01/16/2020

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1 Scope

This document formalizes the system level requirements of the Gemini North Adaptive Optics (GNAO) system. These requirements are the capabilities that the facility must have in order to meet the stakeholder's expectations.

2 Applicable Documents

The following documents are applicable and referenced in the requirements.

	Document #	Title
[AD-01]	ICD 1.9/5.0 RevD	Science and Facility Instruments to Transport, Observatory and Operational Environments Interface Control Document 1.9/5.0
[AD-02]	ICD 1.5.3/1.8b	Instrument Support Structure to Gemini North Adaptive Optics Bench (GN-AOB) Interface Control Document ICD 1.5/1.8b
[AD-03]	INST-REQ-0001 Version C	Facility Instruments Common Requirements Specification INST-REQ-0001
[AD-04]	ICD 1.9/3.6 Rev I	Science and Facility Instruments to ISS System Services ICD

3 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
[RD-01]	N/A	Good Instrument/System Requirements Writing and Check List, Manuel Lazo, Gemini Observatory, V1.0
[RD-02]	GNAO-CoD-04 RevA	Science Case (SC)
[RD-03]	GNAO-CoD-05 RevA	Concept of Operations Document (ConOps)
[RD-04]	gscg.grp.024/05	The Baseline Attribute/Value Interface (Document ID: gscg.grp.024/05)
[RD-05]	GNAO-CoD-06 RevA	System Requirements (at Conceptual Design Stage)

4 Purpose of the Document

The System Requirements are derived in response to the Science Cases [RD-02] and Concept of Operations [RD-03] , and become the Level 1 requirements the design must meet.

These requirements do not intend to prescribe a system design, but do identify the science, performance, operational states and modes, functional, interface, and environmental requirements that the technical design must satisfy.

4.1 Requirements Definition

Excellent conditions: Excellent conditions are defined as 0.42 arcsec seeing in V-band.

Each requirement is written in a specific format, which includes the following information:

Median Conditions*:* Median conditions are defined as 0.56 arcsec seeing in V-band.

Operate*:* To operate means to produce a stable output beam with some level of correction, usable for science.

Performance FOV: The performance FOV is the field of view over which all performance requirements must be met.

Requirement ID*:* This is a unique identifier/name for each requirement, used by requirements database software to maintain traceability.

Requirement: This is the requirements statement itself.

Rationale: This should include background information about the requirement, a description of its origin and justification for its existence.

Shall: "Shall" is a binding statement of requirement. This statement describes something that must be implemented, and verified.

Should: "Should" is a statement of goals or non-mandatory conditions. Although conditions described by *should* statements may be considered, they are not verified.

Technical FOV: The technical FOV is the field of view that is available for guide star selection and as AO-compensated output beam for science, depending on the backend instrument.

Verification*:* This should describe (when known) the intended verification plan for the requirement. This includes: how, when, and by whom the requirement is to be verified. Valid verification methods include: Analysis, Inspection, Demonstration and Test.

Will: "Will" is a statement of fact, or declaration of purpose. This statement is accepted to be true, and does not require verification.

4.2 Requirements Documentation Structure

This System Requirements Document contains the system Functional and Non-functional Requirement/Specifications shown at Level 1 of the GNAO Requirements Flowdown model as Figure 1.

