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Project/WP: Instrumentation System Engineering

Common ICD between the E-ELT Nasmyth Instruments and the Rest of the E-ELT System

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2.1.2	former AD5 -> AD6
2.2	Added RD1 Drawing about additional support points Added RD2 Document about additional support points
3.3.2	[I-INS/ELT-80] Removed TBC [I-INS/ELT-84] and [I-INS/ELT-85] deleted to avoid duplication with #92 and #93
3.3.3	[I-INS/ELT-92] and [I-INS/ELT-93] rephrased

	[I-INS/ELT-518] Added
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4.12	[INFO-INS/ELT-190] and [INFO-INS/ELT-191] Removed reference to 42 meter telescope analysis [INFO-INS/ELT-192] Removed reference to 42 meter telescope analysis and added details on stray light path according to latest analysis results. [INFO-INS/ELT-194] Re-phrased [I-INS/ELT-195] CL630 removed and degradation per 100 days added and moved after #183 in Sec. 4.11 [INFO-INS/ELT-196] to [INFO-INS/ELT-198] deleted [INFO-INS/ELT-520] Newly added [I-INS/ELT-203] Number of scattered laser photons changed.
6.1	[I-INS/ELT-217] Removed TBC [I-INS/ELT-214] Changed LGS launch positions
6.2	[I-INS/ELT-220] Re-phrased and removed TBC Added [I-INS/ELT-509] uplink pointing jitter correction [I-INS/ELT-223] Removed TBC and added "…not longer than…"
7.3.1	[R-INS-498] Rephrased and AD7 added to define possible positions of additional support points.
7.3.2	[I-INS/ELT-245] Safety factor added and rephrased to make it clear that specified load capacity refers to nominal points only [I-INS/ELT-246] Rephrased to make it clear that specified stiffness refers to nominal points only.
7.3.3	[I-INS/ELT-249] Table no. changed [I-INS/ELT-250] Table no. changed
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14.1.2.2	[I-INS/ELT-389] Rephrased [I-INS/ELT-392] and [R-INS/ELT-393] deleted
14.1.2.3	[I-INS/ELT-399] Capacity changed to 12 t and lifting range changed to 7.5m
14.1.3.1	[I-INS/ELT-416] Changed to 10x7.5m
14.1.4.1	[I-INS/ELT-436] Changed to 27m
14.1.4.2	[I-INS/ELT-442/443] Safety factor added
14.1.4.3	[I-INS/ELT-449] Rephrased and joined with [I-INS/ELT-450] [I-INS/ELT-450] Deleted [I-INS/ELT-451] Added angle between slings [I-INS/ELT-453] Rephrased to correct typos
15	[I-INS/ELT-488] Updated Table

Contents

1. Introduction

1.1 Scope

[INFO-INS/ELT-5] This Interface Control Document (ICD) defines requirements for the interface between the *Nasmyth Instruments* (also referred to as *Instruments* for brevity) and the *Rest of the E-ELT System* (also referred to as *E-ELT System* for brevity). The document contains requirements that are applicable to both sides of the interface; a table at the end of the document identifies which side of the interface is responsible for verifying the requirement. The document covers aspects of the interface that are common to all Nasmyth instruments. Instrument-specific requirements are addressed in the corresponding instrument technical specification.

[INFO-INS/ELT-6] In particular this ICD covers the following interfaces categories between these elements:

- General and System
- Optical
- Alignment and Calibration
- Laser Beacons
- Mechanical and Access
- Control System
- Service Connection Points
- Electrical
- Fluids (including Cryogenics)
- Assembly and Installation

1.2 Interfacing Elements List

[INFO-INS/ELT-8] For the purpose of this ICD the *Nasmyth Instruments* comprise:

- Science Instruments Installed on the Nasmyth Platforms
- Adaptive Optics Modules Installed on the Nasmyth Platforms

[INFO-INS/ELT-9] For the purpose of this ICD the *Rest of the E-ELT System* comprises:

Telescope, in particular,

- Hosted units (e.g. mirrors, laser guide stars but excluding *instruments*)
- Optical beams
- Nasmyth platforms
- Prefocal station
- Supplies and services (e.g. SCPs)

Control System

Dome, in particular

- infrastructure available for assembly and test of instruments
- infrastructure available for handling of instruments

Existing Paranal infrastructure, in particular,

- infrastructure available for assembly and test of instruments
- infrastructure available for handling of instruments

[INFO-INS/ELT-10] The following elements of the *Nasmyth Instruments* are specifically excluded from this ICD:

Instrument Specific Interfaces:

- the specific design volume and mounting location allocated to an individual instrument
- the mass allocated to each specific instrument
- the electrical power and cooling allocated to a specific instrument

The characteristics covered by these exclusions are defined in the corresponding instrument technical specification.

1.3 Definitions and Conventions

1.3.1 Requirements and Information

[INFO-INS/ELT-13] This document contains two types of items: requirements and information. Requirements have to be verified by the contractor while information items do not. Both types are binding items.

Requirements are identified with a requirement tag following the format [I-INS/ELT-NNN], where NNN is a unique, non-speaking number. The letter I is intended to convey the meaning "interface requirement".

In addition, each requirement carries a verification tag suggesting the minimum verification method(s) applicable for that requirement verification (D: Design Review; A: Analysis; I: Inspection; T: Test).

Information items are identified with the tag [INFO-INS/ELT-NNN], NNN being a unique, non-speaking number, not used in any requirement identifier. These information items, which are fully binding to this document, refer usually to context, conditions or definitions that have to be taken into consideration for all or for specific requirements.

NNN numbers do not necessarily follow a sequential order. They do not change across all versions of this document. Within this document, cross-references to an item (either requirement or information) are made by referring to the number NNN preceded by the prefix "#".

A verification table at the end of the document identifies which party to the ICD is responsible for verifying each requirement.

1.3.2 Abbreviations and Acronyms

[INFO-INS/ELT-15] The following abbreviations and acronyms are used in this document:

AD	Applicable Document
AIV	Assembly Integration and Verification
arcsec	Arc Second
arcmin	Arc Minute
ART	Adaptive Relay Tower
ARU	Adaptive Relay Unit
BOL	Beginning of Life
CCS	Central Control System
CoG	Centre of Gravity
EH	Entrance Hall
IAA	Instrument Assembly Area at Armazones
ICD	Interface Control Document
LCS	Local Control System
LCU	Local Control Unit
LGS	Laser Guide Star
LOO	Low Order Optimisation
NCR	No Collapse Requirement
NGS	Natural Guide Star
MS	Main Structure
MTR	Main Transit Ring
PFS	Prefocal Station
PTV	Peak to Valley
RBM	Rigid Body Motion

RD	Reference Document
rms	Root Mean Square
SCP	Service Connection Point
TSE	Thermal Self Emission
WFS	Wavefront Sensor

1.3.3 Definitions

[INFO-INS/ELT-17] **Atmospheric Coherence Length**

The diameter of a wavefront area over which the instantaneous rms phase variations due to atmosphere optical turbulence are equal to 1 radians (λ/6.28).

[INFO-INS/ELT-18] **Blind Alignment**

A mode of operation in which the telescope and its optical units are controlled relying on internal metrologies and look-up-tables to compensate the large amplitude distortions of the main structure under gravity and thermal load. The M1 figure is corrected in real time with position actuators controlling the segments positions in piston, tip and tilt, based on the signals of edge sensors monitoring in real time the relative displacements of adjacent segments. No observation of the sky is needed.

[INFO-INS/ELT-19] **Chopping**

A process by way of which the ***pointing*** of the telescope is changed rapidly and periodically by a small amount (ideally with a square wave oscillation). This technique is primarily used to improve suppression of sky background with infrared observations. The oscillation is realised by moving the telescope optics.

[INFO-INS/ELT-20] **Drift**

The change in a characteristic of the system over time compared to its initial value.

[INFO-INS/ELT-21] **Field Distortion Repeatability and Stability**

The repeatability and stability of the field distortions includes:

- errors in the third order optical distortion
- errors in plate scale
- errors in field rotation

The error is specified in units of mas (position error of an image in the focal plane) per arcmin (off-axis field distance). Both angles are projected onto the sky as seen from the entrance pupil.

[INFO-INS/ELT-22] **Guiding**

Tracking using an error signal provided by devices measuring optically the pointing error on a reference star.

[INFO-INS/ELT-23] **Low Order Optimisation**

A mode of operation, traditionally called 'active optics', the quasi-static aberrations of the telescope are observed at the Nasmyth adapter by Natural Guide Star probes and corrected by quasi-static adjustment of the mirror units position and mirror shape (when relevant).

[INFO-INS/ELT-24] **No Collapse Requirement**

A specific set of environmental conditions under which the instruments shall deliver "no collapse" performance. These are defined in the instrument common requirements.

[INFO-INS/ELT-25] **Nodding**

A process by way of which the pointing of the telescope is periodically changed between two neighbouring sky positions. Contrarily to ***chopping***, nodding is realized by acting on the telescope kinematics. This is equivalent to a *preset*.

[INFO-INS/ELT-26] **Non-Speaking Number**

In this context a unique number identifying a requirement that has no additional information encoded into it beyond its uniqueness.

[INFO-INS/ELT-27] **Normal Power**

Electrical power supplied by the SCP to support the normal operation of the SCP client. This power source may be subject to power-shedding or interruption.

[INFO-INS/ELT-28] **Offsetting**

In the context of telescope kinematics, the process by way of which the pointing of the telescope is incrementally changed from one sky position to a nearby one. The E-ELT telescope will realise all offsets larger than a small fraction of an arc second by acting on the telescope kinematics.

[INFO-INS/ELT-29] **Plate Scale**

The conversion factor between on-sky angular distances and on-detector linear scales. The concept assumes that the underlying relation is linear, and plate scale is usually given in arc seconds (on-sky) per mm (on-detector). In practice, optical distortion is rarely zero and, depending on the desired level of fidelity, the transformation of object into image coordinates may require a polynomial expansion (with odd exponents only). In anamorphic systems, distortion may also vary differently along different axes of the image surface.

[INFO-INS/ELT-30] **Pointing**

The actual direction the telescope is pointing (on-axis direction, defined by sky coordinates of the projection of the origin of the as-built coordinates system at the focus of the telescope).

[INFO-INS/ELT-31] **Pointing Error**

The difference between actual and required pointing.

[INFO-INS/ELT-32] **Power Shedding**. A strategy for managing the scenario where the available normal power is lower than its nominal value. According to this strategy some or all SCP clients within the observatory are required to reduce their "normal" electrical power consumption to a specified value.

