [AB Mag]</th></tr><tr><td>K-band (2.2 µm)</td><td>24.6</td></tr><tr><td>H-band (1.65 µm)</td><td>23.9</td></tr><tr><td>J-band (1.25 µm)</td><td>24.2</td></tr></table></td></tr>
<tr><td>Rationale</td><td>This requirement provides the sensitivity needed for driving science cases.</td></tr>
<tr><td>Note</td><td>This is the overall system sensitivity requirement, it must be decomposed to derive AOB performance requirements.

Estimates based on the Gemini Exposure Time Calculators for NIRI with the 22 mas/pixel camera under IQ20 conditions (Wide Field Mode).

For the instrument a transmissivity of > 70% (excluding detector quantum efficiency) is assumed.</td></tr>
<tr><td>Derivation</td><td>Inherited from REQ-L2-AOS-008 (wide field mode sensitivity)</td></tr>
<tr><td>Verification</td><td>Demonstration [OAT]</td></tr>
</table>

Temp ID	[REQ-L3-AOB-7]
Name	**Narrow Field Mode Sensitivity**
Requirement	The AOB shall enable, ● In Narrow Field mode; ● under photometric conditions; ● under median turbulence conditions; ● per hour of on-source integration time; ● measured at the instrument (imager) focal plane; a delivered 5-sigma point source sensitivity of at least: <table><tr><th>Filter</th><th>Sensitivity [AB Mag]</th></tr><tr><td>K-band (2.2 µm)</td><td>25</td></tr><tr><td>H-band (1.65 µm)</td><td>24.5</td></tr><tr><td>J-band (1.25 µm)</td><td>24</td></tr></table>
Rationale	This requirement provides the sensitivity needed for driving science cases.
Note	This is the overall system sensitivity requirement; it must be decomposed to derive the AOB performance requirements. Estimates based on the Gemini Exposure Time Calculators for GeMS/GSAOI under the best Strehl conditions (Narrow Field Mode). For the instrument a transmissivity of > 70% (excluding detector quantum efficiency) is assumed.
Derivation	Inherited from REQ-L2-AOS-009 (narrow field mode sensitivity)
Verification	Demonstration [OAT]

Temp ID	[REQ-L3-AOB-8]
Name	**Closed Loop Seeing limit**
Requirement	The AOB shall enable stable closed loop operations up to a seeing limit of 1.2 arcseconds at a 0.5 μm wavelength.
Rationale	Required for queue operation flexibility and target of opportunity science.
Note	
Derivation	Inherited from REQ-L1-AOS-004 (seeing limit)
Verification	Analysis [PDR]

Temp ID	[REQ-L3-AOB-9]
Name	**Zenith Angle**
Requirement	The AOB shall meet all performance specifications up to a 50 degree zenith angle, and shall be operational up to a 60 degree zenith angle.
Rationale	The Galactic Center at Dec=-29 deg requires observations at 48 deg ZA from Gemini-North. Operability in closed loop up to 60 deg ZA is required for transient follow up and queue operation flexibility.
Note	
Derivation	Inherited from REQ-L2-AOS-003 (zenith angle)
Verification	Analysis [PDR]

Temp ID	[REQ-L3-AOB-10]
Name	**Reconfiguration Time**
Requirement	The AOB shall, once powered up and initialized, be capable of achieving a given device configuration within 60 seconds of being commanded, regardless of the starting state.
Rationale	Required to minimize overhead between observations.
Note	Ideally the AOB reconfiguration will be completed before the telescope has finished slewing to the next target position.
Derivation	Allocated from REQ-L2-AOS-016 (reconfiguration time) via acquisition time budget
Verification	Demonstration [FAT]

10 AOB Functional and Performance Requirements

10.1 Wavefront Sensing

Temp ID	[REQ-L3-AOB-11]
Name	**Residual High-order Wavefront Sensing**
Requirement	The AOB shall be capable of sensing the residual (post correction) high order wavefront across the field of view.
Rationale	Sampling the wavefront after correction provides the error signal required by the wavefront reconstruction algorithm in the RTC.
Note	Derived from REQ-L2-AOS-TBA (Image Quality) via AOS Architecture Design
Derivation	Derived from REQ-L2-AOS-012 (correct wavefront errors)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-12]
Name	**Use of Laser Beacons**
Requirement	The AOB shall use return light from sodium Laser Beacons to sense the high-order wavefront.
Rationale	Sodium Laser Beacons are required to ensure there will always be enough light to sample the high-order wavefront in any given field.
Note	The GNAO Laser Guide Star Facility projects sodium laser beams onto the Mesospheric Sodium Layer to create the beacons.
Derivation	Inherited from REQ-L2-AOS-014 (use of laser beacons)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-13]
Name	**Number of Laser Beacons**
Requirement	The AOB shall have the capability of sensing the high order wavefront from four Laser Beacons simultaneously.
Rationale	The Gemini Laser Guide Star Facility projects up to four independent Laser Beacons simultaneously.
Note	
Derivation	Inherited from REQ-L2-AOS-014 (use of laser beacons)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-14]
Name	**Acquire Laser Beacons**
Requirement	The AOB shall have the capability of directing light from the current laser beacon constellation onto the high-order wavefront sensors.
Rationale	GNAO wide field correction mode and narrow field correction mode use different arrangements of Laser Beacons.
Note	It is assumed that Laser Beacons will be projected as a square constellation with two different radial distances.
Derivation	Derived from REQ-L2-AOS-021 (position of laser beacons)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-15]
Name	**Laser Beacon Intensity**
Requirement	The AOB shall meet its high-order wavefront sensing requirements with a minimum (for Zenith Angle 0 degrees) Laser Beacon return flux of 38.5 photons/s/cm^2/Watt at the top of the telescope. The corresponding laser launch power from the Gemini telescope is 10.0 Watts for each laser beacon.
Rationale	The AOB high order correction must meet specification with the minimum flux estimated using the worst-case sodium return conditions at Mauna Kea.
Note	The given minimum return flux for 0 degrees Zenith Angle is approximately equal to the average flux over all Zenith Angles up to 50 degrees over an entire year (seasonal Na-density variations).
Derivation	Derived from REQ-L2-AOS-014 (use of laser beacons)
Verification	Analysis [PDR]