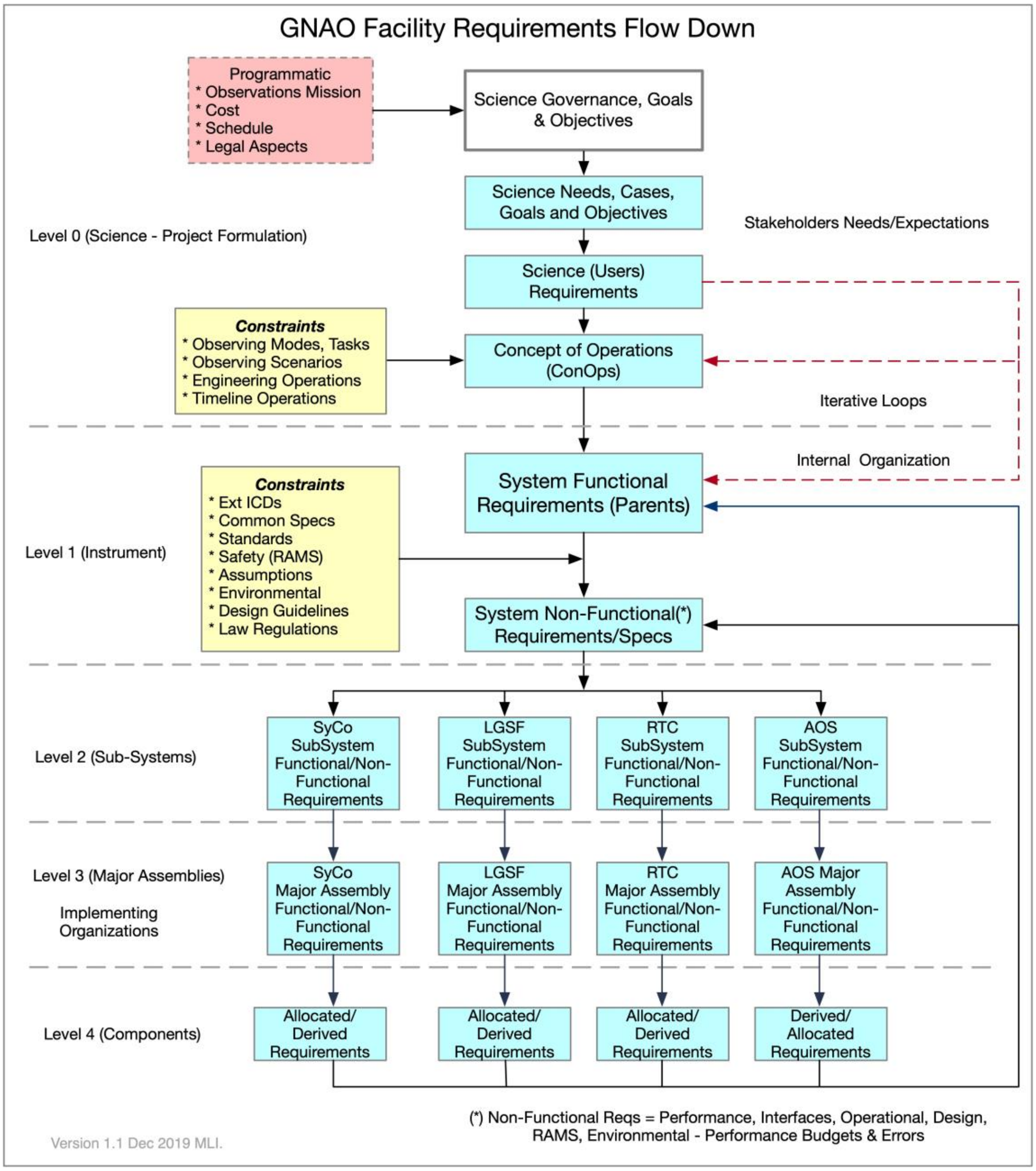

Figure 1. GNAO Requirements Documentation Flowdown

5 Summary of Driving Science Parameters

The following matrix summarizes the driving science parameters, distilled from the Science Cases [RD-02] . The values contained in Table 1. Driving Science are further translated into science requirements in Section 5.

