Programme: **ELT**

Project: **ELT MCAO Construction – MORFEO**

MORFEO Calibration Unit Optomechanical System – Technical Specifications

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1. Related Documents

1.1 Applicable Documents

The following documents and files, of the exact version shown, form part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the content of this document, the content of this document shall be considered as superseding the others.

AD1 ISO 10110 “Optics and optical Instruments – Preparation of optical drawings for optical elements and systems”

AD2 ESO-192984 (GEN-SPE-ESO-50000-4645) ESO Mechanical Standards, issue 2

AD3 ESO-191462 (GEN-SPE-ESO-50000-5600) ESO Engineering Analysis Standard, issue 2

AD4 ESO-193497 (SAF-GEN-MAN-3444) Safety Conformity Assessment Procedure, issue 5

AD5 ESO-262825 E-ELT Electrical and Electronic Design Requirements, issue 1

AD6 E-MAO-PH0-INA-SPE-001_02 Instrument Control Hardware Requirements for MORFEO Subsystems

AD7 E-MAO-SF0-INA-SPE-004_01 MORFEO Optics Common Requirements

AD8 E-MAO-000-INA-PLA-003_03 MAORY Product and Quality Assurance Plan

AD9 E-MAO-PU0-INA-ICD-002_01 MORFEO Calibration Unit Optomechanical System – Optical Interfaces

AD10 E-MAO-PUA-INA-MOD-001_01 MORFEO Calibration Unit – Optical Model (direct)

AD11 E-MAO-PUA-INA-ICD-DWG-001_01 MORFEO Calibration Unit Optomechanical System – PUA (supply) volume

AD12 E-MAO-PUA-INA-ICD-DWG-002_01 MORFEO Calibration Unit Optomechanical System – NGS mask volume and interface

AD13 E-MAO-PUA-INA-ICD-DWG-003_01 MORFEO Calibration Unit Optomechanical System – LGS mask volume and interface

AD14 E-MAO-PUA-INA-ICD-DWG-004_01 MORFEO Calibration Unit Optomechanical System – Fibers Splitting Unit volume

AD15 E-MAO-PUA-INA-ICD-DWG-005_01 MORFEO Calibration Unit Optomechanical System – Kinematic Supports interface

AD16 E-MAO-PUA-INA-ICD-DWG-006_01 MORFEO Calibration Unit Optomechanical System – Connectors Panel volume and interface

AD17 E-MAO-PUA-INA-ICD-DWG-007_01 MORFEO Calibration Unit Optomechanical System – PS panel volume

AD18 E-MAO-PUA-INA-ICD-DWG-008_01 MORFEO Calibration Unit Optomechanical System – DM volume

AD19 E-MAO-PUA-INA-ICD-DWG-009_01 MORFEO Calibration Unit Optomechanical System – Tools interfaces

1.2 Reference Documents

The following documents and files, of the exact version shown herein, are listed as background references and informative complement of the present document. They are not to be construed as a binding complement to the present document.

RD1 ESO-193459 General Definitions and Basic Conventions Related to Interfaces, issue 2

RD2 E-MAO-PUA-INA-TNO-002_01 MORFEO Calibration Unit Optomechanical System – Preliminary optical prescriptions

RD3 E-MAO-PU0-INA-PLA-002_01 MORFEO Calibration Unit Optomechanical System – OFDR Alignment Plan

RD4 E-MAO-PU0-INA-DER-002_01 MORFEO Calibration Unit Optomechanical System – OFDR Design and Analysis Report

RD5 E-MAO-PUA-INA-MOD-002_01 MORFEO Calibration Unit Optomechanical System – Preliminary Mechanical Model

RD6 E-MAO-PUD-INA-DWG-001_01 MORFEO Calibration Unit Test Equipment volume

2. Introduction

2.1 Scope and content

The Multi-conjugate adaptive Optics Relay For ELT Observations, MORFEO (formerly known as MAORY), is the Adaptive Optics Module for ELT.
The Calibration Unit (PU0) is a subsystem of MORFEO.
This document contains the technical specifications for the supply of MORFEO Calibration Unit Optomechanical System (PUA), Calibration Unit Tools (PUD) and Calibration Unit Optomechanical dummy (PUE).
This document contains both Requirements and Information. Requirements shall be verified by the Contractor and are binding, unless otherwise stated. The requirements (or parts of them) labelled as “INFO” are provided as information and do not strictly require a verification. The minimum verification methods to be applied for the requirement verification during the main project phases are reported in **Section 8**.

2.2 Naming Convention

Requirements are identified through a tag following the format [MAO-PU*Y*-*XXXX*], where XXXX is a unique, non-speaking number sequence.

2.3 Abbreviations and Acronyms

AD	Applicable Document
AO	Adaptive Optics
AOI	Angle Of Incidence
CAD	Computer-Aided Design
CNRS	Centre National de la Recherche Scientifique
CII	Core Integration Infrastructure
CU	Calibration Unit
DER	Design Report
DM	Deformable Mirror
DoF	Degree of Freedom
ELT	European Extremely Large Telescope
ESO	European Southern Observatory
FARR	Factory Acceptance Readiness Review
FDR	Final Design Review
FoV	Field of View
FP	Focal Plane
HW	Hardware
IAA	Instrument Assembly Area
ICD	Interface Control Document
ICH	Instrument Control Hardware

ICSS	Instrument Control System Software
INAF	Istituto Nazionale di AstroFisica
INS	Instrumentation Software
INSU	Institut National des Sciences de l'Univers
IWS	Instrument Workstation
IORR	Instrument Operations Readiness Review
IPAG	Institut de Planétologie et d'Astrophysique de Grenoble
IRD	Interface Requirement Document
LCI	Local Communication Infrastructure
LCS	Local Coordinate System
LGS	Laser Guide Stars
LOR	Low Order and Reference
MAIT	Manufacturing Assembly Integration and Test
MORFEO	Multi conjugate adaptive Optics Relay For ELT Observatory
MCAO	Multi Conjugate Adaptive Optics
MCMT	Maximum Corrective Maintenance Time
MICADO	Multi-AO Imaging Camera for Deep Observations
MDT	Mean Down Time
MFD	Modal Field Diameter
MOI	Moment of Inertia
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair/Replace
N/A	Not Applicable
NGS	Natural Guide Star
NP	Nasmyth Platform
NUIG	School of Physics at the National University of Ireland Galway
OAA	Osservatorio Astrofisico di Arcetri
OAAB	Osservatorio Astronomico d'Abruzzo
OAB	Osservatorio Astronomico di Brera
OACN	Osservatorio Astronomico di Capodimonte
OAPD	Osservatorio Astronomico di Padova
OAS	Osservatorio di Astrofisica e Scienza dello Spazio di Bologna
PAC	Preliminary Acceptance Review in Chile
PAE	Preliminary Acceptance Europe
PBS	Product Breakdown Structure
PDR	Preliminary Design Review
PLC	Program Logic Controller
PFS	Primary Focal Station
PH0	(MORFEO) Instrument control Electronics subsystem
PI	Principal Investigator
PM	Pupil Mirror
PM0	(MORFEO) Main Support Structure subsystem
PS	Pupil Sources
PSF	Point Spread Function
PT	Product Tree
PR0	(MORFEO) RTC subsystem
PSD	Power Spectral Density
PS0	(MORFEO) Software subsystem
PT0	(MORFEO) Thermal control subsystem
PU0	(MORFEO) Calibration Unit subsystem
PUA	Calibration Unit Optomechanical System
PUB	Calibration Unit Electronic Cabinet
PUC	Calibration Unit PUA/PUB Connections
PUD	Calibration Unit Tools

PUE	Calibration Unit Optomechanical Dummy
QE	Quantum Efficiency
RAMS	Reliability, Availability, Maintainability and Safety
RBM	Rigid Body Motion
RD	Reference Document
RF	Reference File
RMS	Root Mean Square
RON	Read-Out Noise
RTC	Real-Time Computer
SAT	System Architect Team
SCAO	Single-Conjugate Adaptive Optics
SCS	Standard Coordinates System
SE	System Engineer
SET	System Engineering Team
SOW	Statement Of Work
SMR	Spherical Mounted Retroreflector
SMU	Sensor Monitor Unit
SNR	Signal-to-Noise Ratio
SR	Strehl Ratio
SRR	System Requirements Review
SRS	Standard Reference System
SW	Software
TBC	To Be Confirmed
TBD	To Be Defined
TBW	To Be Written
TE	Test Equipment
TP	Temperature Probe
WFS	Wavefront Sensor
WP	Work Package
WS	Workstation

2.4 Definitions

MAO-PU0-0.0.1: Definition of Handling *(INFO)*

“Handling” defines the handling of the supply during packing, unpacking, assembling, testing and maintenance.

MAO-PU0-0.0.2: Definition of Accessibility *(INFO)*

“Accessibility” defines the access to the supply for inspection and maintenance. All the auxiliary equipment providing access to the PUA volume is also included in the definition.

MAO-PU0-0.0.3: Definition of design value tolerance *(INFO)*

“Design value tolerance” is defined as the maximum allowable deviation from the nominal design value requested. If the value is not specified, it shall be provided by the Contractor.

MAO-PU0-0.0.4: Definition of knowledge tolerance *(INFO)*

"Knowledge tolerance" is defined as the maximum allowed dispersion due to accuracy and precision errors. If the value is not specified, it shall be provided by the Contractor.

MAO-PU0-0.0.5: Zernike decomposition to be used *(INFO)*

Zernike modes are defined according to the convention of Noll: R. Noll, "Zernike polynomials and atmospheric turbulence", J. Opt. Soc. Am., Vol. 66, No. 3, p207 (1976).