Temp ID	[REQ-L3-AOB-16]
Name	**Laser Beacon Wavelength**
Requirement	The AOB shall meet its high-order wavefront sensing requirements with a Laser Beacon wavelength of 589.158954nm to 589.159046nm.
Rationale	This is the wavelength range chosen for most efficient excitation of the Sodium Layer.
Note	The given wavelength range is inherited from the Toptica laser specification.
Derivation	Derived from REQ-L2-AOS-014 (use of laser beacons)
Verification	Analysis [PDR]

Temp ID	[REQ-L3-AOB-17]
Name	**Laser Beacon Altitude Compensation**
Requirement	The AOB shall have the capability to compensate for changes in the apparent laser beacon altitude.
Rationale	The apparent Laser Beacon altitude changes with elevation and, to a lesser extent, over time.
Note	This does not imply that each laser beacon has to be compensated individually. One compensation can be applied to the beacon constellation as a whole.
Derivation	Derived from REQ-L2-AOS-003 (zenith angle)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-18]
Name	**Laser Beacon Altitude Range**
Requirement	The AOB shall compensate for laser beacon altitudes between 85km and 210km.
Rationale	This covers the full Laser Beacon apparent altitude range.
Note	
Derivation	Derived from REQ-L2-AOS-003 (zenith angle)
Verification	Analysis [PDR]

Temp ID	[REQ-L3-AOB-19]
Name	**High-order Wavefront Sampling**
Requirement	The AOB shall be capable of sampling the instantaneous high-order wavefront
Rationale	Sampling the high order wavefront is necessary to determine the wavefront correction error.
Note	
Derivation	Derived from REQ-L2-AOS-012 (correct wavefront errors) via system architecture
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-20]
Name	**High-order Wavefront Sample Rate**
Requirement	The AOB shall be capable of sampling the high-order wavefront at rates up to 1Khz, with a goal of 2Khz.
Rationale	Frequent samples are required to track changes in the high-order wavefront.
Note	Maximum sample rate is limited by the RTC, actual sample rate for any observation will be limited by LGS flux return.
Derivation	Derived from REQ-L2-AOS-012 (correct wavefront errors) via system architecture
Verification	Analysis [PDR]

Temp ID	[REQ-L3-AOB-21]
Name	**Residual Low-order Wavefront Sensing**
Requirement	The AOB shall be capable of sensing the residual (post correction) low-order wavefront across the field of view.
Rationale	Sampling the wavefront after correction provides the error signal required by the wavefront reconstruction algorithm in the RTC.
Note	
Derivation	Derived from REQ-L2-AOS-012 (correct wavefront errors) via system architecture
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-22]
Name	**Use of Natural Guide Objects**
Requirement	The AOB shall use light from Natural Guide Objects to sense the low-order wavefront.
Rationale	Natural guide objects must be used to measure Tip Tilt.
Note	
Derivation	Inherited from REQ-L2-AOS-015 (use of natural guide objects)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-23]
Name	**Acquire Natural Guide Objects**
Requirement	The AOB shall have the capability to direct the light from Natural Guide Objects located anywhere in the technical field of view to the Low-order wavefront sensors.
Rationale	The full field must be accessible to increase sky coverage and optimize the NGO constellation.
Note	
Derivation	Inherited from REQ-L2-AOS-018 (position of natural guide objects)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-24]
Name	**Wavelength of Natural Guide Objects**
Requirement	The AOB shall meet its performance requirements using Natural Guide Objects with a wavelength range of 0.45um to 0.83um.
Rationale	Wavelengths below 0.45um are cut off by the telescope optics, above and including 0.83um are sent to the corrected output beam.
Note	
Derivation	Derived from REQ-L2-AOS-015 (use of natural guide objects) via system architecture
Verification	Analysis [PDR]

Temp ID	[REQ-L3-AOB-25]
Name	**Non-sidereal Guide Objects**
Requirement	The AOB shall have the capability of sensing the low-order wavefront using Natural Guide Objects moving at non-sidereal rates.
Rationale	Non-sidereal tracking is required for solar system observations.
Note	
Derivation	Inherited from REQ-L2-AOS-026 (non-sidereal guide objects)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-26]
Name	**Non-sidereal Guide Object Tracking**
Requirement	The AOB shall have the capability of tracking non-sidereal guide objects at a rate up to 450 arc seconds per hour.
Rationale	This rate enables observation of all planets, asteroid belt, and slow NEOs using sidereal NGS
Note	
Derivation	Derived from REQ-L2-AOS-026 (non-sidereal guide objects)
Verification	Analysis [PDR]