[INFO-INS/ELT-33] **Preset.** A preset is defined as a change in the telescope pointing by an angle larger than 60 arcsec on sky, i.e., larger than 60 arcsec in altitude and 56.4 arcsec in azimuth.

[INFO-INS/ELT-34] **Pupil Compression**. The ratio of the diameters of the entrance and exit pupils.

[INFO-INS/ELT-35] **Repeatability**

The degree to which a characteristic of the system exhibits the same values under the same conditions. This is also known as reproducibility.

[INFO-INS/ELT-507] **Rigid Body Motion** (RBM) of a set of attachment points of an instrument refers to the motion of the set of attachment points of the Nasmyth platform which supports a single instrument, assuming this set of points as a rigid body, without local deformations.

[INFO-INS/ELT-36] **Safety Power**

The only source of electrical power that will remain active under all circumstances e.g. a failure of the external observatory power supply. The purpose of this power source is to supply loads that require continuous electrical supply to ensure the safety of personnel and critical equipment.

[INFO-INS/ELT-37] **Seeing**

Atmospheric seeing is the integrated, long-exposure effect of the atmospheric optical turbulence across the line of sight. When using Fried's model of free atmospheric seeing it is defined as seeing = 0.98 x lambda / r_0 where lambda is the optical wavelength and r_0 is the atmospheric coherence length. Unless otherwise stated, seeing values in this document refer to those measured by the observatory astronomical site monitor at zenith and referenced to a wavelength of 0.5 microns.

[INFO-INS/ELT-38] **Seeing Limited**

A mode of telescope operation in which the blind and LOO control of the telescope is complemented by an additional field stabilisation correction using the wavefront error signal from the telescope Natural Guide Star probes and correcting with the M4 adaptive mirror and the M5 fast tip-tilt mirror.

[INFO-INS/ELT-39] **Stray Light** is light reaching the telescope focal plane either directly or after reflection or scattering from any combination of the telescope surfaces via paths not intended by the telescope design. It includes light originating from the observed celestial source, and from other sources within and outside the telescope field of view.

[INFO-INS/ELT-40] **Telescope**

For the purposes of this interface requirement specification, Telescope shall mean the main structure equipped with all supplies and hosted units with the exception of the instruments.

[INFO-INS/ELT-41] **Tracking**

The kinematic function through which the telescope pointing is dynamically changed to follow a reference. The reference can be a look up table or metrology (see for example blind alignment above) or the reference could be a guide star in which case the term "Guiding" is used (see separate definition above).

1.3.4 Coordinate Systems

[I-INS/ELT-43] D/ / / Unless otherwise specified, the interface characteristics defined in this document and in its applicable documents are based on the Standard Coordinate Systems defined in AD1. This system of coordinates shall also be used in all further detail design and definition of the interfaces.

1.3.5 Naming Conventions

[INFO-INS/ELT-45] The Nasmyth platforms are named Nasmyth A and Nasmyth B respectively as defined in AD1.

2. Related Documents

2.1 Applicable Documents

[INFO-INS/ELT-48] The following documents, 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.

2.1.1 E-ELT Documents

[INFO-INS/ELT-50] AD1 Standard Co-ordinate Systems and Basic Conventions;
ESO-193058 Version 6
https://pdm.eso.org/kronodoc/HQ/ESO-193058/6

[INFO-INS/ELT-51] AD2 E-ELT Electrical and Electronic Design Requirements;
ESO-262825 Version 1
https://pdm.eso.org/kronodoc/HQ/ESO-262825/1

[INFO-INS/ELT-52] AD3 ESO Mechanical Standards;
ESO-192984 Version 2
https://pdm.eso.org/kronodoc/HQ/ESO-192984/2

[INFO-INS/ELT-53] AD4 Interface Control Document Between the E-ELT SCPs and the SCP Clients;
ESO-262869 Version 3
https://pdm.eso.org/kronodoc/HQ/ESO-262869/3

[INFO-INS/ELT-508] AD5 Vacuum and Cryogenics Standard Components,
ESO-046147 Version 5
https://pdm.eso.org/kronodoc/HQ/ESO-046147/5

2.1.2 E-ELT Drawings

[INFO-INS/ELT-55] AD6 Nasmyth Platform Interfaces;

ESO-286456 (CAD-135139) Revision 1

https://pdm.eso.org/kronodoc/HQ/ESO-286456/1

2.2 Reference Documents

[INFO-INS/ELT-57] The following documents, of the exact version shown herein, are listed as background references only. They are not to be construed as a binding complement to the present document.

[INFO-INS/ELT-513] RD1 Additional Support Points for Instruments on the Nasmyth Platform,

ESO-321386 (CAD-153255) Revision 4

https://pdm.eso.org/kronodoc/HQ/ESO-321386/4

[INFO-INS/ELT-516] RD2 Definition of additional support points for instruments on the ELT Nasmyth platforms;

ESO-321039 Version 3

https://pdm.eso.org/kronodoc/HQ/ESO-321039/3

3. General and System Interface Characteristics

[INFO-INS/ELT-59] This document concerns the interface between the E-ELT System and the Instruments on the Nasmyth platforms. Figure 1 shows an artists impression of the E-ELT telescope including the Nasmyth platforms (denoted 'Instrument Platforms' in the figure) including notional volumes for the instruments.

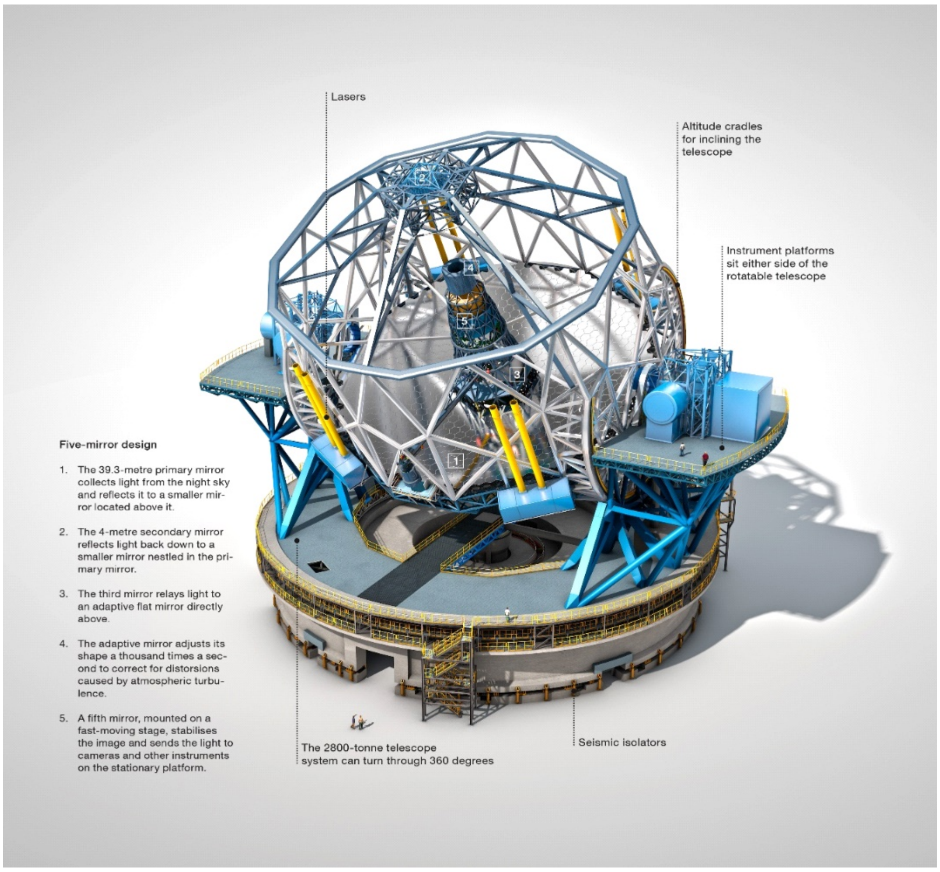

Figure 1: Artists impression of the E-ELT Telescope

3.1 Overall Optical Design

[INFO-INS/ELT-61] The optical solution for the E-ELT is a folded anastigmat, in a Nasmyth configuration. The zemax design file for the nominal prescription is given in the Appendix to this document.

[I-INS/ELT-62] In this configuration, the beams shall exit the telescope after reflection on two folding flats (M4 and M5), straight towards the Nasmyth focus - see Figure 2. The M5 mirror may be

/ / / deployed in one of two configurations to direct the output beam to either of the two Nasmyth platforms.

[INFO-INS/ELT-63]

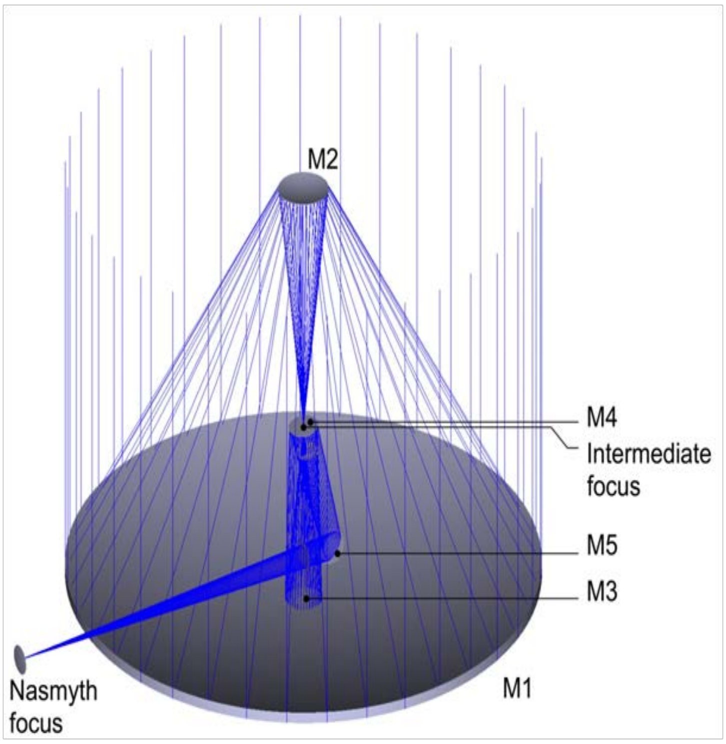

Figure 2. EELT optical solution, Nasmyth foci.