MAO-PU0-0.0.6: Wavefront to surface conversion *(INFO)*

Whenever applicable, the supply shall be compliant with the following definition: the conversion factor between wavefront and reflecting surfaces is 2, i.e., the effect on the conversion factor of the incidence angle on the reflecting surfaces is ignored.

2.5 Coordinate System

The MORFEO coordinate system (Table 1) is centred in the ELT Focus B1 focal plane and has the same orientation of ELT Standard Coordinate System (SCS). The gravity orientation is parallel to the Z axis with opposite verse.

Table 1. Location of MORFEO SCS.

	X [mm]	Y [mm]	Z [mm]	α [deg]	β [deg]	γ [deg]
MORFEO SCS	27200	0	0	0	0	180

The PUA Local Coordinate System (LCS) is referenced to the MORFEO SCS, as defined in **MAO-PUA-1.2.4.2** and shown in **AD11**.

MAO-PUA-1.2.4.2: Local Coordinate System of the Calibration Unit Optomechanical System (PUA)

The PUA Local Coordinate System (LCS) coincides with MORFEO SCS. The PUA LCS (expressed in the MORFEO SCS) shall be used for all deliverable drawings and 3d cad models.

3. Product Description

3.1 Overview

ELT (Extremely Large Telescope) is the world's largest telescope (39m diameter) under construction by ESO (https://elt.eso.org/) at Cerro Armazones in Chile. ELT is considered worldwide to be one of the highest priorities in ground-based astronomy. MORFEO (http://wwwmorfeo.oabo.inaf.it/), as a first-generation ELT instrument, will help compensate for the distortion of light caused by turbulence in the Earth's atmosphere. MORFEO is a Multi-Conjugate Adaptive Optics (MCAO) module that will allow spatially uniform adaptive optics compensation over a large field of view (about 1 arcmin^2) with high sky coverage. Wavefront sensing is performed by six Laser Guide Stars (LGS) and three Natural Guide Stars (NGS), for the measurement of high and low-order wavefront perturbations respectively.
The Post-Focal Relay Optics sub-system of MORFEO re-images the telescope focal plane to the exit ports. It contains the following channels:

- Main Path Optics, which relay the telescope focal plane to the exit ports for the science instruments (MICADO and 2nd instrument);
- LGS Objective (LGSO), which creates an image plane for the laser guide stars, used by the LGS WFS sub-system to measure in real-time the high-order wavefront aberrations for the MCAO mode of MORFEO.

Inside the optical path, two clear planes are created, optically conjugated to two different ranges from the telescope entrance pupil, allowing the insertion of the two MORFEO Deformable Mirrors (conjugated at 6-12Km and 17-20Km).

The Calibration Unit will mimic the telescope, providing a set of calibration light sources (both NGSs and LGSs) for all MORFEO WFSs and MICADO, required to run calibration templates as well as verification and test procedures.
The system will be also used as a Test Unit during MORFEO AIV phase in Europe, by replacing the fixed Pupil Mirror (used in Calibration Unit mode) with a Deformable Mirror (DM). The provision of the DM is under the responsibility of the Consortium. The Contractor shall provide the interface, the tool(s) and the holder for the DM installation, according to the specifications defined in this document.

AD10 contains the optical model of the PUA (shown with MORFEO in Figure 1 and standalone in Figure 2), **AD9** describes the PUA optical interfaces, **RD5** contains the preliminary mechanical design (3d cad model) of the PUA. A description of the Calibration Unit optomechanical system (PUA) design is provided in **RD4**, **RD3** and **RD2**.

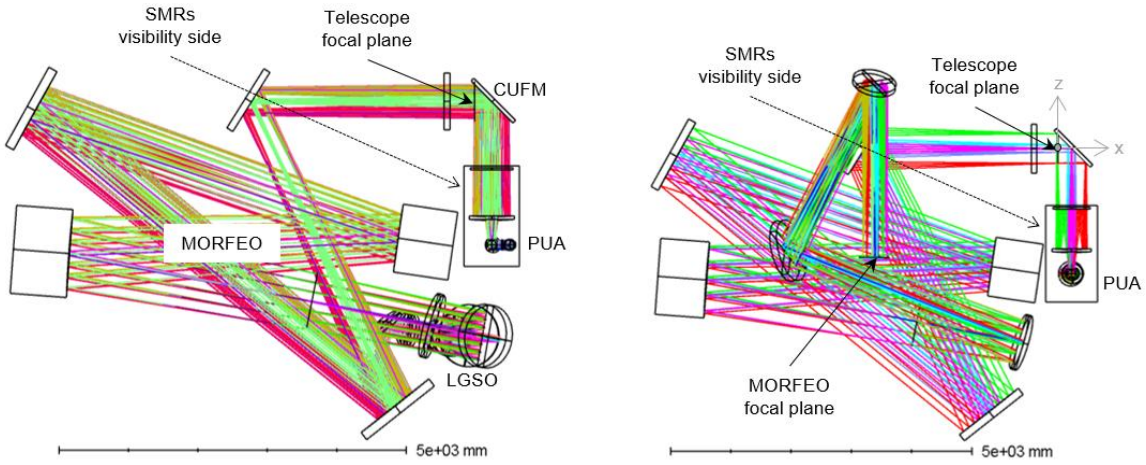
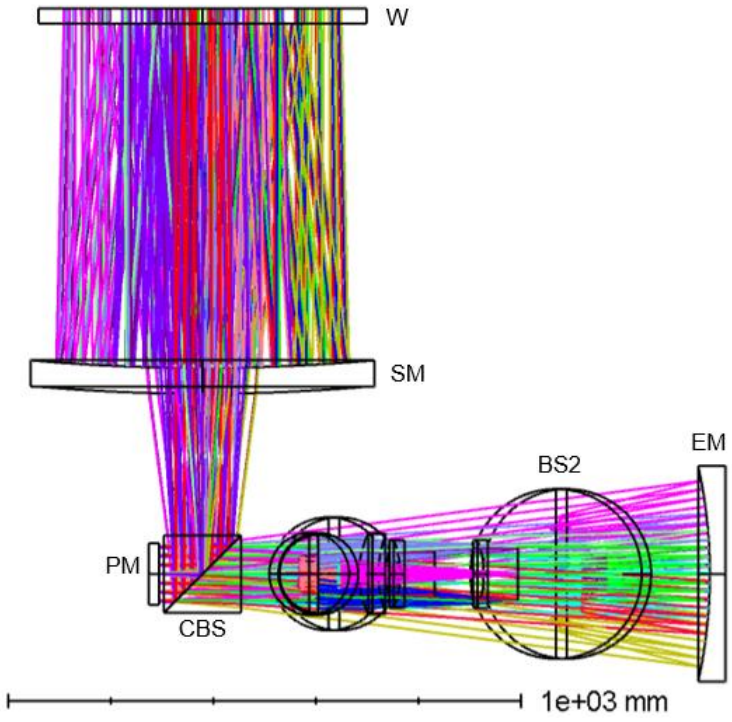


Figure 1. Optical design of PUA plus MORFEO (xz-plane): LGS optical path (left), NGS optical path (right). The continuous arrows point to the ELT focal plane centre, where MORFEO SCS is located (in grey), and to the MORFEO output focal plane.



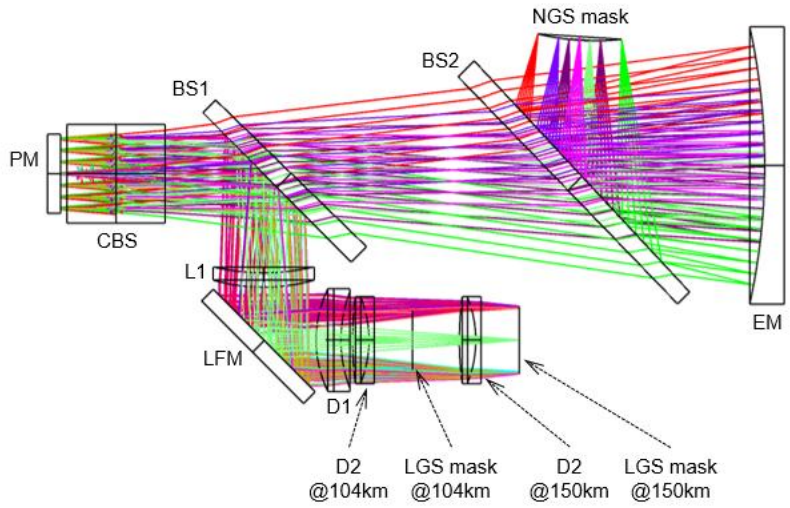


Figure 2. PUA optical design: yz-plane view (top), xy-plane view (bottom, W and SM are not shown).

3.2 Product Breakdown Structure

The Product Breakdown Structure (PBS) of the Calibration Unit subsystem (PU0) is defined in **MAO-PU0-1.0**. The items to be supplied by the Contractor are defined in **Section 3.3** (**MAO-PUA-1.0**, **MAO-PUD-1.0**, **MAO-PUE-1.0**).

MAO-PU0-1.0: Calibration Unit (PU0) Product Breakdown

The Product Breakdown Structure (PBS) of the Calibration Unit subsystem (PU0) shall comply with the one shown in Figure 3. Only the items highlighted in red shall be supplied.

Note:

- The items highlighted in green have one or more sub-items that shall be supplied; for the items highlighted in grey interfaces with the supplied items (highlighted in red) are defined.
- The provided PBS is preliminary and shall be furtherly developed and detailed by the Contractor.