Temp ID	[REQ-L3-AOB-27]
Name	**Multiple Non-sidereal Guide Object Tracking**
Requirement	The AOB shall have the capability of tracking multiple non-sidereal guide objects moving at different rates.
Rationale	Allows a mix of sidereal and non-sidereal objects to be used for low order wavefront sensing and guiding.
Note	
Derivation	Derived from REQ-L2-AOS-026 (non-sidereal guide objects)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-28]
Name	**Use of Science Target as Natural Guide Object**
Requirement	The AOB shall have the capability of using an appropriate science target as a Natural Guide Object.
Rationale	Allows on-axis correction for improved performance
Note	This is possible because wavefront sensors view the field in a different wavelength range.
Derivation	Inherited from REQ-L2-AOS-027 (science target guiding)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-29]
Name	**Low-order Wavefront Sampling**
Requirement	The AOB shall be capable of sampling the instantaneous low-order wavefront
Rationale	Sampling the low order wavefront is necessary to generate the wavefront error signal the RTC uses to calculate corrections.
Note	
Derivation	Inherited from REQ-L2-AOS-012 (correct wavefront errors) via architecture design
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-30]
Name	**Low-order Wavefront Sample Rate**
Requirement	The AOB shall be capable of sampling the low-order wavefront at rates up to 1.0 kHz. (TBC)
Rationale	Frequent sampling of the low order wavefront is required to minimize low order correction loop latency.
Note	Maximum sample rate is set by the RTC
Derivation	Derived from REQ-L2-AOS-012 (correct wavefront errors) via system architecture
Verification	Analysis [PDR]

Temp ID	[REQ-L3-AOB-31]
Name	**Synchronization of Low and High-order Wavefront Samples**
Requirement	The AOB shall have the capability of synchronizing the taking of high and low order wavefront samples.
Rationale	Required by the RTC
Note	RTC processing latency will be increased if Low Order wavefront sample is late in arriving.
Derivation	Derived from REQ-L2-AOS-012 (correct wavefront errors) via system architecture
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-32]
Name	**Alignment of High-order Wavefront Sensor with DM**
Requirement	The AOB shall have the capability aligning (registering) the wavefront sensors to the Deformable Mirror.
Rationale	Required to optimize the wavefront reconstruction process
Note	
Derivation	Inherited from REQ-L2-AOS-012 (correct wavefront errors) via system architecture
Verification	Inspection [PDR]

10.2 Wavefront Correction

Temp ID	[REQ-L3-AOB-33]
Name	**Correction of High-order Wavefront Errors**
Requirement	The AOB shall have the capability to correct high-order wavefront errors.
Rationale	High order wavefront correction is required to improve image resolution.
Note	
Derivation	Derived from REQ-L2-AOS-012 (Image Quality) via system architecture design
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-34]
Name	**Conjugate Altitudes**
Requirement	The AOB shall have one wavefront corrector conjugated to 0 km.
Rationale	This is required for Wide Field Mode Ground-layer AO operation.
Note	This requirement does not preclude the use of more than one wavefront corrector to meet Narrow Field Mode performance requirements, as long as one is conjugated to 0Km.
Derivation	Derived from REQ-L2-AOS-012 (correct wavefront errors) via system architecture design
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-35]
Name	**Use of Deformable Mirrors**
Requirement	The AOB shall be capable of using Deformable Mirrors to correct high-order wavefront errors
Rationale	The GNAO Real-time Controller assumes the use of Deformable Mirrors to correct high-order wavefront errors
Note	
Derivation	Derived from REQ-L2-AOS-012 (correct wavefront errors) via architecture design
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-36]
Name	**Correction of Low-order Wavefront Errors**
Requirement	The AOB shall have the capability to correct low-order wavefront errors.
Rationale	Low order wavefront correction is required to minimize the effects of telescope vibration and atmospheric tip-tilt
Note	
Derivation	Derived from REQ-L2-AOS-012 (correct wavefront errors) via system architecture design
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-37]
Name	**Tip-tilt Wavefront Correction**
Requirement	The AOB shall correct at least the following low order modes: - tip and tilt.
Rationale	Tip-tilt correction is required to compensate for atmospheric tip-tilt and telescope induced vibrations.
Note	
Derivation	Derived from REQ-L2-AOS-012 (correct wavefront errors) via system architecture design
Verification	Inspection [PDR]

10.3 Dispersion Correction

Temp ID	[REQ-L3-AOB-38]
Name	**Atmospheric Dispersion Correction**
Requirement	The AOB shall be capable of correcting Atmospheric Dispersion in the output beam.
Rationale	Atmospheric dispersion correction is required to improve and stabilize the image PSF
Note	
Derivation	Derived from REQ-L2-AOS-013 (correct atmospheric dispersion);
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-39]
Name	**Dispersion Correction Range**
Requirement	The AOB shall have the capability of correcting atmospheric dispersion in the output beam, but not the wavefront sensing beam, between 0.83µm and 2.5µm, over the elevation range of 0 degrees to 60 degrees Zenith Angle.
Rationale	Dispersion compensation is required over the full operating elevation range
Note	Atmospheric dispersion correction is not required for wavefront sensing so the loss of sensitivity is not justified.
Derivation	Derived from REQ-L2-AOS-003 (zenith angle)
Verification	Analysis [PDR]