[I-INS/ELT-64] / / / In addition to the straight through Nasmyth focus, the telescope shall provide lateral focus configurations on each Nasmyth platform. In the lateral focus configuration a subset of the field is intercepted by means of a 45 degree folding flat mirror and sent sideways to the Nasmyth foci. There are two lateral Nasmyth foci per Nasmyth platform.

3.2 Telescope Kinematics

3.2.1 Range of Motion

[I-INS/ELT-67] / / / During science observation the telescope shall allow for the following motion range:

- Azimuth: -270 to +270deg from the geographical East (or -180 to +360deg from South)
- Altitude: +20 to +88.5deg from the horizon (1.5deg radius blind spot at zenith)

[I-INS/ELT-68] / / / Outside science observation, the telescope shall allow for the following motion range:

- Azimuth: -270 to +270deg from the geographical East (or -180 to +360deg from South).

- Altitude: 0 to +90deg from the horizon

3.2.2 Maximum Operational Velocity and Acceleration

[I-INS/ELT-70] / / / The Altitude and Azimuth axes, when fully equipped (or with equivalent dummy masses) shall be

able to rotate simultaneously and independently with velocities:

- Azimuth from -2 to +2deg/s
- Altitude from -1 to +1deg/s

[I-INS/ELT-71] / / / The Altitude and Azimuth axes shall be able to rotate simultaneously and independently with accelerations anywhere on each axis in the range -0.1 to +0.1deg/s^2.

[I-INS/ELT-72] / / / The maximum deceleration of the telescope during braking shall not exceed 2deg/s^2 in Azimuth and 10deg/s^2 in Altitude.

3.3 Wavefront Control

3.3.1 Overall Control Scheme

[INFO-INS/ELT-75] The E-ELT is an adaptive telescope. The control equipment hosted in the telescope will maintain the alignment of the telescope at a level that brings the optical quality at the Nasmyth focus within the capture range of post focal instruments, with temporal and spatial features within their dynamic range. The observations are assisted with adaptive optics corrections performed with resources distributed between the telescope and the post focal modules. The telescope provides low conjugate altitude adaptive correction with 500mm pupil sampling in the M1 space. Multi-conjugate correction capability is supported towards a subset of the focal stations with additional post-focal corrective optics. The telescope is equipped with laser launch telescopes providing a variety of laser asterisms for many kinds of AO modes.

[INFO-INS/ELT-76] The wavefront control is organized in three control layers. The blind control layer relies on internal metrologies and look-up-tables to compensate the large amplitude distortions of the main structure under gravity and thermal load. The M1 figure is corrected in real time with position actuators controlling the segments positions in piston, tip and tilt. This is based on the signals of edge sensors monitoring in real time the relative displacements of adjacent segments. The set point of the edge sensors is determined in calibration mode by means of a phasing station served by a folding mirror inserted at the center field at the Nasmyth platform. The M2, M3 and M4 units are controlled in position at slow rate against their internal metrologies with set points extracted from look-up tables. The Low Order Optimization layer corrects the quasistatic aberrations (one correction every 5 minutes including times when adaptive optics is running) observed at the Nasmyth adapter by Natural Guide Star probes and manages the distribution of strokes between the internal degrees of freedom. The dynamic of the positioning units is specified such that the transient perturbations at the execution of a low order optimization remain within the dynamic range of the post focal adaptive loops. The third layer, the adaptive optics, relies on resources distributed in the telescope (M4 adaptive mirror, M5 fast tip-tilt correction, LGS Launch telescopes) and post focal (LGS Sensing, NGS sensing including truth and tip/tilt sensing).

3.3.2 Image Quality at Acquisition

[I-INS/ELT-78] / / / The image quality at acquisition shall be delivered by the telescope during the preset sequence when an instrument starts to acquire guide stars prior to an observation with enhanced image quality.

[I-INS/ELT-79] / / / The image quality specified in this section shall be delivered at all Nasmyth foci (TBC).

[I-INS/ELT-80] / / / In a seeing of 0.82 arc seconds, the optical performance shall be limited by the mean atmospheric turbulence and slow dynamics such as wind load on M1 over the control period with an additional telescope allocation for quasi-static wavefront errors of 200nm rms, pointing excluded and field aberration less than 100nm / arcmin, field distortions excluded.

[I-INS/ELT-81] / / / The degradation of the optical performance specified above with the seeing is TBD.

[INFO-INS/ELT-82] The degradation of optical performance with seeing is a consequence of the increase in measurement error as the seeing gets worse.

[I-INS/ELT-83] / / / The repeatability of the field distortions (plate scale and field rotation included, star catalogue errors excluded) shall be within +/-30mas/arcmin (TBC) of the as-built value at acquisition.

3.3.3 Seeing Limited Image Quality

[INFO-INS/ELT-87] The telescope shall deliver seeing limited image quality when the blind and the low order optimization layers are running together with additional field stabilisation (and possibly low order wavefront corrections) running on a telescope natural guide star probe.

[I-INS/ELT-88] / / / The seeing limited image quality specified in this section shall be delivered at all Nasmyth foci.

[I-INS/ELT-89] / / / Image quality performance shall be delivered on the condition that the low order optimisation loop applies active optics corrections every 5 minutes assisted by the telescope natural guide star probes.

[I-INS/ELT-90] / / / The telescope shall deliver seeing-limited performance with natural guide star(s) as follows:

- For the 50-percentile (median) seeing conditions the FWHM of a point source generated by an ideal telescope operated in the atmosphere shall not be degraded by more than 1 %

- For the 5-percentile best seeing conditions the FWHM of a point source generated by an ideal telescope operated in the atmosphere shall not be degraded by more than 5%

This requirement applies under the following conditions:

- During a 60 minute exposure (that can be interrupted, one or more times, for a total of 3 minutes)

- Over 95% of the sky reachable by the telescope during science observation as derived from the motion range requirement [#67] except that the applicable altitude range shall be +30 to +88.5deg from the horizon

- For distances to the full moon centre larger than or equal to 25deg

- Under the FoV specified in #123 and #132

- Under the wavelength range specified in #181

- Under the operational environmental conditions

- All wavefront errors including image motion generated by the telescope and the rest of the E-ELT, with the exception of the free atmospheric turbulence, are included.

[I-INS/ELT-91] / / / The repeatability of the field distortions (plate scale and field rotation included, star catalogue errors excluded) shall be within +/-30mas/arcmin (TBC) of the as-built value when the telescope is delivering seeing limited performance.

[I-INS/ELT-92] / / / On time scales of 1 hour and including the effect of low order optimization transients, the field distortions (expected to be dominated by plate scale and field rotation) can change by up to +/-6 mas/arcmin relative to the starting value, including a maximum absolute drift of 12 mas/arcmin.

[I-INS/ELT-93] / / / On time scales of 5 minutes the field distortions (expected to be dominated by plate scale and field rotation) can change by up to 5 mas/arcmin in either direction, positive or negative. This might lead to a maximum absolute drift of 10 mas/arcmin over a time period of 10 minutes.

[INFO-INS/ELT-518] The open loop (before field stabilization) image motion (tip-tilt) per axis at the telescope focal plane is expected to comply with the values indicated in the following table (TBC):

Frequency range (Hz)	0 - 1	1 - 4	4-110
rms error (miliarcsec)	300	20	1

Table 1: Image motion per axis at the telescope focal plane

This image motion is mainly caused by wind load and vibrations due to equipment.

[I-INS/ELT-94] / / / To deliver seeing-limited performance the telescope shall preset (be ready for a science exposure) in no more than 6 minutes, starting from any position on the sky (within the specified range).

3.3.4 Enhanced Image Quality

[I-INS/ELT-96] / / / Enhancement of the image quality beyond the seeing limited performance specified above shall be achieved via a combination of the telescope, instruments and adaptive optics modules working together.

[INFO-INS/ELT-97] Preliminary interfaces related to enhanced image quality (essentially adaptive optics) are expected to be as defined in the accompanying working documents.

3.4 Offsetting and Nodding

[INFO-INS/ELT-99] The following requirements for offsetting and nodding shall apply to the seeing limited image quality delivered by the telescope. Requirements for these characteristics when the system is delivering enhanced image quality will be specified in the accompanying working documents.

[I-INS/ELT-100] / / / Keeping the same guide star(s) and in close on-sky loop, the telescope shall be able to offset the bore sight up to 10 arcsec with an accuracy of 50 mas peak-to-valley and be ready for science observations within 10 seconds.

[I-INS/ELT-102] / / / The telescope shall be able, after a nodding of 60 arcsec and back (with no image correction at the offset position), to re-acquire the guide stars and be ready for science observations within 10 seconds.

[I-INS/ELT-103] / / / The telescope shall also be able, after a nod of 15 arcmin and back (with no image correction at the offset position), to re-acquire the guide stars and meet the image quality requirement within 30 seconds.

[INFO-INS/ELT-104] The telescope does not support chopping.

3.5 Tracking and Guiding

[I-INS/ELT-106] / / / The telescope shall be able to track astronomical targets having differential velocities with respect to the sidereal rate of up to 100 arcsec/h over a period of 60 minutes while maintaining seeing limited performance as long as the guide stars remain within the field of view.

[I-INS/ELT-107] / / / The telescope shall also be able to track astronomical targets having differential velocities with respect to the sidereal rate of 2,000 arcsec/h (as long as the guide stars remain within the FoV of the target), with the goal of maintaining seeing limited image quality. Restrictions may apply depending on the zenith distance of the target to avoid excessive rotation speeds near the zone of avoidance.

[I-INS/ELT-109] / / / The guiding position measurement error (per axis) of a natural guide star shall satisfy the temporal rms values in given frequency ranges as follows (TBC),

Frequency range (Hz)	0.0003-0.02	0.02-1	1-20	20-100
rms error [mas]	150	8	4	9

provided that all of the following conditions are satisfied:

- the low order optimisation loops of the telescope are running
- seeing conditions better than 1 arcsec;
- at least one NGS guide star brighter than mr = 15 is available for being used by the telescope sensing;

a fixed location of the Prefocal Station interface reference coordinate system shall be taken as a reference. This means the quasi-static errors due to absolute and combined motion of the Nasmyth instrument attachment points specified later in section 7.3 are not considered.

[I-INS/ELT-110] / / / The telescope shall adapt the guiding to correct the offset due to atmospheric refraction for a single wavelength specified by the instrument.

[INFO-INS/ELT-111] The telescope does not provide an atmospheric dispersion compensator.