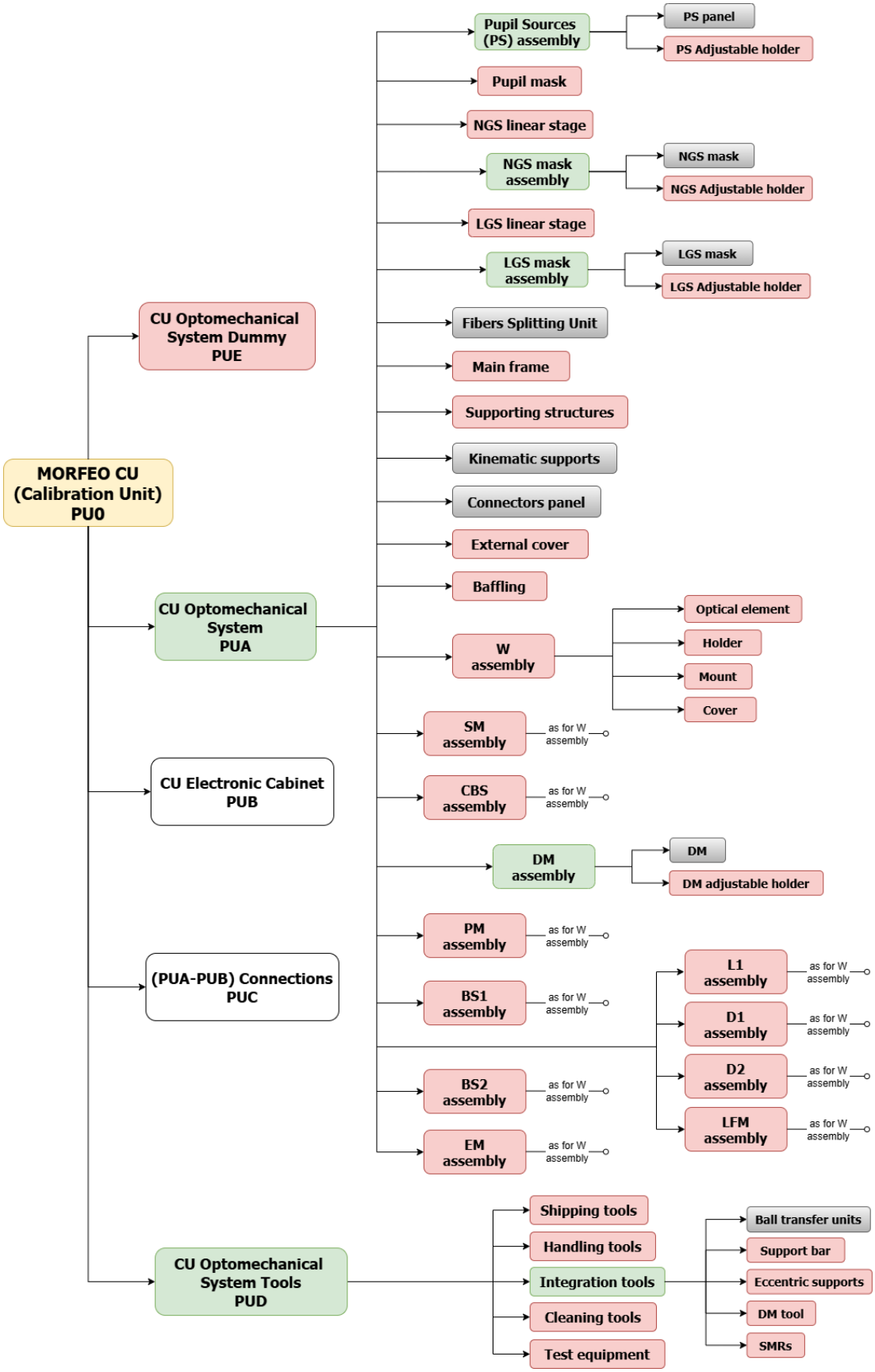

MORFEO CU (Calibration Unit) PU0
CU Optomechanical System Dummy PUE
CU Optomechanical System PUA
CU Electronic Cabinet PUB
(PUA-PUB) Connections PUC
CU Optomechanical System Tools PUD
Pupil Sources (PS) assembly
PS panel
PS Adjustable holder
Pupil mask
NGS linear stage
NGS mask assembly
NGS mask
NGS Adjustable holder
LGS linear stage
LGS mask assembly
LGS mask
LGS Adjustable holder
Fibers Splitting Unit
Main frame
Supporting structures
Kinematic supports
Connectors panel
External cover
Baffling
W assembly
Optical element
Holder
Mount
Cover
SM assembly
as for W assembly
CBS assembly
as for W assembly
DM assembly
DM
DM adjustable holder
PM assembly
as for W assembly
BS1 assembly
as for W assembly
BS2 assembly
as for W assembly
EM assembly
as for W assembly
L1 assembly
as for W assembly
D1 assembly
as for W assembly
D2 assembly
as for W assembly
LFM assembly
as for W assembly
Shipping tools
Handling tools
Integration tools
Cleaning tools
Test equipment
Ball transfer units
Support bar
Eccentric supports
DM tool
SMRs

Figure 3. Preliminary Product Breakdown Structure (PBS) of MORFEO Calibration Unit subsystem (PU0). The items to be supplied are highlighted in red.

3.3 Supply Definition

MAO-PUA-1.0: Calibration Unit Optomechanical System (PUA) supply

The Calibration Unit Optomechanical System (PUA) is part of the MORFEO Calibration Unit subsystem (PU0). PUA supply includes:

- Optomechanical assemblies (W, SM, CBS, PM, BS1, BS2, EM, L1, LFM, D1, D2), each composed of:
  - Optical element (lens/mirror)
  - Holder (mounting cell and/or sub-assembly structure)
  - Mount (kinematic mount where required)
  - Cover (where needed, for protection during handling/maintenance)
- Mechanical assemblies:
  - Main frame
  - Supporting structures
  - NGS adjustable holder
  - LGS adjustable holder
  - PS adjustable holder
  - DM adjustable holder
  - Pupil mask
  - Baffling (baffles and vanes for stray light suppression)
  - External cover (for protection during handling/maintenance and light tightness)
- Devices:
  - LGS linear stage
  - NGS linear stage

MAO-PUD-1.0: Calibration Unit Optomechanical System Tools (PUD) supply

The Calibration Unit Optomechanical System Tools (PUD) are part of the MORFEO Calibration Unit subsystem (PU0). PUD supply includes:

- Integration tools:
  - Support bar
  - Eccentric supports
  - DM tool
  - Spherical Mounted Retroreflectors (SMRs)
- Handling tools
- Shipping tools
- Cleaning tools
- Test Equipment

Note: Additional tools, not specified by the Customer but designed and used by the Contractor for handling, integration and/or alignment purposes, shall be delivered to the Customer as integral part of the supply.

MAO-PUE-1.0: Calibration Unit Optomechanics Dummy (PUE) supply

The Calibration Unit Optomechanics Dummy (PUE) is part of the MORFEO Calibration Unit subsystem (PU0) supply.

3.4 Interface Definition

The Calibration Unit Optomechanical System (PUA) will have the following interfaces:

- Mechanical interfaces, with PUA items not supplied by the Contractor (NGS mask, LGS mask, PS panel, Kinematic Supports, Fiber Splitting Unit, Connectors Panel, DM)
- Mechanical interfaces, with the supplied tools (Shipping tools, Handling tools, Integration tools)
- Electrical interface (LGS linear stage, NGS linear stage).

The Calibration Unit Optomechanical System Tools (PUD) will have the following interfaces:

- Mechanical interfaces, with PUD items not supplied by the Contractor (Ball Transfer Units)
- Mechanical interfaces, with PUA.

MAO-PUA-1.3.5.4: Mechanical Interfaces

The PUA interfaces shall comply with the requirements specified in **Section 5.1**.

MAO-PUA-1.3.5.3: Electrical Interfaces

The PUA interfaces shall comply with the requirements **MAO-PUA-1.7.1.2**, **MAO-PUA-1.7.1.3** and **MAO-PUA-1.7.1.4**.

MAO-PUD-1.3.5.4: Tools mechanical Interfaces

The PUD interfaces shall comply with the requirements specified in **Section 5.1**.

4. Characteristics

4.1 Common Requirements

MAO-PU0-2.0: Common requirements

The PUA shall comply also with the common requirements defined in **AD7**. A verification and compliance matrix shall be produced (non-applicable requirements shall be marked with N/A).

4.2 PUA Performance Requirements

4.2.1 Beam Transfer

MAO-PUA-1.2.7.1: LGS Field of View (FoV)

The PUA LGS FoV shall be annular, centred at 45 arcsec, width of 3 arcsec.

MAO-PUA-1.2.7.2: LGS conjugation altitudes

The PUA LGS focal planes shall be conjugated to 104 km and 150 km.

MAO-PUA-1.2.7.4: LGS waveband

The PUA LGS waveband shall be: (584÷594) nm.

MAO-PUA-1.2.7.6: NGS Field of View (FoV)

The PUA NGS FoV shall be circular, 160 arcsec in diameter.

MAO-PUA-1.2.7.7: NGS conjugation altitude

The PUA NGS focal planes shall be conjugated to infinity.

MAO-PUA-1.2.7.8: NGS wavebands

The PUA NGS wavebands shall be: (700÷900) nm, (1500÷1800) nm.