Temp ID	[REQ-L3-AOB-40]
Name	**Removal of Dispersion Corrector**
Requirement	The AOB shall have the capability of remotely removing atmospheric dispersion correction elements from the output beam when they are not required.
Rationale	If atmospheric dispersion correction is not required throughput can be improved by removing the ADC optics.
Note	
Derivation	Derived from REQ-L2-AOS-013 (correct atmospheric dispersion)
Verification	Test [FAT]

10.4 System Calibration

Temp ID	[REQ-L3-AOB-41]
Name	**Calibration Support**
Requirement	The AOB shall provide the capability to perform system calibrations.
Rationale	Regular calibration is required to maintain system performance
Note	
Derivation	Derived from REQ-L2-AOS-033 (internal calibration) via system architecture design
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-42]
Name	**Internal Calibration**
Requirement	The AOB shall have the capability to perform calibrations using internal calibration sources.
Rationale	Internal calibration sources allow the facility to be calibrated during the daytime as well as at night.
Note	The calibrations to be performed are detailed in separate requirements below.
Derivation	Derived from REQ-L2-AOS-033 (internal calibration) via system architecture design
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-43]
Name	**Entrance Port Shuttering**
Requirement	The AOB shall have the capability of shuttering (blocking) the entrance port.
Rationale	Any light entering through the input port will affect internal and science instrument calibrations
Note	The shutter must block any radiation that would affect internal calibration. See also Enclosure Sealing requirement REQ-L3-AOS-TBA
Derivation	Derived from REQ-L2-AOS-033 (internal calibration) via system architecture design
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-44]
Name	**Exit Port Shuttering**
Requirement	The AOB shall have the capability of shuttering (blocking) the exit port.
Rationale	Any light entering through the exit port will affect internal calibrations
Note	The shutter must block any radiation that would affect internal calibration. See also Enclosure Sealing requirement REQ-L3-AOS-TBA
Derivation	Derived from REQ-L2-AOS-33 (internal calibration) via system architecture design
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-45]
Name	**Deployment of Calibration Source**
Requirement	The AOB shall have the capability of remotely inserting calibration sources into the input beam and removing them from the input beam.
Rationale	Calibration sources are only required during system calibration.
Note	Inserting a calibration injection source blocks the incoming telescope beam
Derivation	Derived from REQ-L2-AOS-033 (internal calibration) via system architecture design
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-46]
Name	**Optical Distortion Calibration**
Requirement	The AOB shall provide the means to calibrate static optical distortion at the instrument focal plane and the Wavefront Sensor focal planes.
Rationale	Accurate distortion calibration is required to meet Astrometric and NCPA requirements.
Note	AOB provides the appropriate calibration source and the means to control it, the AOS System Controller uses it as part of a calibration sequence.
Derivation	Derived from REQ-L2-AOS-34 (system calibrations) via system architecture design
Verification	Test [OAT]

Temp ID	[REQ-L3-AOB-47]
Name	**Optical Distortion Calibration Procedure**
Requirement	The AOB shall provide a written procedure for calibrating optical distortion at the instrument focal plane and wavefront sensor focal planes.
Rationale	Written procedures will ensure calibration is done in a consistent and repeatable way.
Note	The delivered procedure must include the recipe for distortion calibration.
Derivation	Derived from REQ-L2-AOS-057 (documented procedures)
Verification	Inspection [FAT]

Temp ID	[REQ-L3-AOB-48]
Name	**Non-Common Path Aberration Characterization**
Requirement	The AOB shall provide the means to calibrate non-common path aberrations (NCPA).
Rationale	NCPA calibration is required because the science and wavefront sensing beams take different paths after the science dichroic.
Note	AOB provides the appropriate calibration source and the means to control it, the AOS System Controller uses it as part of a calibration sequence.
Derivation	Derived from REQ-L2-AOS-034 (system calibrations) via system architecture design
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-49]
Name	**NCPA Calibration Procedure**
Requirement	The AOB shall provide a written procedure for calibrating non common path errors.
Rationale	Written procedures will ensure calibration is done in a consistent and repeatable way.
Note	
Derivation	Derived from REQ-L2-AOS-057 (documented procedures)
Verification	Inspection [FAT]

Temp ID	[REQ-L3-AOB-50]
Name	**DM to Wavefront Sensor Registration**
Requirement	The AOB shall provide the means to remotely characterize the registration between the wavefront corrector and the wavefront sensors.
Rationale	Adjustment of the DM to wavefront sensor registration is required to maintain alignment between the two components.
Note	AOB provides the appropriate calibration source and the means to control it, the AOS System Controller uses it as part of a calibration sequence.
Derivation	Derived from REQ-L2-AOS-034 (system calibrations) via system architecture design
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-51]
Name	**DM to WFS Registration Procedure**
Requirement	The AOB shall provide a written procedure for registering the WFS to the DM.
Rationale	Written procedures will ensure calibration is done in a consistent and repeatable way.
Note	
Derivation	Derived from REQ-L2-AOS-057 (documented procedures)
Verification	Inspection [FAT]

Temp ID	[REQ-L3-AOB-52]
Name	**Laser Beacon Focus Calibration**
Requirement	The AOB shall provide the means to calibrate the laser beacon focusing system.
Rationale	
Note	AOB only needs to provides the appropriate calibration source to simulate changes in the laser beacon distance, and the means to control it, the AOS System Controller uses it as part of a calibration sequence.
Derivation	Derived from REQ-L2-AOS-034 (system calibrations) via system architecture design
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-53]
Name	**Laser Beacon Focus Calibration Procedure**
Requirement	The AOB shall provide a written procedure for calibrating the laser beacon focusing system.
Rationale	Written procedures will ensure calibration is done in a consistent and repeatable way.
Note	
Derivation	Derived from REQ-L2-AOS-057 (documented procedures)
Verification	Inspection [FAT]