4. Optical Interface

4.1 Definitions and Conventions

[INFO-INS/ELT-114] All data provided in the present section comply with the following conventions:

- Linear dimensions are in millimetres.
- Wavefront data are given in micrometers for amplitude and arc seconds for slopes.
- Angles are given in degrees, unless otherwise specified.
- Field positions are always given as radius off-axis (mm on an image, degrees on-sky).
- Apertures are always specified as diameters.

[I-INS/ELT-115] / / / In this section, when a dimension is specified "before" or "after" a surface, the terms "before" and "after" refer to the nominal direction of light propagation. For example, stating "A is 10 mm before B" means that the light will nominally travel 10 mm from A to B. This convention shall be applied taking into consideration the on-axis ray of light.

4.2 Location of the Telescope Focal Plane on the Nasmyth Platform

[I-INS/ELT-117] / / / The nominal locations of the three telescope focal planes on the Nasmyth A platform shall be at the locations shown in Figure 3 below. Also shown is the footprint of the prefocal station.

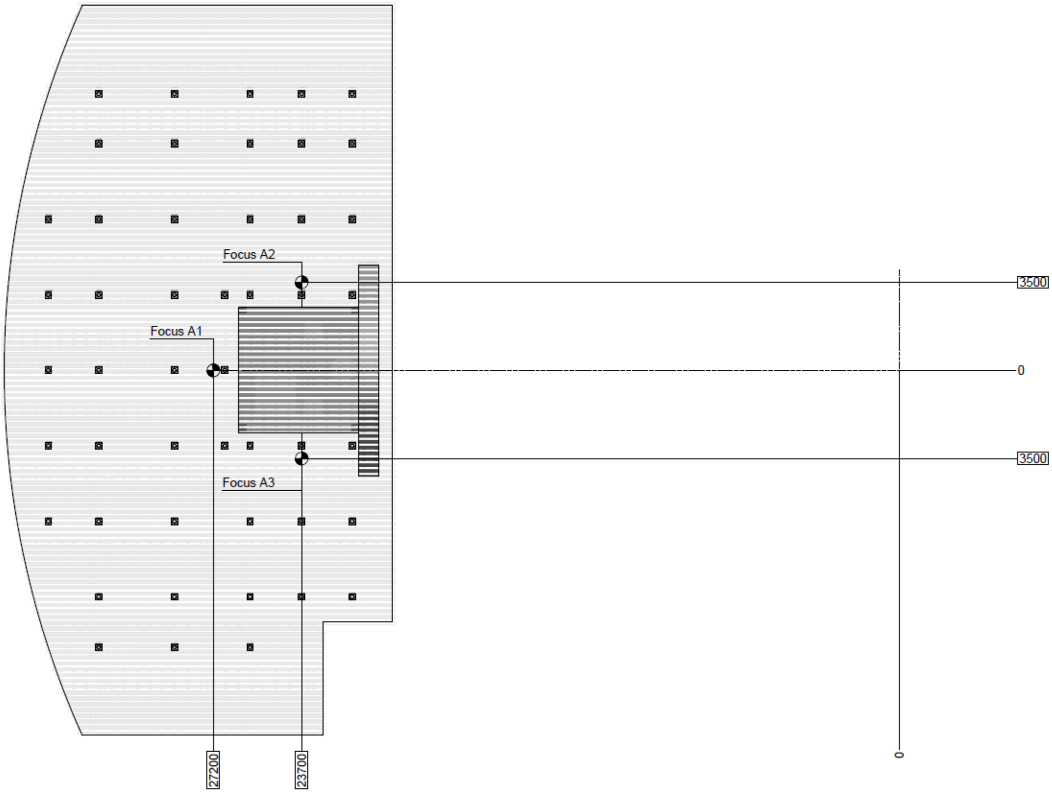

Figure 3: Locations of Telescope Foci on the Nasmyth A Platform and the Footprint of the Prefocal Station

[I-INS/ELT-118] / / / The foci shall be at the nominal positions given in the following table expressed in the azimuth coordinate system [AD1]:

	X		Y		Z
Surface	mm		mm		mm
Straight Through Focus (A1)					
Object at Infinity	-27200		0		0
Laser Beacon at 200km	-29693		0		0
Laser Beacon at 80km	-34114		0		0
Lateral Focus Left (A3)					
Object at Infinity	-23700		-3500		0
Laser Beacon at 200km	-23700		-5993		0
Laser Beacon at 80km	-23700		-10414		0
Lateral Focus Right (A2)					
Object at Infinity	-23700		3500		0
Laser Beacon at 200km	-23700		5993		0
Laser Beacon at 80km	-23700		10414		0

Table 2: Locations of Telescope Foci and Laser Guide Star Conjugates on the Nasmyth A Platform

[I-INS/ELT-119] / / / The nominal height of Nasmyth platform shall be 6000mm below the optical axis.

[I-INS/ELT-120] / / / The telescope shall accommodate adjustments in the position of the focal plane along the optical axis (ie. the back focal length) of +/-50mm with respect to its nominal position.

4.3 Straight Through Nasmyth Focus Field of View

4.3.1 Object at Infinity

[I-INS/ELT-123] / / / The radius of the straight-through Nasmyth field of view delivered by the telescope for an object at infinity shall be 5 arc minutes on-sky.

[INFO-INS/ELT-124] The above field of view corresponds to 993.6 +/- 4.3 mm linear at the focus of the telescope, given the requirement on focal length range below.

[I-INS/ELT-125] / / / The straight-through field of view may be partially vignetted by the telescope wavefront sensors for radii between 2.5 arc minutes and 5 arc minutes on sky. The extent of the vignetting, which may vary over time, is TBD.

4.3.2 Laser Beacons

[I-INS/ELT-127] / / / The field of view delivered by the telescope at the straight through Nasmyth focus for an object at a distance of 80km (i.e. laser beacon at zenith) shall be 4.17 arc minutes off-axis (as seen from the centre of the entrance pupil).

[INFO-INS/ELT-128] The above is the geometrical limitation; the actual laser guide star field may be smaller for control reasons.

[I-INS/ELT-129] / / / The laser beams may be partially vignetted by the telescope wavefront sensors if the laser footprint at the telescope focal plane extends beyond 2.5 arc minutes radius in object space. The extent of the laser footprints depends on the diameter of laser asterism selected by the client instrument. The extent of the vignetting, which may vary over time, is TBD.

4.4 Lateral Focus Field of View

4.4.1 Object at Infinity

[I-INS/ELT-132] / / / The radius of the unvignetted field of view delivered by the telescope at the lateral Nasmyth focus for an object at infinity shall be at least 2.25 arc minutes on-sky for Nasmyth A and 2.5 arc minutes (TBC) on-sky for Nasmyth B .

4.4.2 Laser Beacons

[I-INS/ELT-134] /// The radius of the unvignetted field of view delivered by the telescope at the lateral Nasmyth focus for an object at a distance of 80km (ie. laser beacon at zenith) shall be at least 1.3 arc minutes on-sky.

4.5 Focus Characteristics for an Object at Infinity

[I-INS/ELT-136] /// The telescope shall deliver its nominal focal characteristics within a tolerance range to account for manufacturing variations in the telescope optics. The final as-built characteristics shall be determined during verification and test of the telescope and its subsystems.

[I-INS/ELT-137] /// Characteristics of the telescope focus for an object at infinity and the as-built tolerance range shall comply with the values given in the table below:

Parameter	Value	Tolerance		Unit
		Upper	Lower	
Field Curvature	-9884	+70	-70	mm
Effective Focal Length	684022	+2933	-2933	mm
Image Space F#	17.75	+0.08	-0.08	-
Pupil Compression	18.06	+0.04	-0.04	-
Plate Scale	3.316	+0.014	-0.014	mm/arcsec
Distortion	-0.13	(at edge of field)		%

Table 3: Focal Parameters for an Object at Infinity

[I-INS/ELT-138] /// The direction of the field curvature shall be concave ie. the centre of curvature is before the telescope focus.

[INFO-INS/ELT-139] Distortion is defined as the proportional difference between the actual radial position of the image centroid and the position predicted by a linear law using the on-axis plate scale. Distortion itself varies as the cube of the radial field position starting from zero at centre field. A negative distortion means that the image is closer to the field centre than predicted by the linear plate scale law.

[INFO-INS/ELT-140] The as-designed optical quality at the Nasmyth foci (ie. excluding any wavefront perturbation) for an object at infinity is diffraction limited over the full field of view. The Strehl ratio degradation due to the optical design is less than 5.2% at 1 micron wavelength over the full field and less than 1% up to half-field radius.

4.6 Focus Characteristics Laser Beacons

[INFO-INS/ELT-142] In the following, the geometrical characteristics of the image of the laser beacons (at best focus) are given for different beacon heights. The beacon itself is approximated as a point source at the distance specified.

[INFO-INS/ELT-143] Characteristics of the laser beacon conjugates shall comply with the values given in the table below:

	Laser Beacon Distance (km)				
	80	120	160	200	Unit
Parameter					
Laser Focus Position	6914	4345	3168	2493	mm behind telescope focus
Focal Ratio	20.98	19.78	19.23	18.91	-
Radius of Field Curvature	-9170	-9391	-9507	-9579	mm
Linear Field Radius	979.9	923.8	898.1	883.4	mm (LGS 4.17 arc min off axis)

Table 4: Characteristics of Laser Beacon Conjugates

[INFO-INS/ELT-144] The laser focus position is defined as the axial distance, measured in the direction of light propagation, from the telescope focal plane to the laser beacon image.

[INFO-INS/ELT-145] The linear field radius is specified in the laser focal plane.

[I-INS/ELT-146] / / / The field curvature for the laser beacon images shall be concave towards M5.

[INFO-INS/ELT-147] It is a characteristic of the optical design that the plate scale and, as a consequence, the field radius of the laser beacon images varies with distance to the laser beacon (ie. the telescope elevation and the height of the sodium layer).

[I-INS/ELT-148] / / / The as-designed geometrical wavefront quality (ie. excluding atmospheric turbulence, telescope misalignments and post-focal non-common-path aberrations) for selected beacon distances and field positions shall be no worse with the values given in the table below:

	Laser Beacon Distance (km)				
Wavefront Error (rms)	80	120	160	200	Unit
On axis	0.064	0.036	0.025	0.019	micron
1.3 arc min off-axis	0.181	0.116	0.086	0.068	micron
4.0 arc min off axis	0.563	0.365	0.270	0.214	micron

Table 5: Laser Beacon Wavefront Error for Various Distances

4.7 Entrance Pupil Characteristics

[I-INS/ELT-150] / / / The entrance pupil shall be located 2704 mm above the vertex of the telescope Primary Mirror.