Table 1. Driving Science Parameters

Science case	**Spectral range**	**Field of view**	**Astrometric accuracy**	**Photometric accuracy**
Extragalactic and Cosmology				
High z galaxy dynamics	0.9-2.4 um	3"	<100mas	~10%
Galaxy metallicity maps	0.9-2.4 um	3"	<100mas	~10%
Nuclear star clusters & disks	0.9-2.5 um	20"x20"		
Central parsecs around AGN	0.9-2.5 um	<~ 10"x10"		~10%
Cosmological Constraints from Strongly Lensed, Multiple-source	1.2 -2.5 um	30"	1 mas	~10%
Follow-up and Monitoring Gravitationally Lensed Transients	0.7-2.5 um	2'	10 mas	2%
Galactic and nearby extragalactic				
Galactic young massive star clusters	1-2 um	>2'	<0.3mas	few %
Globular clusters	1.5-2.4 um	4"	<10mas	<20%
Galactic Nucleus	1-2.9(-5) um	>2'	<0.2 mas	few %
Galactic young massive star clusters (Arches, Quintuplet, central pc) in	1-2.9 um	~0.5'		yes

Brown dwarfs, solar system				
The lowest-mass products of star formation (astrometric orbits &	1-2.5 um	~1" | ~10'	n/a | ~1 mas	n/a
Giant Planet Atmospheres and their Disks	1-5 um	1'	<1mas	few %

6 System Requirements

6.1 Driving GNAO Science Requirements

This section includes all Level 0 Science Requirements, derived from the GNAO Science Cases [RD-01] .

GNAO-SCI-001 *Technical Corrected Field of View*	The GNAO system shall have a 2’ circular diameter corrected technical Field of View (FOV).
Rationale	The existing AO fold provides a 2’ FOV.
Note or Source	AO Fold FOV Constraint, JWST synergy (NIRCAM FOV is 2.2’), observing efficiency, FOV System Trade Study
Verification Method	Demonstration, Test

GNAO-SCI-002 *NGS Sky Coverage*	GNAO shall operate with at least 60% sky coverage with 1 NGS at the galactic pole. GNAO shall operate with at least 20% sky coverage with 3 NGSs at the galactic pole.
Rationale	Large NGS sky coverage area is important for observing flexibility and efficiency, especially for extragalactic deep fields.
Note or Source	Targets of opportunity, extragalactic science cases [7]
Verification Method	Analysis, Test

GNAO-SCI-003 *Wavelength Coverage*	GNAO shall deliver a science corrected beam between 0.83 μm < λ < 2.50 μm.
Rationale	The wavelength coverage includes the minimum request of all driving science cases. The lower limit will include CaT at 0.8498, 0.8542, and 0.8662 μm (galaxies and late-type G, K, M stars). L and M-band (2.5 – 5 μm) coverage is desirable for a number of science cases [8.1, 8.6, 8.7, 9.4, 9.5]. It is considered as a goal as long as the optimization for 0.83 μm < λ < 2.5 μm is not compromised.
Note or Source	Driving science cases, CaT coverage
Verification Method	Test

GNAO-SCI-004 *Zenith Angle (ZA)*	GNAO shall meet 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 or Source	Driving science cases [8.6, 8.7], targets of opportunity, ConOps
Verification Method	Demonstration, Test

GNAO-SCI-005 *Seeing Limit for Closed Loop Operations*	GNAO shall perform stable closed loop operations up to a seeing limit of 1.2” at a 0.5 μm wavelength.
Rationale	Required for queue operation flexibility and target of opportunity science.
Note or Source	Targets of opportunity, concept of operations
Verification Method	Analysis, Demonstration

GNAO-SCI-006 *Performance field of view (FOV)*	The GNAO science performance requirements shall be met over a 85” x 85” square FOV.
Rationale	85” x 85” is the square FOV size that can be accommodated within the 2’ technical FOV. Science cases favor the widest-possible performance FOV, especially for wide-field imaging of stellar clusters and the Galactic Center.