10.5 Remote Operation

Temp ID	[REQ-L3-AOB-54]
Name	**Device Control**
Requirement	The AOB shall provide the means to remotely operate all controllable devices.
Rationale	Required for remote setup, operation, and queue integration
Note	Devices to be controlled include Motors, Wavefront Sensors, Calibration Sources, and Environment Sensors.
Derivation	Derived from REQ-L2-AOS-037 (enable remote control)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-55]
Name	**Device Status**
Requirement	The AOB shall allow the status of all devices to be read remotely.
Rationale	Required for remote setup, operation, and queue integration
Note	Devices to be read include Motors, Wavefront Sensors, Wavefront Correctors, Calibration Sources, and Environment Sensors.
Derivation	Derived from REQ-L2-AOS-037 (enable remote control)
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-56]
Name	**Device Controller Configuration**
Requirement	The AOB shall allow all device controllers to be configured remotely.
Rationale	Required for remote setup and system configuration
Note	Devices to be configured include Motors, Wavefront Sensors, Wavefront Correctors, Calibration Sources, and Environment Sensors.
Derivation	Derived from REQ-L2-AOS-037 (enable remote control)
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-57]
Name	**Mechanism Positioning**
Requirement	The AOB shall allow all moving devices to be positioned remotely.
Rationale	Required for remote setup, operation, and queue integration
Note	Mechanisms to be positioned include linear and rotational stages.
Derivation	Derived from REQ-L2-AOS-037 (enable remote control)
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-58]
Name	**Wavefront Sensor Readout Control**
Requirement	The AOB shall provide the means to individually start and stop the readout of wavefront sensors remotely.
Rationale	Required for remote operation
Note	Wavefront sensors include LGS WFSs, NGS WFSs, and SFS.
Derivation	Derived from REQ-L2-AOS-037 (enable remote control)
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-59]
Name	**Wavefront Corrector Actuator Enabling**
Requirement	The AOB shall provide the means to remotely enable and disable the application of actuator positions for each wavefront correction device.
Rationale	Required for AO correction control
Note	This applies to deformable mirrors and a separate tip-tilt mirror if one is included in the design.
Derivation	Derived from REQ-L2-AOS-037 (enable remote control)
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-60]
Name	**Calibration Control**
Requirement	The AOB shall provide the means to remotely control the operation all calibration sources.
Rationale	Required for remote setup and operation
Note	
Derivation	Derived from REQ-L2-AOS-037 (enable remote control)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-61]
Name	**Calibration Source Selection**
Requirement	The AOB shall provide the means to remotely select the calibration source to be used.
Rationale	Required for remote setup and operation
Note	
Derivation	Derived from REQ-L2-AOS-037 (enable remote control)
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-62]
Name	**Calibration Source Illumination Control**
Requirement	The AOB shall provide the means to remotely control the intensity of variable intensity calibration sources.
Rationale	Required for remote setup and operation
Note	
Derivation	Derived from REQ-L2-AOS-037 (enable remote control)
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-63]
Name	**Power Control**
Requirement	The AOB shall provide the means to remotely control the supply of power to all powered devices.
Rationale	Required for remote setup and operation
Note	
Derivation	Derived from REQ-L2-AOS-037 (enable remote control)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-64]
Name	**Power Devices Individually**
Requirement	The AOB shall allow the power to each individual powered device to be turned on and off independently.
Rationale	To aid in maintenance and troubleshooting
Note	
Derivation	Derived from REQ-L2-AOS-037 (enable remote control)
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-65]
Name	**Read Power Status**
Requirement	The AOB shall allow the power state (on/off and current consumption) for each individual powered device to be read remotely.
Rationale	To aid in maintenance and troubleshooting
Note	
Derivation	Derived from REQ-L2-AOS-037 (enable remote control)
Verification	Test [FAT]

11 Operational Requirements

Temp ID	[REQ-L3-AOB-66]
Name	**Remote Field Viewing**
Requirement	The AOB shall provide the capability of remotely viewing the Technical Field of View seen by the Low Order wavefront sensors.
Rationale	Essential for field and guide star acquisition
Note	
Derivation	Derived from REQ-L2-AOS-043 (view low order WFS patrol field) via system architecture design
Verification	Test [FAT]