MAO-PUA-1.2.7.21: Output f-number

The PUA f-number on each output focal plane shall be:

- 17.745 (NGS)

- 20.27 (LGS conjugated to 104 km)
- 19.41 (LGS conjugated to 150 km)

Tolerance: ±1%.

MAO-PUA-1.2.7.25: NGS output focal plane curvature

The PUA output focal plane (NGS) shall be concave with a radius of curvature of 9884 mm. The associated tolerance will be provided during the final design phase.

MAO-PUA-1.2.7.27: Sources configuration

The PUA shall provide all the required wavebands at the same time.

MAO-PUA-1.2.7.28: LGS optical quality

The PUA shall provide LGS sources with a net rms wavefront error smaller than 100 nm, within the specified waveband and FoV. The specified value is intended with respect to a common focal plane, static in a time interval of at least 1 h. The static (common) contributions of tip/tilt and defocus can be excluded from the specified value, however defocus shall not exceed 100 nm rms. The full temperature range of operational conditions (0°-15°C) shall be considered.

Note: The specified wavefront error budget of 100 nm rms does not include the ELT nominal wavefront error contribution (~90 nm rms and ~60 nm rms, for 45 arcsec off-axis sources conjugated to 104km and 150km, respectively). Details of the ELT WFE contribution, that shall be reproduced by the PUA, will be provided by the Customer at the beginning of the Final Design phase.

MAO-PUA-1.2.7.29: NGS optical quality

The PUA shall provide NGS sources with a rms wavefront error smaller than:

- 60 nm, averaged within the (700÷900) nm waveband and across the full FoV (160 arcsec);
- 150 nm, averaged within the (1500÷1800) nm waveband and across the full FoV (160 arcsec);
- 60 nm, averaged within the (1500÷1800) nm waveband and across a square central portion of the FoV (52 arcsec side).

The specified wavefront error budgets are intended with respect to a common focal plane, static in a time interval of at least 1h. The static (common) contributions of tip/tilt and defocus can be excluded from the specified values, however defocus shall not exceed 150 nm rms. The full temperature range of operational conditions (0°-15°C) shall be considered.

MAO-PUA-1.2.7.30: NGS/LGS exit pupil optical quality

The PUA shall provide an exit pupil with the following characteristics, for all the specified wavebands and referring to the nominal exit pupil diameter specified in **MAO-PUA-1.3.2.3**:

- Blur smaller than 1% of the exit pupil diameter;
- Distortion smaller than 1% of the exit pupil diameter;

- Elongation smaller than 1% of the exit pupil diameter.

MAO-PUA-1.3.2.3: NGS/LGS exit pupil plane

The PUA exit pupil shall coincide with the ELT exit pupil, in diameter and position, for all the specified wavebands, with an accuracy of 3%. Nominal exit pupil distance from MORFEO SCS: 37867.5 mm. Nominal exit pupil diameter: 2134 mm.

MAO-PUA-1.6.1.1: Optical components Geometrical parameters

The main geometrical parameters of the PUA optical components (clear apertures, thicknesses, radii of curvature) are reported in Table 2, in agreement with **RD2**. Small deviations from the specified values are allowed, provided that all the performance and physical requirements are met. Melt and tool adaptation are in charge of the Contractor.

Table 2. Main geometrical parameters of the PUA optical components. (*) Optics with an aspherical surface.

Component	Name / Description	Aperture type	Min. Clear aperture (mm)	Central Thickness (mm)	Radius of curvature (mm)
W	(semi-reflecting) Window	Circular	Ø620	30	infinity (all)
SM	(semi-reflecting) Spherical Mirror	Circular	Ø650	50	3700 3700
PM*	Pupil Mirror	Circular	Ø108	20	infinity
CBS	Cube Beam Splitter	Square	146 x 146	150	infinity (all)
BS1	Beam Splitter 1	Elliptical	290 x 200	30	infinity (all)
BS2	Beam Splitter 2	Elliptical	455 x 310	30	infinity (all)
EM*	Ellipsoidal Mirror	Circular	Ø400	35	974.947
L1	(Lgs) Lens #1	Circular	Ø142	22	-279.235 -336.912
D1*	(Lgs) Doublet #1	Circular	Ø144	38	-203.522 infinity -174.628
D2	(Lgs) Doublet #2	Circular	Ø123	33	infinity 172.801 -502.819
LFM	Lgs Folding Mirror	Elliptical	210 x 150	25	Infinity

MAO-PUA-1.6.1.2: Focal plane ghosts

The PUA shall provide sources whose intensity on the output focal planes, with respect to the most intense generated ghost, is:

- At least 50 times higher, for LGS sources;
- At least 100 times higher, for NGS sources.

MAO-PUA-1.6.1.3: Pupil plane ghosts

The PUA, in any operating condition, should not present spatial overlaps between pupil image and pupil ghosts. If this is not achieved:

- The pupil ghost full width diameter shall be smaller than 10% of the pupil image diameter;
- The distance between pupil ghost and pupil image centroids shall be smaller than 7.5% of the pupil image diameter.

MAO-PUA-1.6.1.4: Global throughput

The PUA global throughput shall be higher than:

- 0.2% for NGS sources;
- 0.5% for LGS sources.

MAO-PUA-1.6.1.5: Optical components throughput

The values of reflectivity and transmissivity of the PUA optical surfaces are reported in Table 3, in agreement with **RD2**. Small deviations from the specified values are allowed, provided that the requirement **MAO-PUA-1.6.1.4** is met. The throughput values shall be valid for the Angles of Incidence (AOI) reported in Table 3 and in **RD2**.

Table 3. Reflectivity and transmissivity values of the PUA optical components. (*) Random Anti-Reflection (RAR) coating technology is recommended to minimize the surface reflectivity.

Component	Surface	Reflectivity (%)	Transmissivity (%)	Wavebands (nm)	AOI (deg)
W	W-S1	<3.5% <3%	>97%	580÷600 700÷1800	0 ± 15
	W-S2	50%	50%	580÷1800	
SM	SM-S1	50%	50%	580÷1800	0 ± 15
	SM-S2	<3.5% <3%	>97%	580÷600 700÷1800	
PM	(mirror)	>95%	-	580÷1800	0 ± 10
CBS	CBS-S1	<2%	>98%	580÷600 700÷900 1500÷1800	0 ± 10
	CBS-S2	<1%(*)	>98%		
	CBS-S3	<2%	>98%		
	CBS-S5 (diag)	50%	50%		45 ± 6
BS1	BS1-S1	<3%	>97%	700÷1800	45 ± 10
	BS1-S2	>85% <15%	<15% >85%	580÷600 700÷1800	
BS2	BS2-S1	50%	50%	700÷1800	45 ± 17
	BS2-S2	<3%	>97%		45 ± 10
EM	(mirror)	>95%	-	700÷1800	0 ± 10

L1	L1-S1	<0.5%	>99%	580÷600	0 ± 20
	L1-S2	<0.5%	>99%		
D1	D1-S1	<0.5%	>99%	580÷600	0 ± 20
	D1-S2	-	-		
	D1-S3	<0.5%	>99%		
D2	D2-S1	<0.5%	>99%	580÷600	0 ± 20
	D2-S2	-	-		
	D2-S3	<0.5%	>99%		
LFM	(mirror)	>98.5%	-	580÷600	45 ± 10

MAO-PUA-1.6.1.6: Optical transmission / reflectivity degradation

The Contractor shall provide an estimation of the degradation of the transmission / reflectivity curve(s), considering a cleanliness better than ISO 7.2 (median) and ISO 8 (90% percentile).

MAO-PUA-1.6.1.7: Optical components reflectivity measurements

The reflectivity measurements shall be done on witness samples coated together with the optics. The qualification shall be performed at AOI spanning from 0 deg to 70 deg (nominal AOI are defined in **MAO-PUA-1.6.1.5** and **RD2**). Test wavelengths shall be defined during the final design phase. An uncertainty of 1% on the measurement is allowed for nominal reflectivity values higher than 40%. The Contractor shall provide a representative set of min. 3 glass samples (size 1-2 inches) for each coating type, to be deployed in Chile at ESO's Paranal Observatory for coating verification and coating ageing studies.

MAO-PUA-1.6.1.8: Micro-roughness

The micro-roughness of all optical surfaces within each clear aperture shall not exceed:

- Rq = 2 nm, spatial band: (0.0025 – 0.080) mm
- Wq = 3 nm, spatial band: (0.08 – 3) mm

The values are also specified in **RD2** (according to **AD1**, part 8).

MAO-PUA-1.6.1.9: Polished surface imperfections

Surface imperfections over the polished clear apertures of the PUA optical components are specified in **RD2** (according to **AD1**).

MAO-PUA-1.6.1.10: Optical components surface quality (low orders)

The PUA optical components' low spatial frequency surface error is reported in Table 4, specified for each optical surface as a tolerance value referred to an interval of Zernike modes. This shall be achieved under gravity load and reference operational condition corresponding to: temperature of 9°C, pressure of 712 mbar, humidity of 15% (RH). Small

deviations from the specified values are allowed, provided that all the performance requirements (e.g., wavefront error) are met.

Table 4. Surface flatness (low spatial frequencies) of PUA optical components.

Component	Surface	Tolerance (nm rms)	
		Zernike interval Z5 – Z11	Zernike interval Z12 – Z36
W	W-S1	20	6
	W-S2	10	5
SM	SM-S1	10	5
	SM-S2	20	10
PM	-	5	4
CBS	all	10	5
BS1	BS1-S1	20	10
	BS1-S2	10	5
BS2	BS2-S1	10	5
	BS2-S2	20	10
EM	-	10	5
L1	all	10	5
D1	all	20	10
D2	all	20	10
LFM	-	10	5

MAO-PUA-1.6.1.11: Optical components surface quality (mid-high orders)

The PUA optical components' mid-high spatial frequency surface error is specified by the following PSD.