Note or Source	Wide-field driving science cases [8.1, 8.6, 8.7]; Consistency with backend imager
Verification Method	Analysis, Demonstration

GNAO-SCI-007 *Strehl Ratio*	The GNAO K-band (2.2 μm) Strehl ratio shall be no less than 30% over the performance FOV under median conditions, and no less than 50% over the performance FOV under excellent conditions. The GNAO H-band (1.65 μm) Strehl ratio shall be no less than 14% over the performance FoV under median conditions, and no less than 20% over the performance FoV under excellent conditions. The GNAO J-band (1.25 μm) Strehl ratio shall be no less than 5% over the performance FoV under median conditions, and no less than 8% over the performance FoV under excellent conditions. This requirement shall be met up to the largest performance ZA of 50 degrees and assumes an idealized NGS constellation of 3 stars on an equilateral triangle embedded in the technical FOV.
Rationale	This requirement defines the minimum J, H, and K Strehl ratios to be achieved at the largest performance ZA of 50 deg, while Strehl ratios are expected to improve toward smaller ZAs. The requirement covers the minimum Strehl ratios needed for the driving science cases. Reflects set of conditions accessible with a queue-operated facility.
Note or Source	Driving science cases [e.g. 7.7, 8.1, 9.4]
Verification Method	Demonstration, Analysis

<table>
<tr><td>GNAO-SCI-008
Sensitivity</td><td>GNAO shall enable the following 5-sigma imaging sensitivities per hour of integration time over the performance ZA range under photometric conditions:
<table><tr><td>Filter</td><td>Sensitivity [AB mag]</td><td>Assumed Strehl ratio</td></tr><tr><td>K</td><td>25.0</td><td>30% in K</td></tr><tr><td>H</td><td>24.0</td><td>14% in H</td></tr><tr><td>J</td><td>23.2</td><td>5% in J</td></tr></table>
(This requirement assumes a GSAOI-like backend imager.)</td></tr>
<tr><td>Rationale</td><td>This sensitivity represents an estimate of the limiting magnitudes required at the largest ZA of 50 deg under median conditions assuming a GSAOI-like imager. Science cases with stronger sensitivity constraints can be observed at smaller ZA or in better conditions to achieve higher Strehl ratios and sensitivities.</td></tr>
<tr><td>Note or Source</td><td>Driving science cases [7.7, 9.5]</td></tr>
<tr><td>Verification Method</td><td>Analysis, Test</td></tr>
</table>

GNAO-SCI-009 *Astrometric accuracy*	GNAO shall enable a relative astrometric accuracy with an error of less than or equal to 0.2 mas across the performance FOV and ZA range in the H and K bands. This requirement assumes a high signal-to-noise regime, so that the theoretical position measurement errors are negligible. This requirement assumes median conditions and an idealized NGS constellation of 3 stars on an equilateral triangle embedded in the technical FOV.
Rationale	Driving science cases require at least 0.3 mas of relative astrometric accuracy while accuracy of up to 0.1 mas is desirable. This requirement includes the backend instrument. Assuming an approximate position measurement uncertainty of $\sigma x = \lambda/(\pi D\ SNR)$ [Lindegren 1978], where λ is the wavelength, D is the telescope diameter, and SNR is the signal-to-noise ratio, a SNR of at least 150 is required to achieve a measurement uncertainty of less than 0.2 mas.
Note or Source	Driving science cases [8.1, 8.6, 8.7]; requires PSF uniformity/stability, calibration methods, PSF knowledge
Verification Method	Analysis

GNAO-SCI-010 *Photometric Accuracy*	GNAO shall enable a relative photometric accuracy with an error of less than or equal to 2% across the performance FOV and ZA range for high signal-to-noise detections with a signal-to-noise ratio of at least 100. This requirement assumes median conditions and an idealized NGS constellation of 3 stars on an equilateral triangle embedded in the technical FOV.
Rationale	Driving science cases require 2%-3% of relative photometric accuracy, including the backend instrument. This requirement assumes a high signal-to-noise regime, so that random measurement errors are not the limiting factor.
Note or Source	Driving science cases [7.4, 8.1, 8.6, 8.7]; requires PSF uniformity/stability, calibration methods, PSF knowledge
Verification Method	Analysis