12 Interface Requirements

Temp ID	[REQ-L3-AOB-67]
Name	**A&G Adaptive Optics Fold Mirror Interface**
Requirement	The AOB shall accept an input beam with the characteristics defined in the 1.6/1.15.2.1 A&G Telescope Beam to AOB Interface Control Document [AD-02].
Rationale	This is the beam delivered by the telescope
Note	The Adaptive Optics Fold Mirror interface defines input beam characteristics in terms of: - Field of View - Focal Ratio - Plate Scale - Wavelength Coverage - Exit Pupil Position - Telecentricity - AO Focal Distance from ISS - Static Distortion - Field Curvature - Spherical Aberration, Astigmatism, and Coma - Strehl Ratio and Homogeneity - Wavefront Error - Throughput - Emissivity - Chromatic Shift - Lateral and Axial Color - Residual Dispersion
Derivation	Inherited from REQ-L2-AOS-045 (AO fold to AOS interface)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-68]
Name	**A&G Science Fold Mirror Interface**
Requirement	The AOB shall deliver an output beam with the characteristics defined in the 1.15.2.1 to 1.6 AOB Corrected Beam to A&G Interface Definition Document (IDD) [AD-03].
Rationale	These are the output field characteristics required by GIRMOS
Note	Image Quality requirements labeled as TBD or TBC (e.g. Optical Transmission, Emissivity, Scattered Light, and Ghosting) in this IDD are to be derived by vendor. Once this is done, an Interface Control Document (ICD) will be generated by the vendor. The Science Fold Mirror interface codifies the output beam characteristics, and therefore defines the system requirements for: - Field of View - Focal Ratio - Focal Plane Distance from AOB/ISS Interface - Plate Scale - Exit Pupil Position - Wavelength Coverage - Pointing Precision and Timeframe - Distortion: Absolute, Stability, and Timeframe - Field Curvature - Spherical Aberration, Astigmatism, and Coma - Wavefront Error - Residual High-order NCPA - Pupil Tilt - Pupil Distortion: Absolute, Relative, and Timeframe - Pupil Chromatic Distortion - Transmissivity - Emissivity - Flux: Accuracy and Precision - Scattered Light - Ghosts - Residual Dispersion - Color: Lateral and Axial - Residual Image Jitter due to Vibration
Derivation	Inherited from REQ-L2-AOS-046 (AOS to Sci Fold Interface)
Verification	Analysis [PDR], Test [FAT]

Temp ID	[REQ-L3-AOB-69]
Name	**Telescope Instrument Support Structure Interface**
Requirement	The AOB shall comply with all requirements detailed in the 1.5.3 to 1.15.2.1 Instrument Support Structure to GNAO Adaptive Optics Bench (GNAO-AOB) Interface Control Document [AD-06]
Rationale	The AOB will be mounted on the Instrument Support Structure
Note	The ISS interface defines the system requirements for: - ISS Mounting Interface - AOB Mass, Moment, and CG - Induced Vibration - AOB Space Envelope - Focal Plane Location - Thermal Interface
Derivation	Inherited from REQ-L2-AOS-047 (ISS interface)
Verification	Inspection [PDR], Test [FAT]

Temp ID	[REQ-L3-AOB-70]
Name	**AOS System Controller Interface**
Requirement	The AOB shall comply with all requirements defined in the 1.15.2.1 to 1.15.2.3 GNAO Adaptive Optics Bench to Adaptive Optics System Controller Interface Definition Document [AD-04].
Rationale	Required for integration with the AOS System Controller
Note	The RTC interface control document defines AOB requirements relating to the low-level control of: - Moving Devices - Wavefront Sensors - Wavefront Correctors - Calibration Sources - Environmental Sources
Derivation	Derived from REQ-L2-AOS-054 (internal interface definition)
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-71]
Name	**Real-Time Controller Interface**
Requirement	The AOB shall comply with all requirements defined in the 1.15.2.1 to 1.15.2.2 GNAO Adaptive Optics Bench to Real Time Controller Interface Definition Document [AD-05].
Rationale	Interface compliance is required for integration with the RTC
Note	The RTC interface control document defines AOB requirements relating to: - Communications Protocol - Wavefront Sensor Data Formats - Deformable Mirror Data Formats - Tip-tilt Mirror (if used) Data Format
Derivation	Derived from REQ-L2-AOS-054 (internal interface definition)
Verification	Test [FAT]

Temp ID	[REQ-L3-AOB-72]
Name	**Gemini North System Services Interface**
Requirement	The AOB shall comply with all requirements defined in the 1.9 to 3.6 Science and Facility Instrument to ISS System Services ICD [AD-07]
Rationale	GNAO must use the services supplied by the Gemini Telescope Facility.
Note	The System Services interface defines the system requirements for: - Services Patch Panel Connections - Coolant - Compressed Air - Fiber Optics Communication - AC Power
Derivation	Inherited from REQ-L2-AOS-048 (GN system services interface)
Verification	Inspection [PDR]

13 RAMS Requirements

Temp ID	[REQ-L3-AOB-73]
Name	**Downtime Due to Failure**
Requirement	The AOB shall have <2% unscheduled technical downtime.
Rationale	To meet the facility requirement for instrument downtime
Note	Technical downtime does not include routine maintenance and upgrades.
Derivation	Inherited from REQ-L2-AOS-56 (availability)
Verification	Analysis [PDR]

Temp ID	[REQ-L3-AOB-74]
Name	**Lifetime**
Requirement	The AOB shall operate reliably, without needing major overhaul, for at least 12 years.
Rationale	To meet the facility requirement for instrument lifetime
Note	Routine upgrading software and computer hardware is not considered a major overhaul.
Derivation	Inherited from REQ-L2-AOS-055 (design lifetime)
Verification	Analysis [PDR]

Temp ID	[REQ-L3-AOB-75]
Name	**Engineering Operations**
Requirement	The AOB shall conform to engineering operations requirements defined in the applicable sections of the INST-REQ-0001 Facility and Science Instruments Common Requirements [AD-08]
Rationale	All Gemini instruments and facilities must comply with the relevant INST-REQ-0001 requirements.
Note	
Derivation	Inherited from REQ-L2-AOS-038 (engineering operations)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-76]
Name	**Enclosure Sealing**
Requirement	The AOB shall be sealed from intrusion by light, dust, and insects, except when the entrance and exit shutters are opened for operation.
Rationale	Reduce optical surface cleaning and wear on moving devices.
Note	
Derivation	Derived from REQ-L2-AOS-039 (design guidelines)
Verification	Inspection [FAT]