$PSD = \{A/f^B\}$ for $0.01\ mm^{-1} \leq f \leq 0.1\ mm^{-1}$

where: PSD [m^3], f [1/m], A [$m^2\ m^{(1-B)}$]

and: $A=2x10^{-16}$, B=2.0

This shall be achieved under gravity load and the reference operational condition corresponding to: temperature of 9°C, pressure of 712 mbar, humidity of 15% (RH).

The specified PSD is not binding. However, the real PSD shall not introduce a rms surface departure larger than 5 nm over the clear aperture.

INFO: particular attention should be paid to the following surfaces: W-S2, SM-S1, EM.

MAO-PUA-1.6.1.12: Total emissivity

The PUA emissivity of the non-optical surfaces shall be agreed during the final design phase (e.g., type of paint).

MAO-PUA-1.6.2.1: Stray light suppression

The Contractor shall provide a baffling system to suppress PUA stray light. Where a baffle is not applicable, alternative solutions for stray light suppression shall be implemented (e.g., black absorptive treatments). The Contractor shall also provide an external cover to avoid any propagation of unwanted light outside the PUA and to ensure PUA insensitivity to any outside illumination (light tightness). Baffling and external cover concepts are provided in **RD5**.

MAO-PUA-1.6.2.2: Stray light level

The Contractor shall verify that the PUA values of Signal-to-Noise Ratio (SNR), measured at the PUA output focal planes, are in agreement with the specifications defined in Table 5.

Note: The input sources to be used are binding, while the conditions are not, provided that comparable SNR values are achievable within comparable exposure times (T_{exp}).

Table 5. SNR values required to PUA sources (λ_c is the source central wavelength, MFD is the fiber mode field diameter).

Input FP source	Test camera and conditions	Spec.
Single-mode fiber λ_c = 1600 nm, $\Delta\lambda$ = 100 nm (max) MFD < 4.5 um @1600nm Position: NGS input FP	Camera: OWL1280 gain=10 | dark=19000 | RON=180 | QE=0.8	SNR > 10
	T_{exp} = 90 ms | Input power = $3x10^{-9}$ W	
Multi-mode fiber λ_c = 800 nm, $\Delta\lambda$ = 200 nm (max) Core diameter = 400 um Position: NGS input FP	Camera: Fingerlake Flicamera Proline PL4240 gain=1.35 | dark=1 | RON=10 | QE=0.6	SNR > 850
	T_{exp} = 1 s | Input power = $1x10^{-7}$ W	
Pinhole λ_c = 589 nm, $\Delta\lambda$ = 10 nm (max) Diameter = 3 mm Positions: LGS input FPs	Camera: Fingerlake Flicamera Proline PL4240 gain=1.35 | dark=1 | RON=10 | QE=0.95	SNR > 400
	T_{exp} = 0.1 ms | Input power = $4x10^{-3}$ W	

4.2.2 Positioning

MAO-PUA-1.2.4.10: Mechanical reference position

The PUA shall be equipped with six Spherical Mounted Retro-reflectors (SMR), to reference its position. SMR size: 0.5 inch.

It shall be possible to retrieve the as-built LCS from the acquisition of the SMRs within the following tolerances:

- Dx: ±1 mm
- Dy: ±1 mm
- Dz: ±1 mm
- Rx: ±3 arcmin
- Ry: ±3 arcmin

- Rz: ±3 arcmin

The position of the SMRs must be referenced also with respect to the interface with the kinematic supports. The exact SMRs position will be agreed with the Customer during the final design phase, however all SMRs shall be visible from a laser tracker along the direction specified in Figure 1.

Note:
- The fitting procedure shall be agreed with the Contractor.
- It is not foreseen to dismount the SMRs from the PUA.

4.2.3 Additional requirements

MAO-PUA-1.2.4.3: Internal pupil plane and pupil mask

The PUA shall provide an internal accessible pupil plane to allow the replacement of the Pupil Mirror (PM) with a Deformable Mirror (DM, not supplied by the Contractor). The internal pupil plane shall be located ideally on the PM/DM optical surface, the exact pupil size and position shall be defined through a thin Pupil Mask (in agreement with **MAO-PUA-1.2.7.21**) with a central obstruction and six thin spiders. The Pupil Mask shall be located as close as possible to the PM/DM optical surface, shall be easily replaceable, its aperture shall be defined with an accuracy of 0.1%, and the accuracy of its positioning shall be guaranteed in case of PM/DM switch.

MAO-PUA-1.7.1.1: LGS conjugation altitudes switch

The LGS adjustable holder shall be mounted on a motorized linear stage (LGS linear stage), so that the LGS mask (not supplied by the Contractor) can be positioned with high precision and repeatability (defined in **MAO-PUA-1.7.1.2**) on the input focal planes defined in **AD10** and **AD13**. The D2 assembly shall also be mounted on the same stage, so that its distance from the LGS mask remains fixed during motion.

MAO-PUA-1.7.1.2: LGS linear stage

The LGS motorized linear stage shall meet the following requirements:

a) Travel range ≥ 180 mm
b) Focusing accuracy ≤ 10 um
c) Pitch, Yaw & Roll shall ensure to keep the optical alignment within the requirements when switching between the CU nominal conjugation altitudes and adjusting for focus (preliminary estimation < 150 urad)
d) Load capacity (gravity direction) ≥ 100 N
e) Minimum speed ≥ 5 mm/s
f) Repeatability ≤ 2 um
g) Operating temperature range: -5°C to 35°C
h) MTBF ≥ 15000 h

i) No preventive maintenance shall be foreseen. In case of failure of electrical parts (motor or encoder), it shall be possible to repair the stage preserving the internal PUA optical alignment.
j) The stage shall be provided with a 2-phase stepper or BLDC motor, according to the specifications reported in Section 3 of **AD5** and in Sections 6.4.1, 9 and 10 of **AD6**.
k) Encoders type shall ensure noise and interference rejection over a cabling distance up to 50 meters, being provided with reliable communication protocols, according to the specifications reported in Section 3 of **AD5** and in Section 9 of **AD6**.
l) Limit switches and reference signals shall ensure noise and interference rejection (e.g., 24 VDC logic or provided with differential line driver) over a cabling distance up to 50 meters, according to the specifications reported in Section 3 of **AD5** and in Section 10 of **AD6**.
m) The stage shall be provided with separate connectors for motor and signals (encoder and limit switches), according to the specifications reported in Section 10 of **AD6**.
n) Connector types shall be D-sub or M-type (metal shield, matte black finish or black coated or covered, to prevent reflections), compliant to Section 3.8 of **AD5** and Section 7.3 of **AD6**.
o) Connection cables to the stage, with a minimum length of 10.0 meters, shall be included in the supply.

MAO-PUA-1.7.1.3: NGS linear stage

The NGS motorized linear stage shall meet the following requirements:

a) Travel range ≥ 10 mm
b) Focusing accuracy ≤ 2 um
c) Pitch, Yaw & Roll shall ensure to keep the optical alignment within the requirements when focusing the NGS sources (preliminary estimation < 50 urad)
d) Load capacity (gravity direction) ≥ 20 N
e) Repeatability ≤ 2 um

The requirements specified in the points from g) to o) of **MAO-PUA-1.7.1.2** shall be also met.

MAO-PUA-1.7.1.4: Grounding

A common grounding between PUA and the rest of MORFEO shall be defined during the final design phase and provided with the PUA.

MAO-PUA-1.8.1.1: Optical alignment

The PUA alignment procedure shall be defined by the Contractor during the final design phase, in agreement with the Customer. A preliminary alignment strategy, defined by the Customer, is reported in **RD3**. The Contractor shall also provide comprehensive training to the Consortium on the various aspects related to the PUA alignment procedure and on the use of any integration and/or alignment tool delivered to the Customer.

MAO-PUA-1.8.1.2: Optical components degrees of freedom

The PUA optical components degrees of freedom (DoF), their range and resolution, shall be defined by the Contractor, based on the agreed alignment procedure. As a reference, the optical components DoF, ranges and resolutions preliminarily defined by the Customer are reported in Table 6 (local coordinate axes defined in **RD3**).

Table 6. Preliminary adjustment ranges and resolutions defined for the PUA opto-mechanics.

		DecX	**DecY**	**PistZ**	**RotX**	**RotY**	**RotZ**
		mm	*Mm*	*mm*	*deg*	*deg*	*deg*
W	*Range*	-	-	±2	±0.2	±0.2	-
	Resolution	-	-	0.05	0.002	0.002	-
SM	*Range*	±2	±2	±3	±0.1	±0.1	-
	Resolution	0.1	0.1	0.03	0.001	0.001	-
W+SM (block)	*Range*	±1	±1	±3	±0.2	±0.2	-
	Resolution	0.05	0.05	0.03	0.003	0.003	-
PM / DM	*Range*	±2	±2	±2	±0.2	±0.2	±1
	Resolution	0.02	0.02	0.05	0.002	0.002	0.05
CBS	*Range*	±2	±2	±2	±0.2	±0.2	±0.2
	Resolution	0.05	0.05	0.05	0.002	0.002	0.002
BS1, BS2	*Range*	-	-	±3	±0.3	±0.3	±0.3
	Resolution	-	-	0.03	0.003	0.003	0.003
EM	*Range*	±3	±3	±5	±0.2	±0.2	-
	Resolution	0.01	0.01	0.01	0.001	0.001	-
L1	*Range*	±1	±1	-	±0.1	±0.1	-
	Resolution	0.01	0.01	-	0.001	0.001	-
LFM	*Range*	-	-	-	±0.3	±0.3	-
	Resolution	-	-	-	0.001	0.001	-
D1	*Range*	±1	±1	-	±0.1	±0.1	-
	Resolution	0.01	0.01	-	0.001	0.001	-
D2	*Range*	±1	±1	-	±0.1	±0.1	-
	Resolution	0.01	0.01	-	0.001	0.001	-
L1+LFM+D1+D2 (block)	*Range*	±1	±1	-	±0.2	±0.2	-
	Resolution	0.02	0.02	-	0.002	0.002	-

MAO-PUA-1.8.1.3: NGS adjustable holder

The Contractor shall provide an adjustable holder for the support and positioning of the NGS mask (not supplied by the Contractor).