GNAO-SCI-011 *PSF uniformity*	The variation in Strehl ratio across the performance FOV shall be less than or equal to 10%, relative, at any given ZA within the performance ZA range under median conditions.
Rationale	PSF uniformity is required to ensure uniform sensitivity and to facilitate accurate differential photometry and astrometry. For differential photometry and astrometry it is assumed that variations at a 10% level can partially be compensated during post-processing if PSF knowledge is available. The Strehl ratio metrics does not capture all aspects of PSF shape variations (e.g. elongation, encircled energy) relevant for different science cases. Efforts by the science team to identify alternative metrics are ongoing.
Note or Source	Driving science cases [7.4, 7.7, 8.1, 8.6, 8.7]
Verification Method	Analysis

GNAO-SCI-012 *PSF Temporal Stability*	Short term stability: Any variation in Strehl ratio beyond the predicted change with ZA shall be less than or equal to 10%, relative, on any star within the performance FOV during the course of a night under stable atmospheric conditions. Long term stability: The variation in Strehl ratio on any star within the performance FOV shall be less than or equal to 10%, relative, for repeated visits of the same field at a similar telescope position and Cass rotator angle under median conditions.
Rationale	Short term stability is required to guarantee a stable PSF over the course of an observation length (typically 1 hour for imaging). Long-term stability is required for accurate multi-epoch astrometry or photometry. It is assumed that PSF variations at a 10% level can partially be compensated during post-processing if PSF knowledge is available. The Strehl ratio metrics does not capture all aspects of PSF shape variations (e.g. elongation, encircled energy) relevant for different science cases. Efforts by the science team to identify alternative metrics are ongoing.
Note or Source	Driving science cases [8.6, 8.7], multi-epoch monitoring observations, Concept of Operations
Verification Method	Analysis

GNAO-SCI-013 *PSF Performance under Guided Offsets*	The variation in Strehl ratio on any given star within the performance FOV under median conditions shall be less than or equal to 10%, relative, when performing a guided offset as defined in GNAO-CONOPS-004. This requirement applies to any given ZA within the performance ZA range and to any available NGS constellation within the offset range.
Rationale	Since dithering (performing guided offsets) is an essential technique for near-infrared observations the change in PSF performance under dithers shall be minimized. The Strehl ratio metrics does not capture all aspects of PSF shape variations (e.g. elongation, encircled energy) relevant for different science cases. Efforts by the science team to identify alternative metrics are ongoing.
Note or Source	Concept of Operations, GNAO-CONOPS-003
Verification Method	Analysis

GNAO-SCI-014 *Narrow Field Mode*	GNAO shall be capable of sensing the on-axis wavefront to provide a narrow-field mode with enhanced on-axis Strehl ratio compared to the default wide field mode.
Rationale	Fraction of narrow field science cases and long-standing ALTAIR SCAO user community.
Note or Source	Driving science Cases [7.2], Concept of Operations
Verification Method	Demonstration, Test

GNAO-SCI-015 *Acquisition Time*	GNAO shall perform all necessary steps to acquire NGSs and LGSs and begin closed loop operations in less than 10 minutes excluding telescope slew time.
Rationale	This allows for rapid follow-up for newly discovered transients and enables increased completion rates and efficiency.
Note or Source	Parent: GNAO-CONOPS-001 Availability, Science Case for rapid follow up with GNAO
Verification Method	Test, Demonstration

6.2 Driving GNAO ConOps Requirements

This section includes all the level 1 requirements derived from the GNAO Concept of Operations [RD-03] .

GNAO-CONOPS-001 *Availability*	GNAO Shall be available to the user community on any given night via nominal Gemini queue operations.
Rationale	This allows for rapid follow-up for newly discovered transients, and enables GNAO to supplement JWST when it its seasonal orbital constraints preclude some target observations. Additionally, queue scheduling enables increased completion rates and efficiency.
Note or Source	Rapid follow-up science
Verification Method	Demonstration

GNAO-CONOPS-002 *Operational Staffing*	GNAO shall require no additional staff beyond regular operations (telescope operator and observer) to operate the facility
Rationale	GNAO must be available any given night, and therefore be operable via the queue and with normal observatory staffing. This allows for rapid follow-up for newly discovered transients, and enables GNAO to supplement JWST when it is seasonal orbital constraints preclude some target observations. Additionally, queue scheduling enables increased completion rates and efficiency.
Note or Source	Parent: GNAO-CONOPS-001 Availability
Verification Method	Demonstration