[I-INS/ELT-151] / / / The entrance pupil shall be defined as circular with a diameter of 38542 mm. This is the entrance pupil diameter that is unvignetted over the field of view (apart from the effect of telescope spiders).

[INFO-INS/ELT-152] The entrance pupil is slightly smaller than the full primary mirror. The intersect of the two is shown in figure 4 below.

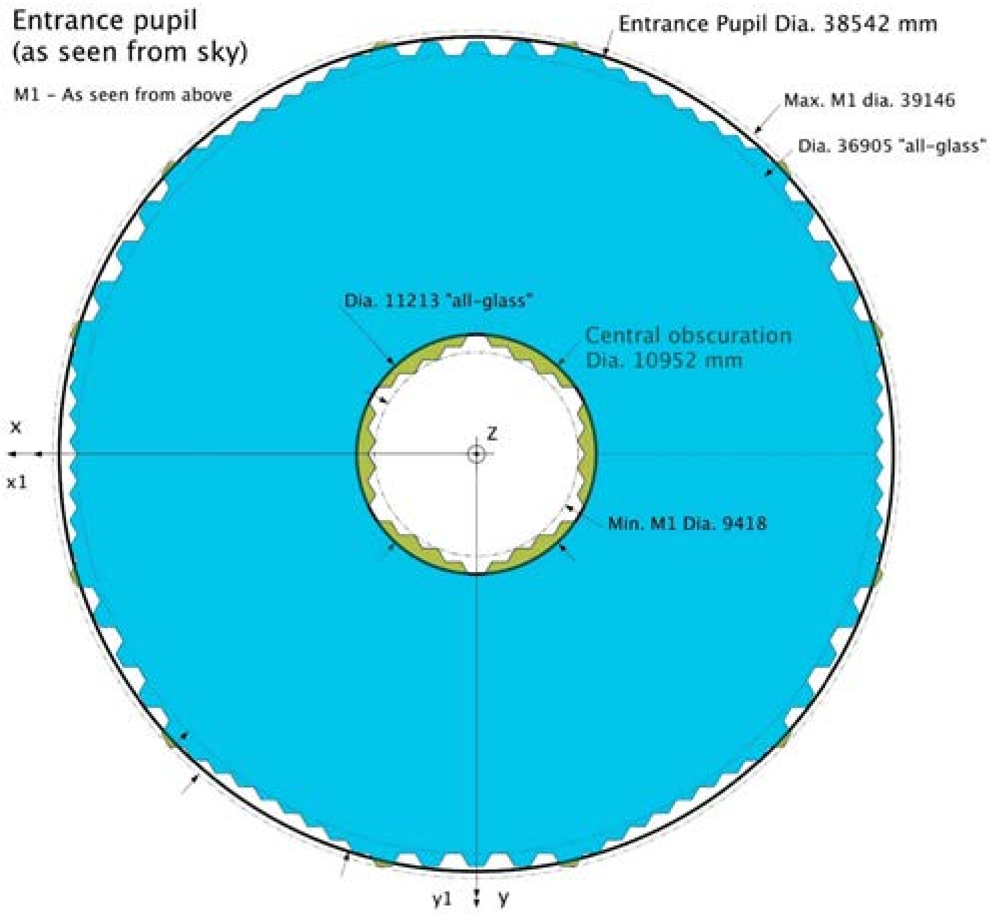

Figure 4: Intersect between the entrance pupil and primary mirror

[I-INS/ELT-153] /// The central obscuration, as projected onto the entrance pupil, shall be circular with a diameter of 10952 mm.

[I-INS/ELT-154] /// In addition to the central circular obscuration, radial three- or six-fold symmetrical obscuration by spiders and/or on-board cranes shall be allowed. The nominal geometry of the radial obstruction is shown in Figure 5 (grey shaded areas). *Spiders* do not only refer to the spiders supporting the M2 Unit but may also include additional ones supporting the central structures that host the M3-M4-M5 Units or on-board cranes.

[I-INS/ELT-155] /// The normal (on-axis) projection of each spider leg onto M1 shall be confined within an overall envelope of width 540mm under operational conditions. This includes the nominal width of the spider, fabrication and integration tolerances, and displacement of the spider under operational conditions, and the motion of M1 with respect to the spider.

[I-INS/ELT-156] /// The lateral displacement of the spider projection onto M1 due to the optical field effect shall be no greater than +/-45mm at the edge of the field 5 arc minutes off axis.

[I-INS/ELT-157] / / /

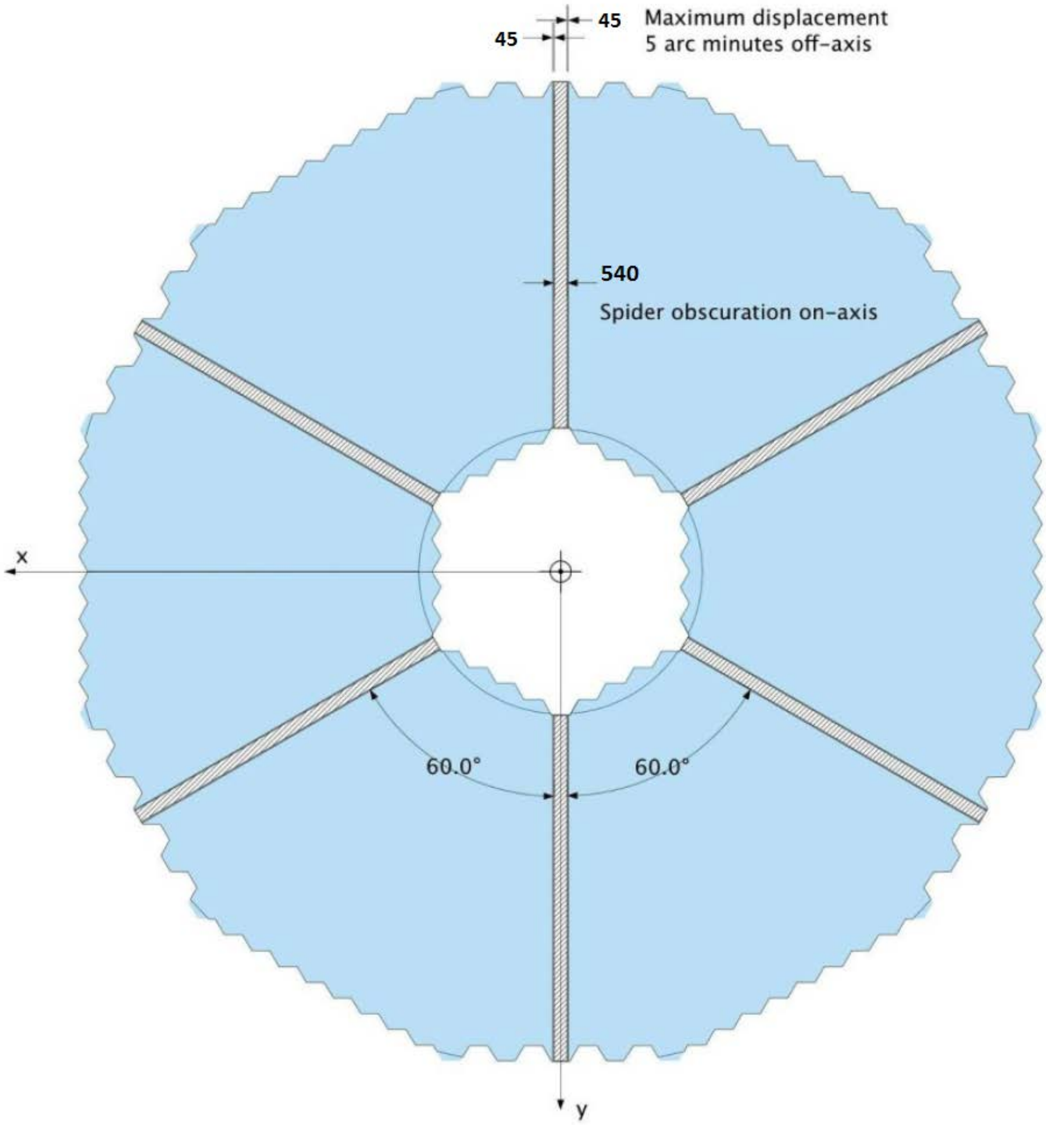

Figure 5: Maximum allowable obscuration by spiders and/or on-board cranes, as projected onto the entrance pupil (as seen from sky). Units: mm.

4.8 M4 Mirror

[I-INS/ELT-159] / / / The fourth mirror of the telescope is a high order deformable mirror segmented into six petals with a nominally flat surface prescription. This mirror shall provide wavefront correction for perturbations including but not limited to atmospheric, telescope and instrument perturbations to the optical wavefront.

[I-INS/ELT-160] / / / The outer limit of M4 shall have the following geometry:

Zone	Geometry	Diameter	Unit
Clear Aperture	Circular	2387	mm
All Glass	Circular	2540	mm

[I-INS/ELT-161] / / / The inner limit of M4 shall have the following geometry:

Zone	Geometry	Diameter	Unit
Clear Aperture	Circular	540	mm
All Glass	Circular	536	mm

[INFO-INS/ELT-162] The central hole in M4 is the limiting aperture determining the telescope central obscuration when projected onto M1.

[I-INS/ELT-163] / / / The gaps between the mirror segments shall be aligned such that they are hidden behind the telescope spider to the maximum extent permitted by the spider design.

[INFO-INS/ELT-164] The segmentation pattern of M4 and the telescope spiders separate from each other in the field of view. The separation occurs beyond ~1.4 arc minute off-axis. The figure below (not to scale) shows the projections on M4, at the edge of the FOV. This figure is for illustration only and an instrument system designer shall perform an independent analysis to derive performance from this effect.

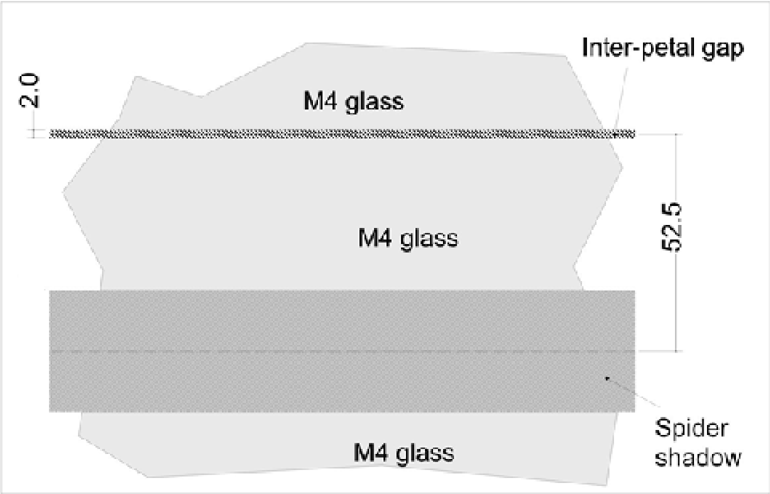

Figure 6: Separation of the M4 segmentation and the spider pattern at the edge of the telescope field of view.