The following DoF shall be provided (local coordinate system defined in **RD3**):

- decenter X
- decenter Y
- piston Z
- rotation X
- rotation Y

Preliminary ranges and resolutions are reported in Table 7. The final values shall be defined by the Contractor during the final design phase, also considering the agreed alignment procedure.

Note: The motorization of the Z-axis piston, for dynamic defocus compensation under varying operational conditions in Europe (for testing) and Chile (for operation), is required as part of the risk mitigation strategy. Such DoF shall be provided through a linear stage (NGS linear stage), whose specifications are defined in **MAO-PUA-1.7.1.3**

Table 7. Preliminary adjustment ranges and resolutions defined for the NGS adjustable holder.

		DecX	**DecY**	**PistZ**	**RotX**	**RotY**	**RotZ**
		mm	*mm*	*mm*	*deg*	*deg*	*deg*
NGS adj. holder	*Range*	±5	±5	±5	±0.5	±0.5	-
	Resolution	0.01	0.01	0.001	0.001	0.001	-

MAO-PUA-1.8.1.4: LGS adjustable holder

The Contractor shall provide an adjustable holder for the support and positioning of the LGS mask (not supplied by the Contractor).

The following DoF shall be provided (local coordinate system defined in **RD3**):

- decenter X
- decenter Y

Preliminary ranges and resolutions are reported in Table 8. The final values shall be defined by the Contractor during the final design phase, also considering the agreed alignment strategy.

Table 8. Preliminary adjustment ranges and resolutions defined for the LGS adjustable holder.

		DecX	**DecY**	**PistZ**	**RotX**	**RotY**	**RotZ**
		mm	*mm*	*mm*	*deg*	*deg*	*deg*
LGS adj. holder	*Range*	±5	±5	-	-	-	-
	Resolution	0.01	0.01	-	-	-	-

MAO-PUA-1.8.1.5: Pupil Sources (PS) adjustable holder

The Contractor shall provide an adjustable holder for the support and positioning of the PS panel (not supplied by the Contractor).

The following DoF shall be provided (local coordinate system defined in **RD3**):

- piston Z
- rotation X
- rotation Y

Ranges and resolutions are reported in Table 9.

Table 9. Adjustment ranges and resolutions defined for the PS adjustable holder.

		DecX	DecY	PistZ	RotX	RotY	RotZ
		mm	*mm*	*mm*	*deg*	*deg*	*deg*
PS adj. holder	*Range*	-	-	±2	±1	±1	-
	Resolution	-	-	0.1	0.05	0.05	-

4.3 PUD Performance Requirements

MAO-PUD-1.4.1: Handling Tools requirements

The Contractor shall provide proper and safe handling tools for all the handling activities involving PUA and PUE.

As a minimum, the tools shall be used to carry out the following activities (both in Europe and Chile):

- Packing and unpacking;
- Lifting and moving;
- Maintenance.

For all the activities the Contractor shall provide detailed documentation on procedures (operating and maintenance manuals) and comprehensive training to the Customer and ESO personnel.

The following requirements shall be met:

- An interface (e.g., eyebolt) for PUA crane handling shall be provided, whose position shall be adjustable around the nominal (x-y) position of the PUA CoG;
- Temporary supports shall be provided, to safely lay the PUA on a horizontal (x-y) plane;
- Any PUA relative motion shall be avoided during the handling;
- Lifting and moving tools shall be CE certified;
- A total payload of 4000 N shall be considered, aligned to the gravity vector and acting on the interface points with the PUA.

MAO-PUD-1.4.2: Shipping Tools requirements

The shipping tools shall be designed to protect the PUA during all transport phases, in agreement with Sections 3.1 and 3.8 of **AD7,** and to preserve the alignment of the optical components (see also **MAO-PUA-1.4.14)**. They shall be equipped with one or more shock and tilt sensors. If a shipping box is made of or contains wood parts, they shall comply with the custom Chile wood treatment regulations.

MAO-PUD-1.4.3: Cleaning Tools requirements

The Contractor shall provide proper and safe tools for the cleaning of all PUA optical components, with particular care for the cleaning of the window W. All procedures, required tools and documentation for the cleaning (including the washing) shall be developed, tested and delivered with the supply. The Contractor shall also provide comprehensive training to the Customer and/or ESO personnel.

MAO-PUD-1.4.4: Integration Tools requirements

The Contractor shall provide proper and safe integration tools. The Support Bar shall be designed considering a total payload of 2000 N, while 1000N shall be considered for each Eccentric Support, aligned to the gravity vector and acting on the interface points defined for each one.

MAO-PUD-1.4.5: Test Equipment requirements

The Contractor shall provide a Test Equipment (TE) to allow the Customer to perform all the required quality tests at the customer's premises. The final design of the Test Equipment supply shall be agreed with the Customer during the final design phase. As a reference, a test setup layout, preliminarily defined by the Customer, is described in **RD4** and **RD6**.

The following requirements shall be met:

a) The TE (structure plus optical and auxiliary components) shall be designed to have full access to the output focal planes (both NGS and LGSs) of the PUA, in order to perform all the required quality tests (e.g., NGS off-axis sources wavefront error measurement).
b) The TE shall include motorized slides for the scanning of the full CU output focal plane(s) (selection of NGS and LGS sources), operating at a temperature range from -5°C to 35°C. Cables' minimum length: 10 meters.
c) Considering the reference system in **RD6**, the maximum size of the TE (completely mounted) shall be: 1,5 metres (x), 2.5 metres (y), 3.5 metres (z).
d) The TE shall be easily assembled/disassembled and transported in an appropriate box (included in the supply), designed in agreement with the specifications reported in Sections 3.1 and 3.8 of **AD7**.

The Contractor shall also provide comprehensive documentation on the mounting and dismounting, as well as on the packing and unpacking procedures for the TE, and a description of the Test & Verification procedures to be performed with the TE on the PUA. Comprehensive training to the Customer on the mounting and use of the supplied test equipment is also required.

MAO-PUD-1.4.6: Additional tools requirements

Any additional tool, not defined or detailed by the Customer but delivered as a part of the supply, shall be designed considering as a minimum the set of requirements specified in **AD7** and in this **Section 4.3** (according to use and typology of each one).

4.4 Physical Requirements

MAO-PUA-1.2.3.1: Optical Materials

The materials of the PUA optical components are defined in **RD2**. Equivalent materials (similar refraction index and Abbe number) can be accepted, provided that all the performance requirements are met. Substrate specifications such as thickness,

homogeneity and striae, bubbles and inclusions, stress birefringence, are indicated in **RD2**: small deviations from the specified values are allowed, provided that all the performance and physical requirements are met. Melt and tool adaptation are in charge of the Contractor.

Note: Particular attention shall be paid to the CBS substrate, to maximise its homogeneity.

MAO-PU0-1.2.3.2: Mechanical Materials

The material(s) of all the supplied mechanical components shall be resistant to the corrosion, alternatively all parts shall be treated against corrosion.

MAO-PUA-1.2.5.2: Thermal induced rigid-body motion

The PUA, under thermal load, shall not have a static rigid-body motion (absolute value with respect to the LCS) larger than:

- Dx: 0.1 mm
- Dy: 0.1 mm
- Dz: 0.1 mm
- Rx: 1.5 arcmin
- Ry: 1.5 arcmin
- Rz: 1.5 arcmin

Gravity load and the full temperature range of operational conditions (0°-15°C) shall be considered.

MAO-PUA-1.2.1.1: Mass budget

The total mass of the PUA (supply) shall not be higher than 320 Kg.

MAO-PUA-1.2.1.2: Volume

The available volume for the PUA (supply) and its position with respect to the LCS are defined in **AD11**. A number of sub-volumes shall be reserved for the sub-assemblies not supplied by the Contractor, in agreement with the requirements of **Section 5.1**.

MAO-PUA-1.2.1.6: Moments of Inertia

The PUA moments of inertia (with respect to MORFEO SCS) shall be provided by the Contractor during the final design phase.

MAO-PUA-1.2.1.7: Centre of Gravity (CoG)

The position of the PUA CoG (with respect to MORFEO SCS) shall be provided by the Contractor during the final design phase. The following coordinates shall be assumed as a reference for the PUA CoG: (x, y, z) = (230, 350, -1800) mm. Large deviations (>10%) from the specified x-y values shall be agreed with the Customer, the z value shall not be higher than -1750 mm.

MAO-PUA-1.2.1.8: Acting forces

The values of the forces acting on the interfaces described in **Section 5.1** shall be provided by the Contractor during the final design phase. Unless elsewhere specified, the acting forces shall be computed starting from the earthquake analysis, according to **MAO-PUA-1.1.2**.