GNAO-CONOPS-003 *Offsetting*	GNAO shall support guided offsetting with a maximum move per step of 40 arcsecs assuming that an available NGS constellation is within offset range, and unguided offsetting.
Rationale	Offsetting is the default way to be able to account for the background and to subtract it in order to arrive at science quality data. This is a fundamental requirement for most science cases. Guided offsetting (dithering) is further used to fill the spots left behind by bad pixels, columns, regions, also important for most science cases. For isolated, more extended sources, guided offsets up to 40" (roughly half the field-of-view of the detector) are required for sky subtraction as long as the dithers are slightly larger than the source size. For more extended targets or crowded fields, unguided offsets to empty sky fields will be necessary.
Note or Source	Parent: ConOps
Verification Method	Test

GNAO-CONOPS-004 *Non-sidereal Tracking*	GNAO shall support non-sidereal tracking when all objects being used as NGSs are moving with respect to the science object and/or with respect to each other at rates of less than or equal to 450 arcsecs per hour.
Rationale	Non-sidereal tracking will enable a number of solar system science cases that require a differential tracking between the target and NGS(s). The 450 arcsecs per hour rate enables observation of all planets, asteroid belt, and slow NEOs using sidereal NGS.
Note or Source	Solar system science cases, ConOps
Verification Method	Test, Demonstration

GNAO-CONOPS-005 *System Calibration*	GNAO shall provide means to calibrate and maintain (i.e. service, intervene, and prevent failures and degradation) the system .
Rationale	To consistently meet performance requirement, calibration is necessary to correct for system changes over time, known errors, and condition changes.
Note or Source	ConOps, GNAO-SCI-010 PSF Temporal Stability, GNAO-RAMS-005 Maintainability
Verification Method	Test, Demonstration

GNAO-CONOPS-006 *System Telemetry*	GNAO shall provide system and real-time performance telemetry suitable for use for system diagnostics, performance motoring and optimization, calibration, and science data correlation.
Rationale	Real-time performance telemetry allows users to correlate science data to system conditions and reconstruct PSF. It also allows performance monitoring over time.
Note or Source	ConOps, GNAO-SCI-009, GNAO-SCI-010, PSF Temporal Stability
Verification Method	Test, Demonstration

GNAO-CONOPS-007 *GLAO Compatibility*	The GNAO system must not preclude the ability to perform Laser assisted Ground Layer Adaptive Optics (GLAO).
Rationale	GLAO system for Gemini would offer significant improvements in image quality and observing efficiency, by reduced point spread function (PSF) size and increased encircled energy (EE) within small apertures. Gemini plans to enable this capability by deploying an adaptive secondary mirror. The GNAO system will need to be compatible with this upgrade.
Note or Source	“Entering into the Wide Field Adaptive Optics Era on Maunakea” Astro2020 Decadal Science White paper (by Gaetano Sivo), Concept of Operations
Verification Method	Demonstration

6.3 Driving GNAO RAMS Requirements

This section includes the level 1 Reliability, Availability, Maintainability, and Safety (RAMS) and related requirements.

GNAO-RAMS-001 *Reliability*	GNAO shall have <2% unexpected downtime from scheduled telescope time.
Rationale	The Observatory has a goal of 1% time loss due to instrument and AO faults (Gemini Operations Report for 2015A (internal)). The majority of current Observatory instruments have downtime of 0-2% (Gemini Current Instruments Report for 2015A (internal)). Therefore, possible failure, fault and error modes, how to prevent or reduce the possibility of these modes occurring, and how to facilitate/expedite recovery from an occurrence should be analyzed and understood.
Note or Source	Gemini Operations Report for 2015A (internal), Gemini Current Instruments Report for 2015A (internal)
Verification Method	Analysis