[INFO-INS/ELT-165] The fourth mirror is located nominally at $X_{Alt}=Y_{Alt}=0$ and $Z_{Alt}=+9636.305$mm in the altitude coordinate system and tilted at an angle of 7.75 degrees with respect to the Z_{Alt} axis.

[INFO-INS/ELT-166] The fourth mirror is conjugated in object space at an altitude of 621 m above the telescope entrance pupil and the conjugate is tilted at 55.3 degrees with respect to the telescope Z_{Alt} axis.

[INFO-INS/ELT-167] The M4 lateral stability is specified here in its local coordinate frame (ie. as seen from the centre of the straight through focal plane on the X_{Az} axis). Displacement of the Nasmyth platform attachment points (absolute and combined) that may contribute to additional apparent motion of M4 are specified in section 7.3.

[I-INS/ELT-168] / / / The maximum range of the M4 lateral motion due to main structure deflections shall be not greater than +/-0.5% of its diameter per axis during operation.

[I-INS/ELT-500] / / / The quasi-static rate of the M4 lateral motion due to main structure deflections shall be not greater than +/- 0.5% of the M4 diameter per axis in one hour.

[I-INS/ELT-501] / / / The RMS of the M4 image dynamic motion range of frequencies 0.1 - 2 Hz shall be not greater than 0.02% of the M4 diameter per axis. This motion shall be correlated to the exit pupil dynamic motion, i.e., they shall move synchronously with the same phase.

[I-INS/ELT-502] / / / The maximum rotation range of M4 due to main structure deflections shall be +/- 2.2 mrad.

This refers to a rotation around the optical axis, i.e., the axis defined by the cross/vector product of the x- and y-axis of the M4's local coordinate frame.

[I-INS/ELT-503] / / / The quasi-static rate of the M4 rotation due to main structure deflections shall be not greater than +/- 2.2 mrad in one hour.

4.9 Exit Pupil Characteristics

[I-INS/ELT-170] /// The circular exit pupil shall have a diameter of 2134 ± 5 mm.

[I-INS/ELT-171] /// The nominal exit pupil axial position shall be 37868 ± 78 mm before the Nasmyth focus.

[I-INS/ELT-173] /// During operation, the maximum range of the exit pupil lateral motion in its local coordinate frame (ie. as seen from the centre of the straight through focal plane on the X_{Az} axis) due to main structure deflections shall be not greater than +/-0.5% of the pupil diameter per axis.

[I-INS/ELT-174] /// During operation, the quasi-static rate of the exit pupil lateral motion due to main structure deflections shall be not greater than +/-0.5% of the pupil diameter per axis over a period of 1 hour.

[I-INS/ELT-504] /// The RMS of the exit pupil dynamic lateral motion in the range of frequencies 0.1 - 2 Hz shall be not greater than 0.02% of the exit pupil diameter per axis.

[I-INS/ELT-505] /// The maximum rotation range of the exit pupil due to main structure deflections shall be not greater than +/- 1.1 mrad.

This refers to a rotation around the optical axis, i.e., the axis defined by the cross/vector product of the x- and y-axis of the pupil's local coordinate frame.

[I-INS/ELT-506] /// The quasi-static rate of the exit pupil rotation due to main structure deflections shall be not greater than +/- 1.1 mrad in one hour.

[I-INS/ELT-512] /// Not taking into account instrument internal contributions, the overall apparent exit pupil lateral motion during operation experienced by an instrument shall be not greater than +/-0.8% of the pupil diameter per axis at the straight through focal port, and not greater than +/-0.9% of the pupil diameter per axis at the lateral focal port.

4.10 M5 Mirror

[I-INS/ELT-176] /// The fifth mirror shall have an elliptical outer circumference and a nominally flat optical prescription. It provides tip tilt field steering of the telescope output beam.

[I-INS/ELT-177] /// The major and minor axes of the M5 mirror shall have clear apertures of not less than 2665mm and 2125mm respectively.

[I-INS/ELT-178] /// M5 shall be located 29872.4 mm before the telescope focus and tilted at an angle of 37.25 degrees to the Z_Alt axis.

[INFO-INS/ELT-179] The fifth mirror is conjugated in object space 3307 m below the telescope entrance pupil and the conjugate is tilted at 86.0 degrees with respect to the telescope Z_Alt axis.

4.11 Optical Transmission and Transmission Uniformity

[I-INS/ELT-181] /// The telescope shall transmit the wavelength range 0.3 – 24 microns.

[I-INS/ELT-182] /// In the baseline design mirrors M1, M2, M3 and M5 shall be coated with protected silver and M4 shall be coated with aluminium.

[I-INS/ELT-183] /// Assuming fresh coatings on all mirrors, the transmission of the telescope mirror train M1 - M5 and M1-M6N versus wavelength, shall be as given by the curves in the figure below. This requirement covers mirror reflectivity, but does not include throughput losses from other effects such as obscuration, missing segments or segment gaps/chamfers.

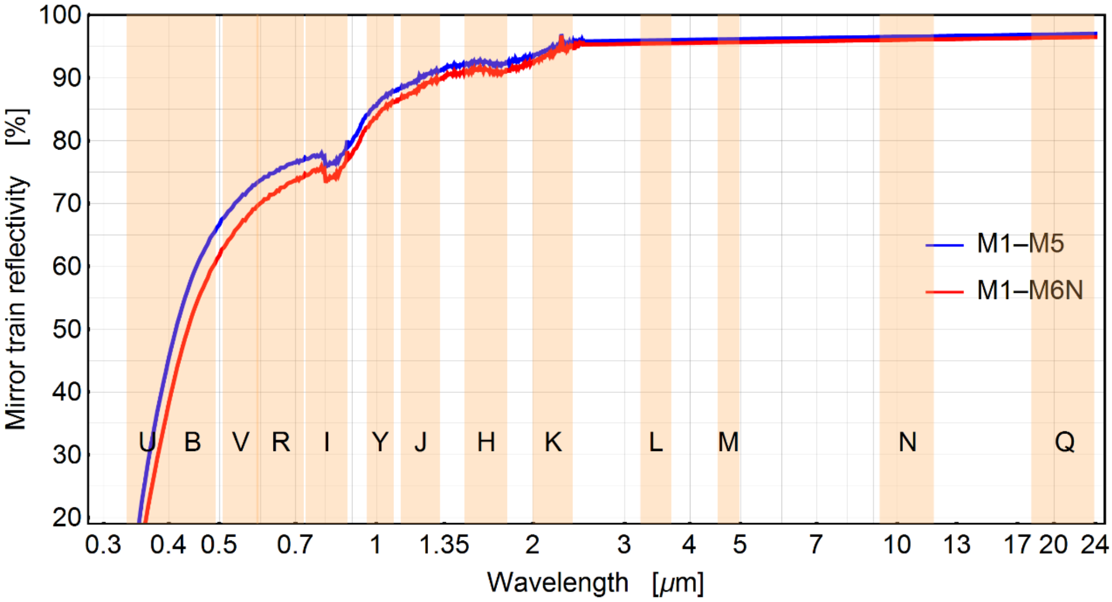

Figure 7: Telescope transmission for M1-M5 and M1-M6N shown for wavelengths from 0.35 to 20 microns assuming fresh coating on each mirror.

[INFO-INS/ELT-195] The predicted contamination accumulation and coating degradation with time causes a reflectivity loss of about 1.5% per 100 days of exposure without intermediate cleaning for upward facing telescope mirrors. For inclined mirrors, the vertically projected area counts. For the M1-M5 mirror train, the reflectivity loss is estimated to be about 4.2% per 100 days and for M1-M6N it is 4.3% per 100 days of uncleaned exposure.

[I-INS/ELT-184] /// Compared to freshly coated mirrors, the time-averaged transmission loss shall be no larger than 11.7% for the mirror train M1-M5 and 12% for the mirror train M1-M6N, respectively, independent of wavelength. These values assume average dust accumulation between mirror recoating periods.

[I-INS/ELT-185] /// The transmission non-uniformity across the pupil, not taking into account missing segments, shall be better than 10% peak to valley.

[I-INS/ELT-186] / / / The number of missing M1 segments at a given time shall be no more than 7 (TBC). Any distribution of missing segments may occur.

[I-INS/ELT-514] / / / Unless there will be a failure in the handling equipment involved in the segment replacement, segments shall not be physically missing but might not be in their nominal configuration and therefore might be excluded from the M1 figure loop (e.g. malfunctioning, badly phased, at wrong positions, replaced by a dummy etc.). The position of the missing segments shall be made available by the Central Control System.

[I-INS/ELT-515] / / / In order to avoid generating optical aberrations, the missing segments shall be completely moved out of the optical beam unless a failure in their positioning mechanisms will prevent to do so.

4.12 Stray Light

[INFO-INS/ELT-188] Sources of stray light which may be present at the telescope focal plane are:

- Ghosts

- Scattered light from contaminated optical surfaces

- Thermal self emission

- Scattered laser light

4.12.1 Stray Light and Ghosts

[INFO-INS/ELT-190] Stray light due to ghost images is defined as stray light reaching the focal plane either directly or after reflections from the telescope mirrors; it excludes scattered light and thermal emission.

[INFO-INS/ELT-191] Stray light from sources within a radius of 0.5 degrees of the telescope axis does not have a path to the telescope focal plane.

[INFO-INS/ELT-192] At angles larger than 0.5 degrees and less than 20 degrees from the optical axis there are paths for stray light to reach the focal plane both directly and after reflection from one or more mirror surface. In more details:

A) From 3.9deg to 4.9deg, light is hitting M1 then M2 and reaches the focal plane with very high angle of incidence. Baffle should be foreseen at instrument level.