MAO-PUA-1.2.1.9: Structural frequencies

The PUA lowest eigenfrequency shall not be lower than 30 Hz.

The corresponding analytical verification shall assume:

- Infinitely rigid interfaces with the Kinematic supports
- Equivalent masses (provided by the Customer with the application points) for the items not supplied by the Contractor

Note: The total mass of the non-supplied items is estimated to be less than 40 kg.

MAO-PUA-1.2.1.10.1: Vibration allowed

The values of force reported in Table 10 shall be considered as limit for the vibration induced by the PUA on its interface with the Kinematic Supports. The final values are pending on MORFEO vibration analysis and will be provided by the Customer during the final design phase.

Table 10. Specification on the maximum vibration induced by the PUA.

Frequency Range [Hz]	1 - 4.45	4.45 - 56	56 - 110
Force (x,y,z) [N] rms per one-third octave frequency bands	0,25	0,1	0,5

MAO-PUA-1.2.1.10.2: Vibration received

Unless elsewhere specified, the values of force reported in Table 11 shall be considered as the level of vibration received by the PUA on its interface with the Kinematic Supports. Final values are pending on MORFEO vibration analysis and will be provided by the Customer during the final design phase.

Table 11. Specification on the vibration received by the PUA.

Frequency Range [Hz]	1 – 4.45	4.45 - 56	56 - 110
Force (x,y,z) [N] rms per one-third octave frequency bands	3	1	3

MAO-PUE-1.2.2.2: Calibration Unit Optomechanics Dummy (PUE) requirements

With respect to the designed PUA, the PUE shall preserve:

- Volume

- Mechanical interface with Kinematic supports
- CoG absolute position, with a tolerance of ± 20 mm
- Position of SMRs, with a tolerance of ± 5 mm
- Mechanical interfaces with Handling and Integration tools.

The PUE mass shall be equal to the one of the designed PUA plus the contribution of the non-supplied items, estimated to be less than 40 kg (Kinematic supports are not considered, the exact mass value will be provided during the final design phase).

Note: PUE shall be an early deliverable.

4.5 Environmental Conditions

MAO-PUA-1.1.2: Specific conditions for PUA

In addition to the requirements specified in Section 3 of **AD7**, the following conditions shall be considered:

- Air pressure in Europe: 1045 mbar
- Operating temperature range in Europe: 15°C ÷ 25°C
- Operating humidity range in Europe: 50% ÷ 80% (RH)
- No wind load will act on the PUA
- Earthquake quasi-static accelerations: $a_x = \pm 3.3g$, $a_y = \pm 3.3g$, $a_z = \pm 2.185g$ (expressed in the MORFEO SCS and valid at Armazones)
- Gravity orientation during integration could vary up to 90 deg with respect to the nominal position
- Unless otherwise specified, MORFEO operating reference temperature at Armazones is 9°C.

4.6 Optical Tests and Verifications

MAO-PUA-1.2.6.2: Coatings durability

The PUA coatings shall be qualified in agreement with ISO 9211-3, Category of use C. The compliance shall be demonstrated on witness samples coated together with the optical component. A standard coating qualification plan shall be provided by the Contractor during the final design phase. As specified also in **MAO-PUA-1.6.1.7**, the Contractor shall provide a representative set of min. 3 glass samples (size 1-2 inches) for each coating type, to be deployed in Chile at ESO's Paranal Observatory for coating verification and coating ageing studies.

MAO-PUA-1.2.6.3: Optical measurements

Unless otherwise specified, optical measurements on each PUA optical element shall be performed by interferometry (after coating deposition), and the results shall be delivered to the Customer in a format usable for optical analyses (e.g., Zernike coefficients).

MAO-PUA-1.2.6.4: Measurement errors in optical verifications

The error budget shall include the measurement errors with a confidence level of at least 2.5 sigma.

MAO-PUA-1.2.6.5: Thermal and turbulence effects in optical verifications

Thermal and turbulence effects on the optical test setup shall be taken into account. The verification of the thermal effects during the tests shall be based on optical analyses and validated by optical tests.

MAO-PUA-1.2.6.6: Performance verification (Europe)

A detailed performance verification considering the operating conditions in Europe shall be provided by the Contractor. Analyses, tests and verifications shall be performed under the conditions specified in **MAO-PUA-1.1.2**.

MAO-PUA-1.2.6.7: Performance verification (Armazones)

A detailed performance verification considering the operating conditions at Armazones shall be provided by the Contractor, at least by analysis. Analyses, tests and verifications shall be performed under the conditions specified in **MAO-PUA-1.1.2**.

5. Interfaces

5.1 Mechanical Interfaces

I-PUA-1.2.2.1: Interface with Kinematic supports

The PUA shall provide a mechanical interface with the Kinematic Supports (not supplied by the Contractor). The interface shall be defined on the Main Frame by 3 holes, as defined in **AD11** and **AD15**.

I-PUA-1.2.2.2: Interface with NGS mask

The PUA shall provide a mechanical interface with the NGS mask (not supplied by the Contractor). The interface shall be defined on the NGS adjustable holder by 8 holes. The volume to be reserved for the NGS mask and size and position of the interface holes are defined in **AD12**.

Note: The Contractor shall also consider any dynamic volume necessary for the NGS mask integration, alignment and focusing.

I-PUA-1.2.2.3: Interface with LGS mask

The PUA shall provide a mechanical interface with the LGS mask (not supplied by the Contractor). The interface shall be defined on the LGS adjustable holder, by 3 contact points with adjustment screws and 6 contact points with traction springs' eyelets, as defined in **AD13**. The volume to be reserved for the LGS mask is defined in **AD13**.

Note: The Contractor shall also consider any dynamic volume necessary for the LGS mask integration, alignment and focusing.

I-PUA-1.2.2.4: Interface with Fiber Splitting Unit

The PUA shall provide a mechanical interface with the Fiber Splitting Unit (not supplied by the Contractor). The interface shall be defined on the Main Frame by at least 4 holes. The volume to be reserved for the Fiber Splitting Unit is defined in **AD14**.

I-PUA-1.2.2.5: Interface with Connectors Panel

The PUA shall provide a mechanical interface with the Connectors Panel (not supplied by the Contractor). The volume to be reserved for the Connectors Panel and size and position of the interface holes are defined in **AD16**. The interface shall be defined by 10 holes.

I-PUA-1.2.2.6: PM/DM Interface

The PUA shall provide a mechanical interface to ensure a repeatable switch between PM assembly (supplied by the Contractor) and DM assembly (DM not supplied by the Contractor). The interface shall ensure at least 20 um of positioning repeatability of the

PM/DM optical surface. The static volume of the DM and the direction of the insertion/extraction of the DM assembly are defined in **AD18**.

I-PUA-1.2.2.7: Interface with PS panel

The PUA shall provide a mechanical interface with the PS panel (not supplied by the Contractor). The interface shall be defined on the PS adjustable holder by at least 4 holes. The volume to be reserved for the PS panel is defined in **AD17**.

Note: The Contractor shall also consider any dynamic volume necessary for the PS panel integration and alignment.

I-PUA-1.2.3.1: Interface with Handling Tools

The PUA shall provide mechanical interfaces with the Handling Tools. The interfaces shall be defined on the Main Frame by holes. Preliminary size and position of the interface holes are defined in **AD19**.

I-PUA-1.2.3.2: Interface with Integration Tools

The PUA shall provide mechanical interfaces with the supplied Integration Tools. The interfaces shall be defined on the Main Frame by holes. Size and position of the interface holes are defined in **AD19**. The SMRs interfaces (not indicated in **AD19**) shall be defined during the final design phase, in agreement with **MAO-PUA-1.2.4.10**. The integration tool for the DM (included in **MAO-PUD-1.0**) shall enable the insertion and removal of the DM, in agreement with the volume and the direction defined in **AD18**.

I-PUD-1.2.3.3: Interface with Ball Transfer Units

The supplied Integration Tools shall provide mechanical interfaces with the Ball Transfer Units (not supplied by the Contractor).

The interfaces shall be defined on:

- the Eccentric Supports, by 2 holes (one for each support)
- the Support Bar, by 2 holes.

Size and position of the interface holes are defined in **AD19**.

6. Additional requirements

MAO-PUA-1.4.4: Window cover

The Contractor shall provide a cover to protect the window W during PUA integration and handling. When mounted onto PUA, the window cover shall not exceed the volume defined in **AD11**. Mounting and removal of the cover shall be possible without risking damage (e.g., using guides).

INFO: When PUA is mounted in MORFEO and in operation, the window W will be protected thanks to a mechanism which is not part of the Calibration Unit subsystem.

MAO-PUA-1.4.10: Packing requirements

The packing and transport container used for the delivery to the Customer shall be reusable for the shipping in Italy and to the telescope site (see also **MAO-PUD-1.4.2,** further packing recommendations will be provided to the Contractor during the final design phase).

Note: The minimum estimated time between the delivery to the Customer and the shipping to Chile is 4 years.

MAO-PUA-1.4.14: Level of disassembly before packing

PUA shall be packed and shipped fully integrated and aligned.

MAO-PUA-1.4.15: Bonding compatibility with cleaning

The adhesive material selected for the bonded parts (if any) of the PUA shall not degrade due to exposure to CO_2 snow, alcohol, acetone, detergents and water, used for regular cleaning of the optical surfaces.

MAO-PUA-2.6.4.4.1: Labels

All the delivered items requiring inspection, replacement or maintenance, and all the items identified in the spare parts list shall be labelled with a unique identification code.