Temp ID	[REQ-L3-AOB-77]
Name	**Mechanical Safety**
Requirement	The AOB shall comply with all relevant mechanical safety standards defined in INST-REQ-0001 [AD-08].
Rationale	All Gemini instruments and facilities must comply with the relevant INST-REQ-0001 requirements.
Note	
Derivation	Inherited from REQ-L2-AOS-059 (mechanical safety)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-78]
Name	**Electrical Safety**
Requirement	The AOB shall comply with all relevant electrical safety standards defined in INST-REQ-0001 [AD-08].
Rationale	All Gemini instruments and facilities must comply with the relevant INST-REQ-0001 requirements.
Note	
Derivation	Inherited from REQ-L2-AOS-060 (electrical safety)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-79]
Name	**Safety Labelling**
Requirement	The AOB shall comply with all relevant labelling standards defined in INST-REQ-0001 [AD-08].
Rationale	All Gemini instruments and facilities must comply with the relevant INST-REQ-0001 requirements.
Note	
Derivation	Inherited from REQ-L2-AOS-061 (safety labelling)
Verification	Inspection [FAT]

Temp ID	[REQ-L3-AOB-80]
Name	**Operating Safety**
Requirement	The AOB shall comply with all applicable requirements in the Gemini Observatory Safety Manual [AD-10].
Rationale	All Gemini instruments and facilities must comply with the relevant safety manual requirements.
Note	
Derivation	Inherited from REQ-L2-AOS-062 (operating safety)
Verification	Inspection [PDR]

14 Environment

Temp ID	[REQ-L3-AOB-81]
Name	**AOB Environmental Condition Requirements**
Requirement	The AOB shall comply with all environmental requirements specified in the 1.9 to 5.0 Science and Facility Instruments to Transport, Observatory, and Operational Environments Interface Control Document [AD-09]
Rationale	The AOB must operate to specification under all environmental conditions encountered at the Gemini North facility.
Note	The Environmental ICD defines AOB requirements relating to the: - Transportation Environment - Non-operating (offline and storage) Environment - Operating (online and observing)
Derivation	Derived from REQ-L2-AOS-041 (environmental conditions)
Verification	Analysis [PDR]

15 Design Constraints

Temp ID	[REQ-L3-AOB-82]
Name	**Use of Metric Fasteners**
Requirement	The AOB shall only use metric fasteners in all mechanical assemblies.
Rationale	For compatibility with all other Gemini instruments and facilities.
Note	
Derivation	Derived from REQ-L2-AOS-039 (design guidelines)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-83]
Name	**Transportation and Handling**
Requirement	The AOB shall comply with all transport and handling requirements defined in the 1.9 to 5.0 Science Instrument to Facility Handling Equipment Interface Control Document [AD-09].
Rationale	The AOB must be compatible with the GN Telescope handling equipment.
Note	The Handling Equipment ICD defines the AOB requirements for: - Hoisting and Rigging - Use of the Air Bearing Pallet - Use of the Instrument Platform Lift - Use of the Gantry Crane
Derivation	Inherited from REQ-L2-AOS-042 (handling equipment)
Verification	Inspection [PDR]

Temp ID	[REQ-L3-AOB-84]
Name	**Documentation Standards**
Requirement	The AOB shall conform to documentation requirements defined in the INST-REQ-0001 Facility and Science Instruments Common Requirements [AD-08]
Rationale	All Gemini instruments and facilities must comply with the relevant INST-REQ-0001 requirements.
Note	Documentation Standards include: - Language - Dimensioning - Coordinate Systems - Document Format
Derivation	Inherited from REQ-L2-AOS-040 (documentation standards)
Verification	Inspection [CDR]

Temp ID	[REQ-L3-AOB-85]
Name	**Documented Procedures**
Requirement	The AOB shall provide fully documented procedures for calibration, alignment, and routine maintenance tasks.
Rationale	To reduce maintenance time and ensure consistent calibrations are performed
Note	
Derivation	Derived from REQ-L2-AOS-057 (documented procedures)
Verification	Inspection [FAT]

Temp ID	[REQ-L3-AOB-86]
Name	**User and Maintenance Manuals**
Requirement	The AOB shall provide user and maintenance manuals adequate for routine operation and maintenance of the system.
Rationale	To reduce staff training and maintenance time
Note	
Derivation	Derived from REQ-L2-AOS-058 (user and maintenance manuals)
Verification	Inspection [FAT]