B) From 6.8 to 7.1 deg, M3 is illuminated through the hole of M4. M2 mount should act as a natural baffle. (TBC)

C) From 12 deg to 13.1, light surrounding M4 is reflected by M5. M4 mount should act as a natural baffle. (TBC)

D) From 13.7deg to 17.2deg, direct light falling on M5 through M4 hole. ADC Volume could be used to insert a baffle (TBC)

4.12.2 Thermal Self Emission

[INFO-INS/ELT-194] The Thermal Self-Emission (TSE) as a percentage of the background emission due to a black body at the night time temperature has been analysed for a number of different scenarios corresponding to cold stop geometries.

[I-INS/ELT-520] D/A/ / The TSE of the telescope shall be computed as follows:

100 - perfect reflectivity + emissivity contributors

The perfect reflectivity assumes fresh coating of all mirrors and no losses from effects such as obscuration, missing segments or segment gaps/chamfers. It is given in figure 7 and has a significant dependency on the wavelength.

The emissivity contributors that shall be considered are given below. To a good approximation they can be considered independent of the wavelength:

1. Dust on the telescope mirrors (see #184): 11.7% for the straight-through focus and 12% for the lateral foci
2. Segment gaps including segment chamfers: 1%
3. M2 spider: 4.3%
4. Central obscuration: 10%

This assumes that a cold stop masking any non-glass portion of the pupil is implemented in the instrument (see section 4.7, figure 4).

Item 3 and 4 can be neglected depending on the masking approach implemented by the instrument.

4.12.3 Scattered Laser Light

[I-INS/ELT-200] / / / The central wavelength of the laser guide star light shall be taken to be 589.16nm in vacuum.

[I-INS/ELT-201] / / / The total optical power of all stray laser light outside the spectral band 580-600nm shall be no more than 10^{-4} of the total stray light due to the laser guide stars.

[INFO-INS/ELT-202] The stray light is specified in units of photons per second per square meter (projected onto the entrance pupil) per square arcsec (projected onto the sky).

[I-INS/ELT-203] / / / The total stray light contamination produced by the laser sources shall not be greater than 5×10^3 photons/s/m^2/arcsec^2 at the Nasmyth focus within a 20 arcsec field of view around each laser guide star (excluding first order Rayleigh and Mie scattering).

5. Alignment and Calibration

5.1 Alignment Interfaces

[INFO-INS/ELT-206] Alignment targets on the Nasmyth platform, temporary fixtures on the Nasmyth platform and on the instruments will form part of the prefocal station and instrument alignment stratey.

[I-INS/ELT-207] D/A/I/T For the purposes of alignment, instruments shall provide alignment targets (for example laser tracker targets) attached to the structure of the instruments and referenced to the internal optics (for example the optical axis) according to an alignment plan to be agreed with ESO.

5.2 Calibration Interfaces

[I-INS/ELT-209] D/A/I/T Interfaces related to calibration are TBD.

6. Laser Beacons

6.1 General

[I-INS/ELT-212] /// The telescope shall generate at least six sodium laser beacons for use as guide stars with the possibility of installing up to a maximum of 8 laser beacons.

[I-INS/ELT-213] /// The lasers shall be launched from the elevation structure around the rim of the telescope primary mirror.

[I-INS/ELT-214] /// Under nominal gravity load, when the telescope is pointing at Zenith (+/- 2 deg), the launching point for each of the 8 LGS given in the Altitude Coordinate System (see AD1) shall be

LGS Plattform	LGS	X_{Alt} Coordinate [mm]	Y_{Alt} Coordinate [mm]
+B	1	13505	16779.9
	2	10906.92	18279.9
+A	3	-10906.92	18279.9
	4	-13505	16779.9
-A	5	-13505	-16779.9
	6	-10906.92	-18279.9
-B	7	10906.92	-18279.9
	8	13505	-16779.9

The launching point be defined as the center of the circular cross-section of the LGS unit's baffling tube projected onto the LGS support platform (Z_{Alt} coordinate -5100 mm).

[I-INS/ELT-215] /// The laser sources shall have continuous wave format.

[I-INS/ELT-216] /// Each LGS Unit shall provide a Sodium photon return flux ≥ 4.4×10^6 photons/s/m^2 at the entrance pupil of the ELT, with a yearly availability >90% at 1.5°<ZD<50° and >75% at 50°<ZD<60° for seeing < 2.0 arcsec and photometric sky conditions

[I-INS/ELT-217] /// Telescope errors set aside, under median seeing conditions at the E-ELT site, the laser beam quality shall be such that the long exposure LGS beacon image (excluding perspective elongation) does not exceed 1.5 arc seconds FWHM.

6.2 Positioning and Focusing

[I-INS/ELT-219] / / / Each LGS Unit shall be able to position the LGS anywhere in a circular sector with vertex on the ELT optical axis, with a radius of 4 arcmin from the ELT optical axis and with arc amplitude ≥ 100° Peak-to-Peak. The circular sectors shall be evenly distributed around the ELT optical axis.

[I-INS/ELT-220] / / / The on sky accuracy of each LGS Unit to position and maintain the LGS to the target location without offset commands from the post-focal AO instruments and modules shall be ≤ 10 arcsec PTV.

[I-INS/ELT-221] / / / Each laser beacon shall be capable of receiving pointing offsets from the adaptive optics instruments and modules.

[I-INS/ELT-222] / / / Pointing offsets commanded by the client instrument shall have a resolution step less than or equal to 0.2 arc seconds on sky, as measured on the outgoing beam.

[I-INS/ELT-223] / / / The maximum settling time for LGS position offset commands shall be not longer than 0.2s. Settling time is defined as the time required to reach the interval [90%-110%] for an input position step command of 1 arcsec PTV on sky.

[I-INS/ELT-509] / / / Each LGS Unit shall provide the capability to compensate for fast LGS uplink angular pointing jitter (due to atmospheric turbulence) based on sensing information from the post-focal AO instrument and modules.

6.3 Detuning

[I-INS/ELT-225] / / / For the background measurements within the AO wavefront sensor, each LGS shall have the capability to be detuned in frequency to deactivate the resonant scattering excitation in the mesosphere.

[I-INS/ELT-226] / / / The time to detune and retune each LGS shall be shorter than 10 s in each direction.

7. Mechanical Interface

7.1 Definitions and Conventions

[I-INS/ELT-229] / / / All dimensions in AD6 are valid at 20ºC.

[I-INS/ELT-230] / / / The geometry of the interface areas defined in the interface drawings shall be understood as applicable under nominal gravity load when the telescope is pointing to Zenith (±2º).

[I-INS/ELT-231] / / / Displacements of the interface flanges supporting the Nasmyth instruments are expressed in the Azimuth coordinate system.

[I-INS/ELT-497] / / / The mean displacements of the instrument attachment points given in the subsequent sections shall be understood as the best fit rigid body motion of the (equally weighted) Nasmyth Plattform interface points of each instrument (for a certain load case). The peak-to-valley displacement numbers defined are the maximum minus minimum of these displacements considering all possible load cases relevant for the requirement.

7.2 Design Volume

[INFO-INS/ELT-233] The design volume allocated to individual instruments will be specified in the corresponding instrument technical specification.

[I-INS/ELT-234] D/A/I/ No element of a Nasmyth Instrument shall extend beyond its design volume.

[I-INS/ELT-235] D/A/ / The requirements for design volumes shall be valid in any operational configurations and any survival conditions (earthquake loads, wind load, etc.).

[I-INS/ELT-236] D/ /I/ With the exception of specifically designated access paths, the requirements for design volumes shall apply during installation and removal of the instrument and during maintenance.

[I-INS/ELT-237] /A/ / The interface areas on the Nasmyth platform shall be assumed rigid when verifying that internal deflection of each Nasmyth Instrument under loads will not violate its design volume constraint.

7.3 Mounting Interface

7.3.1 Mounting Interface Location

[I-INS/ELT-240] D/ /I/ Nasmyth instruments shall use the mounting interface provided by the Main Structure defined in AD6. The attachment points allocated to each specific instrument will be specified in the corresponding instrument technical specification.

[I-INS/ELT-241] / / / The attachment points shall be provided by the Main Structure.

[I-INS/ELT-498] D/ /I/ If it is required by an instrument and if it is demonstrated by design that it will be advantageous for the system, additional support points can be provided by ESO at intermediate positions beyond the ones defined in AD6

The possible allowed positions and the design of these additional support points wrt the nominal ones is defined in RD1.

The exact position on where additional support points shall be placed as well as their respective performance shall be agreed with ESO for each instrument on a case by case basis, see also RD2.

[I-INS/ELT-242] D/ /I/ With the exception of any infrastructure specified in this document (e.g. dome crane), the mounting mechanisms and adjusting devices to place the Nasmyth instruments at their nominal position shall be defined and provided by the instruments.

[I-INS/ELT-243] / / / The absolute and combined motion specified below may occur independently or in combination.

7.3.2 Load Handling Capacity and Stiffness

[I-INS/ELT-245] D/A/ / The force exerted by any of the Nasmyth instruments on any attachment point defined in [AD6] shall not exceed a maximum load of:

- Force: 500 kN in the X_{Az} and Y_{Az} directions
- Force: 1000 kN tensile and 1250 kN compression in the Z_{Az} directions

this shall apply in any operational configuration and any survival condition (NCR, earthquake loads, wind load, etc.).

The flanges shall be loaded with the forces directed to the centre of the flanges in order to avoid local moments. The maximum eccentricity of loads as defined in EN 1998-1-8 section 2.7 shall be <10% of the width of the flange.

For the calculation of the forces on the flanges a safety factor SF=1.5 shall be considered in all load cases, including survival and accidental load cases. This safety factor shall be considered in lieu of the safety factor for allowable stress and material safety factor defined in ESO Engineering Analysis Standard (ESO-191462), those do not apply for the calculation of the support force.

[I-INS/ELT-246] / / / The minimum local attachment point stiffness of the interface flanges defined in [AD6] shall be at least:

- ≥300x10^{6}N/m for kx (=Fx/ux) and ky = (Fy/uy) in Zone A, and ≥200x10^{6}N/m in Zone B
- ≥300x10^{6}N/m for kz (=Fz/uz) in zone A and ≥150x10^{6}N/m in zone B.

Zone A is the main part of the Nasmyth platform.

Zone B corresponds to the outer 13 auxiliary interface flanges.

7.3.3 Attachment Point Displacements During Loading and Unloading

[INFO-INS/ELT-248] The displacement of the instrument attachment points during loading and unloading are specified here as *absolute* motion in the Azimuth coordinate system [AD1].