7. Product and Quality Assurance, RAMS

MAO-PU0-2.6.1.1: Lifetime

All the supplied items shall have a minimum lifetime of 15 years, as defined in **AD7** (MAO-SF0-2.6.1.1). In particular, the durability of coatings and bondings shall be 15 years.
No recoating activity is allowed.

MAO-PUA-1.5.4: ESO standards

In order to properly perform verifications and to facilitate the integration, operation and maintenance of the PUA in the ELT observatory, the Contractor shall follow the design guidelines reported in:

- **AD2** (all Sections)
- Section 5 of **AD3** (with the exception of subsection 5.2.4)
- **AD4** (all Sections)
- **AD5** (whenever applicable).

MAO-PUA-1.5.5: Quality Assurance plan

The quality assurance procedures for the PUA supply shall comply with **AD8**.

MAO-PUA-1.5.7: Safety and human intervention

The safety of the PUA itself shall not require human intervention if the PUA is powered off.

MAO-PUA-1.5.8: Witness tests

Witness samples, as described in **AD8**, shall be agreed for all critical processes and materials.

MAO-PUA-1.5.9: Analysis code and references

Any code used in engineering calculations shall be indicated, and references for formulas, assumptions, material data, etc. shall be provided.

MAO-PUA-1.5.10: Development tests

Development tests shall be performed (as needed) to determine component characteristics and/or to validate analysis methods and assumptions.

MAO-PUA-1.5.11: Qualification of components before system tests

Qualification tests shall preferably be performed at component level (as needed) if system level tests are not sufficient to simulate worst case conditions.

MAO-PUA-1.5.12: Accessibility

PUA shall be designed to provide easy accessibility for inspection, maintenance, repair and part substitution, in order to minimize downtime and potential hardware damages.

MAO-PUA-1.5.13: Spares

The Contractor shall deliver:

- A spare LGS linear stage (described in **MAO-PUA-1.7.1.2**), or spare parts of it (at least motor and encoder) if easily replaceable without dismounting the whole device (considering **MAO-PUA-1.7.1.2)**;
- A spare NGS linear stage (described in **MAO-PUA-1.7.1.3**), or spare parts of it (at least motor and encoder) if easily replaceable without dismounting the whole device (considering **MAO-PUA-1.7.1.3)**.

MAO-PUA-1.5.2.1: MTBF

The PUA supply shall have a MTBF as defined in **MAO-PUA-1.7.1.2** and **MAO-PUA-1.7.1.3**.

MAO-PUA-1.5.3.1: MTTR

The PUA supply shall have a maximum Mean Time To Repair (MTTR) of 2 h.

8. Requirements Verification

Wherever feasible, requirement verification is expected to be performed by analysis at the Final Design Review (FDR), and by Test & Inspection at the Factory Acceptance Readiness Review (FARR).

Table 12. Verification table of technical specifications.

Requirement ID	FDR Verification	FARR Verification
MAO-PU0-1.0	Design	Inspection
MAO-PU0-1.2.3.2	Design	Design/Inspection
MAO-PU0-2.0	Design/Analysis	Design/Analysis Inspection/Test
MAO-PU0-2.6.1.1	Design/Analysis	Design/Analysis
MAO-PUA-1.0	Design	Design/Inspection
MAO-PUA-1.1.2	Design/Analysis	Design/Analysis
MAO-PUA-1.2.1.1	Analysis	Test
MAO-PUA-1.2.1.2	Design/Analysis	Inspection/Test
MAO-PUA-1.2.1.6	Analysis	Analysis
MAO-PUA-1.2.1.7	Analysis	Analysis
MAO-PUA-1.2.1.8	Analysis	Analysis
MAO-PUA-1.2.1.9	Analysis	Analysis
MAO-PUA-1.2.1.10.1	Analysis	Analysis
MAO-PUA-1.2.1.10.2	Analysis	Analysis
MAO-PUA-1.2.3.1	Design/Analysis	Analysis/Test
MAO-PUA-1.2.3.2	Design/Analysis	Analysis/Inspection
MAO-PUA-1.2.4.2	Design	Design
MAO-PUA-1.2.4.3	Design	Design/Analysis Inspection/Test
MAO-PUA-1.2.4.10	Design	Inspection/Test
MAO-PUA-1.2.5.2	Design/Analysis	Analysis/Test

MAO-PUA-1.2.6.2	Design/Analyses	Analysis/Inspection
MAO-PUA-1.2.6.3	Analyses	Analysis/Test
MAO-PUA-1.2.6.4	Analysis	Test
MAO-PUA-1.2.6.5	Analysis	Analysis/Test
MAO-PUA-1.2.6.6	Design/Analysis	Analysis/Test
MAO-PUA-1.2.6.7	Design/Analysis	Analysis/Test
MAO-PUA-1.2.7.1	Design	Test
MAO-PUA-1.2.7.2	Design	Analysis/Test
MAO-PUA-1.2.7.4	Design	Analysis/Test
MAO-PUA-1.2.7.6	Design	Test
MAO-PUA-1.2.7.7	Design	Analysis/Test
MAO-PUA-1.2.7.8	Design	Analysis/Test
MAO-PUA-1.2.7.21	Analysis	Test
MAO-PUA-1.2.7.25	Analysis	Test
MAO-PUA-1.2.7.27	Design	Test
MAO-PUA-1.2.7.28	Analysis	Test
MAO-PUA-1.2.7.29	Analysis	Test
MAO-PUA-1.2.7.30	Analysis	Analysis/Test
MAO-PUA-1.3.2.3	Analysis	Analysis/Test
MAO-PUA-1.3.5.3	Design	Inspection/Test
MAO-PUA-1.3.5.4	Design	Inspection/Test
MAO-PUA-1.4.4	Design	Design/Inspection
MAO-PUA-1.4.10	Design	Design/Inspection
MAO-PUA-1.4.14	Design	Inspection
MAO-PUA-1.4.15	Design	Design
MAO-PUA-1.5.2.1	Design/Analysis	Design/Analysis

MAO-PUA-1.5.3.1	Design/Analysis	Design/Analysis
MAO-PUA-1.5.4	Design/Analysis	Design/Analysis/ Inspection
MAO-PUA-1.5.5	Design/Analysis	Design/Analysis Inspection
MAO-PUA-1.5.7	Design	Design
MAO-PUA-1.5.8	Design	Inspection/Test
MAO-PUA-1.5.9	Design	Design/Inspection
MAO-PUA-1.5.10	Design/Analysis	Analysis/Test
MAO-PUA-1.5.11	Design/Analysis	Test
MAO-PUA-1.5.12	Design	Inspection
MAO-PUA-1.5.13	Design	Inspection
MAO-PUA-1.6.1.1	Design	Test
MAO-PUA-1.6.1.2	Analysis	Test
MAO-PUA-1.6.1.3	Analysis	Test
MAO-PUA-1.6.1.4	Analysis	Test
MAO-PUA-1.6.1.5	Analysis	Test
MAO-PUA-1.6.1.6	Analysis	Analysis
MAO-PUA-1.6.1.7	Analysis	Test
MAO-PUA-1.6.1.8	Design	Analysis/Test
MAO-PUA-1.6.1.9	Design	Analysis/Test
MAO-PUA-1.6.1.10	Analysis	Analysis/Test
MAO-PUA-1.6.1.11	Analysis	Analysis/Test
MAO-PUA-1.6.1.12	Analysis	Analysis
MAO-PUA-1.6.2.1	Design	Inspection/Test
MAO-PUA-1.6.2.2	Analysis	Test
MAO-PUA-1.7.1.1	Design/Analysis	Inspection/Test

MAO-PUA-1.7.1.2	Design	Inspection/Test
MAO-PUA-1.7.1.3	Design	Inspection/Test
MAO-PUA-1.7.1.4	Design	Inspection
MAO-PUA-1.8.1.1	Analysis	Test
MAO-PUA-1.8.1.2	Analysis	Inspection/Test
MAO-PUA-1.8.1.3	Design/Analysis	Inspection/Test
MAO-PUA-1.8.1.4	Design/Analysis	Inspection/Test
MAO-PUA-1.8.1.5	Design/Analysis	Inspection/Test
MAO-PUA-2.6.4.4.1	Design	Inspection
MAO-PUD-1.0	Design	Inspection
MAO-PUD-1.3.5.4	Design	Inspection/Test
MAO-PUD-1.4.1	Design/Analysis	Inspection/Test
MAO-PUD-1.4.2	Design	Inspection
MAO-PUD-1.4.3	Design	Inspection
MAO-PUD-1.4.4	Analysis	Inspection
MAO-PUD-1.4.5	Design/Analysis	Inspection/Test
MAO-PUD-1.4.6	Design/Analysis	Inspection/Test
MAO-PUE-1.0	Design	Inspection
MAO-PUE-1.2.2.2	Design/Analysis	Inspection/Test

Table 13. Verification table of PUA and PUD interfaces requirements.

Requirement ID	FDR Verification	FARR Verification
I-PUA-1.2.2.1	Design	Inspection/Test
I-PUA-1.2.2.2	Design	Inspection/Test
I-PUA-1.2.2.3	Design	Inspection/Test
I-PUA-1.2.2.4	Design	Inspection

I-PUA-1.2.2.5	Design	Inspection
I-PUA-1.2.2.6	Design	Inspection/Test
I-PUA-1.2.2.7	Design	Inspection/Test
I-PUA-1.2.3.1	Design	Inspection/Test
I-PUA-1.2.3.2	Design	Inspection/Test
I-PUD-1.2.3.3	Design	Inspection/Test

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