16 Appendix A – Specifications to be Derived by Vendor

i. Wavefront Sensing

Temp ID	[REQ-L3-AOB-87]
Name	**Wide Field Mode Laser Beacon Constellation**
Requirement	Wide Field Mode constellation configuration (position of beacons in the field) requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-88]
Name	**Narrow Field Mode Laser Beacon Constellation**
Requirement	Narrow Field Mode constellation configuration (position of beacons in the field) requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-89]
Name	**Laser Beacon Altitude Compensation Accuracy**
Requirement	Laser beacon altitude compensation accuracy requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-90]
Name	**Number of High-order Wavefront Modes**
Requirement	Number of modes requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-91]
Name	**Number of High-order Wavefront Sensor Subapertures**
Requirement	Number of subapertures requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-92]
Name	**High-order Wavefront Sensor Subaperture Geometry**
Requirement	Subaperture geometry requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-93]
Name	**High-order Wavefront Sample Readout Latency**
Requirement	Sample readout latency requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-94]
Name	**High-order Wavefront Sample Jitter**
Requirement	Sample jitter requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-95]
Name	**High-order Wavefront Sample Accuracy**
Requirement	Sample jitter requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-96]
Name	**High-order Wavefront Sample Synchronization**
Requirement	Sample synchronization requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-97]
Name	**Number of Natural Guide Objects**
Requirement	Number of Natural Guide Objects requirement to be derived by vendor.
Rationale	
Note	RTC currently supports a maximum of 6 NGO
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-98]
Name	**Intensity of Natural Guide Objects**
Requirement	Intensity of Natural Guide Objects requirement to be derived by vendor.
Rationale	
Note	The RTC currently supports a maximum of 6 NGO
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-99]
Name	**Number of Low-order Wavefront Modes**
Requirement	Number of modes to be corrected requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-100]
Name	**Number of Low-order Wavefront Sensor Subapertures**
Requirement	Number of subapertures requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-101]
Name	**Low-order Wavefront Sensor Subaperture Geometry**
Requirement	Subaperture geometry requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-102]
Name	**Low-order Wavefront Sample Readout Latency**
Requirement	Sample readout latency requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-103]
Name	**Low-order Wavefront Sample Jitter**
Requirement	Sample jitter requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-104]
Name	**Low-order Wavefront Sample Accuracy**
Requirement	Sample accuracy requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-105]
Name	**Low-order Wavefront Sample Synchronization**
Requirement	Sample synchronization requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-106]
Name	**Sample Synchronization Tolerance**
Requirement	Synchronization tolerance of low and high order wavefront samples requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-107]
Name	**Wavefront Sensor Alignment Tolerance**
Requirement	WFS to DM tolerance requirement to be derived by vendor.
Rationale	
Note	Any dynamic WFS-WFS or WFS-DM misalignments caused by e.g. changing thermal environment/gravity vector should be included in the vendor requirements derivation.
Derivation	
Verification	

ii. Wavefront Correction

Temp ID	[REQ-L3-AOB-108]
Name	**Deformable Mirror Clear Apertures**
Requirement	Clear aperture of deformable mirror requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-109]
Name	**Deformable Mirror Number of Actuators**
Requirement	Number of DM actuators requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-110]
Name	**Deformable Mirror Actuator Array Geometry**
Requirement	DM actuator array geometry requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-111]
Name	**Deformable Mirror Actuator Stroke**
Requirement	DM actuator stroke requirement to be derived by vendor.
Rationale	
Note	Both individual stroke and inter-actuator differential stroke
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-112]
Name	**Deformable Mirror Position Resolution**
Requirement	DM position resolution requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-113]
Name	**Deformable Mirror Position Stability**
Requirement	DM position stability requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-114]
Name	**Deformable Mirror Position Linearity**
Requirement	DM position linearity requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-115]
Name	**Deformable Mirror Position Hysteresis**
Requirement	DM position hysteresis requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-116]
Name	**Deformable Mirror Temporal Response**
Requirement	DM temporal response requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-117]
Name	**Tip-tilt Corrector Clear Aperture**
Requirement	Tip-tilt corrector clear aperture requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-118]
Name	**Tip-tilt Corrector Range of Motion**
Requirement	Tip-tilt corrector range of motion requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-119]
Name	**Tip-tilt Corrector Angular Resolution**
Requirement	Tip-tilt corrector angular resolution requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-120]
Name	**Tip-tilt Corrector Temporal Response**
Requirement	Tip-tilt corrector temporal response requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

iii. Dispersion Correction

Temp ID	[REQ-L3-AOB-121]
Name	**Dispersion Correction Accuracy**
Requirement	Dispersion correction accuracy requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-122]
Name	**Dispersion Correction Wobble**
Requirement	Dispersion correction accuracy requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-123]
Name	**Dispersion Corrector Insertion Repeatability**
Requirement	Dispersion corrector insertion repeatability requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

iv. System Calibration

Temp ID	[REQ-L3-AOB-124]
Name	**Calibration Sources Insertion Repeatability**
Requirement	Calibration source insertion repeatability requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-125]
Name	**Optical Distortion Calibration Source**
Requirement	Optical distortion calibration source requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-126]
Name	**Optical Distortion Calibration Accuracy**
Requirement	Optical distortion calibration accuracy requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-127]
Name	**NCPA Characterization Source**
Requirement	NCPA characterization source requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-128]
Name	**NCPA Characterization Accuracy**
Requirement	NCPA characterization accuracy requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-129]
Name	**DM to WFS Registration Source**
Requirement	DM to WFS registration source requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-130]
Name	**DM to WFS Registration Accuracy**
Requirement	DM to WFS registration accuracy requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-131]
Name	**Laser Beacon Focus Calibration Source**
Requirement	Laser Beacon Focus Calibration source requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	

Temp ID	[REQ-L3-AOB-132]
Name	**Laser Beacon Focus Calibration Accuracy**
Requirement	Laser Beacon Focus Calibration accuracy requirement to be derived by vendor.
Rationale	
Note	
Derivation	
Verification	