GNAO-RAMS-002 *Lifetime*	GNAO shall meet requirements throughout a lifetime of 10 years without major overhaul.
Rationale	GNAO is a workhorse facility that will be required to be available in the queue continuously. Therefore, the system should reliably operate without needing major overhaul and downtime for at least 10 years.
Note or Source	
Verification Method	Analysis

GNAO-RAMS-003 *Safety*	GNAO shall comply with safety standards defined in INST-REQ-0001 Science and Facility Instruments Common Requirements Specification.
Rationale	Ensuring safety is a Gemini standard.
Note or Source	
Verification Method	Analysis

GNAO-RAMS-004 *Accessibility*	GNAO shall provide access to all critical components.
Rationale	Access to critical components allows operations staff to perform repair and maintenance with minimum downtime.
Note or Source	
Verification Method	Analysis

GNAO-RAMS-005 *Maintainability*	GNAO shall be maintainable without significant retraining of operations staff.
Rationale	Software and hardware should be designed to allow the operations staff to maintain the system without needing specialized knowledge.
Note or Source	
Verification Method	Analysis

6.4 Driving Telescope to GNAO Interface Requirements

This section includes GNAO External Interface Requirements.

GNAO-INT-001 *Environmental*	GNAO Shall comply with Science and Facility Instruments to Transport, Observatory and Operational Environments Interface Control Document 1.9/5.0
Rationale	GNAO will be exposed to and must reliably operate under environmental conditions described in ICD.
Note or Source	
Verification Method	Test, Analysis

GNAO-INT-002 *Telescope Optical Interface*	GNAO shall comply with optical requirements specified in Instrument Support Structure to Gemini North Adaptive Optics Bench (GN-AOB) Interface Control Document ICD 1.5/1.8b
Rationale	GNAO must optically interface with the Gemini facility.
Note or Source	
Verification Method	Test, Demonstration

GNAO-INT-003 *Telescope Mechanical Interface*	GNAO shall comply with Telescope mechanical interface requirements, including those specified in Instrument Support Structure to Gemini North Adaptive Optics Bench (GN-AOB) Interface Control Document ICD 1.5/1.8b
Rationale	GNAO must mechanically interface with the Gemini facility.
Note or Source	
Verification Method	Demonstration

GNAO-INT-004 *Telescope Electrical Interface*	GNAO shall comply with electrical interface requirements specified in the Science and Facility Instruments to ISS System Services ICD [AD-04]
Rationale	GNAO must electrically interface with the Gemini facility.
Note or Source	
Verification Method	Test, Demonstration

GNAO-INT-005 *Telescope Service Interface*	GNAO shall comply with the telescope service interface requirements specified in the INST-REQ-0001 Science and Facility Instruments Common Requirements Specification.
Rationale	GNAO will utilize the Gemini service infrastructure described in the ICD.
Note or Source	
Verification Method	Demonstration

GNAO-INT-006 *Telescope Software Interface*	GNAO shall comply with Gemini software interface requirements specified in The Baseline Attribute/Value Interface (Document ID: gscg.grp.024/05)
Rationale	GNAO control software will interface with Gemini telescope software.
Note or Source	
Verification Method	Test

7 Appendix A: Acronyms and Abbreviations

Acronym	Meaning
ADC	Atmospheric Dispersion Corrector
AGN	Active Galactic Nucleus
AO	Adaptive Optics
AOB	Adaptive Optics Bench
BD	Brown Dwarf
FOV	Field of View
GeMS	Gemini Multi-Conjugate Adaptive Optics System
GLAO	Ground-Layer Adaptive Optics
GNAO	Gemini North Adaptive Optics
JWST	James Webb Space Telescope
ICD	Interface Control Document
LGS	Laser Guide Star
NEO	Near Earth Object
NIR	Near Infrared
NGS	Natural Guide Star
NIRCAM	Near Infrared Camera
MCAO	Multi-Conjugate Adaptive Optics
PSF	Point Spread Function
SCAO	Single-Conjugate Adaptive Optics
SEMP	Systems Engineering Management Plan
TBC	To Be Confirmed
TBD	To Be Determined
ZA	Zenith Angle