[I-INS/ELT-249] / / / When an instrument is mounted onto (or removed from) the Nasmyth platform, the peak-to-valley Rigid Body Motion (RBM) of the whole set of attachment points supporting the same Nasmyth instrument shall be no larger than the values given in the table below:

Motion	Value	Unit
Displacement X	2.5	mm
Displacement Y	0.25	mm
Displacement Z	2.5	mm
Rotation X	0.025	mrad
Rotation Y	0.075	mrad
Rotation Z	0.025	mrad

Table 8: Nasmyth Attachment Point Displacement Instrument Loading

[I-INS/ELT-250] / / / The peak-to-valley RBM of the whole set of attachment points supporting one Nasmyth Instrument due to the weight of any other single instrument being mounted onto (or removed from) the Nasmyth platform shall be no larger than:

Motion	Value	Unit
Displacement X	2.5	mm
Displacement Y	0.5	mm
Displacement Z	2.5	mm
Rotation X	0.175	mrad
Rotation Y	0.175	mrad
Rotation Z	0.025	mrad

Table 9: Nasmyth Attachment Points Displacement Cross Coupling During Instrument Loading

7.3.4 Structural Deflection and Stability Under Operational Conditions

[INFO-INS/ELT-252] The Rigid Body Motion (RBM) of the instrument and PFS attachment points are specified here as *absolute* motion in the Azimuth coordinate system [AD1]. On the straight through focus X is parallel to the direction of light propagation. On the lateral focus, Y is parallel to the direction of light propagation.

[I-INS/ELT-253] / / / The peak-to-valley RBM displacement of the whole set of attachment points supporting the PFS and instruments under all operational conditions shall not exceed the values in the table below. A uniform thermal expansion of the Main Structure (and the hosted units) with a uniform Coefficient of Thermal Expansion less than or equal to $12.5x10^{-6}K^{-1}$ has been subtracted from the deformations.

Motion	Value	Unit
Displacement X	5	mm
Displacement Y	2.5	mm
Displacement Z	2.5	mm
Rotation X	0.25	mrad
Rotation Y	0.25	mrad
Rotation Z	0.25	mrad

Table 10: Limits of Absolute Rigid Body Motions of Nasmyth Instruments

[I-INS/ELT-254] / / / The repeatability of the RBM of the whole set of attachment points supporting a Nasmyth instrument due to structural hysteresis shall be limited to less than the values shown in table below:

Motion	Value	Unit
Displacement X	0.5	mm
Displacement Y	0.25	mm
Displacement Z	0.25	mm
Rotation X	0.025	mrad
Rotation Y	0.025	mrad
Rotation Z	0.025	mrad

Table 11: Repeatability of Absolute Rigid Body Motion of Nasmyth Instruments

[I-INS/ELT-499] / / / For any instrument installed on the Nasmyth platform, the maximum quasi-static peak-to-valley displacement under operational conditions of any individual attachment point on the Nasmyth platform wrt the RBM of the complete set of attachment points corresponding to the same instrument shall not exceed the following values:

- For instruments supported on a <6x6m footprint: Ux=0.2mm; Uy=0.2mm; Uz=0.3mm
- For instruments supported on a <10x10m footprint: Ux=0.2mm; Uy=0.2mm; Uz=0.6mm

This requirement is defined for nominal attachment points defined in [AD.5]. Maximum displacements for additional support points (Section 7.3.1) shall be evaluated in a case by case basis.

7.3.5 Combined Motion Under Operational Conditions

[INFO-INS/ELT-256] The combined motion of the instrument attachment points relative to the focal plane is specified under operational conditions in the Azimuth coordinate system [AD1].

[I-INS/ELT-257] / / / The quasi-static peak-to-valley RBM of the whole set of attachment points supporting a Nasmyth instrument under operational conditions at the straight through focus relative to the focal plane shall not exceed the values in the table below. A uniform thermal expansion of the Main Structure (and the hosted units) with a uniform Coefficient of Thermal Expansion less than or equal to 12.5x10^{-6}K^{-1} has been subtracted from the deformations.

Motion	Value	Unit
Displacement X	1.5	mm
Displacement Y	1.5	mm
Displacement Z	1.5	mm
Rotation X	0.05	mrad
Rotation Y	0.05	mrad
Rotation Z	0.05	mrad

Table 12: Quasi-static displacement of the Nasmyth instrument attachment points relative to the straight through focal plane

[I-INS/ELT-258] / / / The quasi-static peak-to-valley RBM of the whole set of attachment points supporting a Nasmyth instrument under operational conditions on a lateral focus relative to the focal plane shall not exceed the values in the table below. A uniform thermal expansion of the Main Structure (and the hosted units) with a uniform Coefficient of Thermal Expansion less than or equal to 12.5x10^{-6}K^{-1} has been subtracted from the deformations.

Motion	Value	Unit
Displacement X	4.00	mm
Displacement Y	5.00	mm
Displacement Z	2.00	mm
Rotation X	0.40	mrad
Rotation Y	0.10	mrad
Rotation Z	0.35	mrad

Table 13: Quasi-static displacement of the Nasmyth instrument attachment points relative to the lateral focal plane

7.4 Accessibility

7.4.1 Access Categories

[I-INS/ELT-261] /// For the definition of the access parameters needed for the tasks on equipment installed by ESO or other Contractors, the following access categories are defined:

[I-INS/ELT-262] /// a. Access Category A: Man-lift Access

[I-INS/ELT-263] /// This access solution shall bring persons and material to the specified locations with the use of an aerial work platform.

[I-INS/ELT-264] /// The basket(s) of man-lift(s) shall provide a minimum floor space of 2m x 1m.

[I-INS/ELT-265] /// The load in the basket shall be up to 400kg and allow the presence of 2 persons and 200kg of tools or materials.

[I-INS/ELT-266] /// The transfer of persons from the basket to other platforms or locations shall not be foreseen for the normal operation.

[I-INS/ELT-267] /// For emergency cases a procedure shall be provided which allows one person to leave the basket and transfer to another location on the Dome or Main Structure or suitable ESO equipment in a safe manner.

[I-INS/ELT-268] /// A procedure for the hand-out of material between persons in the man-lift basket and persons on other suitable locations shall be provided.

[I-INS/ELT-269] /// The positioning system of the man-lift shall be precise enough to safely move as close as 0.2m to a location or surface where work needs to be done without the danger of contact between the man-lift and other structures.

[I-INS/ELT-270] /// The access solution shall serve as a rescue facility for persons who need to be rescued from locations on the Main Structure or the Dome. This includes the rescue of persons which have been saved by fall protection systems.

[I-INS/ELT-271] /// The boarding location for the basket shall be reachable via Access Category C.

[I-INS/ELT-272] /// b. Access Category B: Ladder Access

[I-INS/ELT-273] /// This access solution shall bring persons and material to the specified locations via ladders or a combination of ladders and walkways.

[I-INS/ELT-274] /// Access ladders shall comply with EN ISO 14122-4 Safety of machinery - Permanent means of access to machinery - Part 4: Fixed ladders.

[I-INS/ELT-275] /// The access solutions shall bring one or up to three persons subsequently to the specified location.

[I-INS/ELT-276] /// The persons using the access solution shall be able to carry small tools or materials in secure pockets or backpacks with a maximum weight of 10 kg and maximum volume of 5l.

[I-INS/ELT-277] /// Enough resting positions shall be foreseen in case of long ascents, also considering the high altitude of the ELT site.

[I-INS/ELT-278] /// Access walkways shall have a minimum clear width of 600mm and a minimum clear height of 2m.

[I-INS/ELT-279] /// Access walkways shall support safely 3 persons standing close to each other in any location.

[I-INS/ELT-280] /// Fall protection shall be installed according to European industrial safety regulations.

[I-INS/ELT-281] /// The access solutions shall consider that persons use protective clothing for cold weather and working gloves.

[I-INS/ELT-282] /// The terminals of the routes covered by Access category B shall be reachable via Access Category C.

[I-INS/ELT-283] /// c. Access Category C: Stair Access

[I-INS/ELT-284] /// This access solution shall bring persons and material to the specified locations via stairs, walkways, elevators or a combination of them.

[I-INS/ELT-285] /// The access solution shall allow 2 persons walking side-by side and/or carrying goods in boxes or other suitable containers up to the ergonomic weight limits for 2 persons.

[I-INS/ELT-286] /// The access solution shall allow the use of barrows with loads of 120kg weight and a size up to 1.0m x 0.9m x 2.0m (LxWxH).

[I-INS/ELT-287] /// Accesses in the C Category shall have a minimum clear width of 1200mm and a minimum clear height of 2.2m.

[I-INS/ELT-288] /// Doors in the access walkways shall have a minimum clear width of 1000 mm and a clear height of 2m.

[I-INS/ELT-289] /// d. Access Category D: Elevator Access

[I-INS/ELT-290] /// This access solution shall bring persons and material to the specified locations via walkways and elevators or a combination of them.

[I-INS/ELT-291] /// The access solution shall allow 2 persons walking side-by side and/or carrying goods in boxes or other suitable containers up to the ergonomic weight limits for 2 persons.

[I-INS/ELT-292] /// The access solution shall allow the use of pallet trucks or other wheeled carriages with loads up to 2000kg weight and a size up to 2.0m x 1.2m x 2.0m (LxWxH) including the carriage.

[I-INS/ELT-293] / / / Doors in the access walkways or into elevators shall have a minimum clear width of 1500mm and a minimum clear height of 2.2m.

[I-INS/ELT-294] / / / e. Access Category E: Scaffolding access

[I-INS/ELT-295] / / / This access solution shall bring persons and material to the specified locations via temporarily erected scaffolding.

[I-INS/ELT-296] / / / Scaffoldings shall comply with all parts of EN 12810 Façade scaffolds made of prefabricated components and EN 12811 Temporary works equipment, All parts.

[I-INS/ELT-297] / / / Scaffoldings shall have a minimum width of 0.9m and support safely a distributed load of $4.5kN/m^2$.

[I-INS/ELT-298] / / / The access according to the above categories shall be possible during anytime compatible with the safety requirements, at daytime and night-time, with the dome closed and with the MS in the configuration specified.

7.4.2 Accessibility Requirements

[I-INS/ELT-300] D/ /I/ Access to the Nasmyth Instruments shall be for the following purposes:

- installation and deinstallation
- commissioning
- maintenance (preventive and corrective)

[I-INS/ELT-301] / / / Access to the Nasmyth Instruments and PFS for personnel shall be via the Nasmyth platform

[I-INS/ELT-302] / / / An elevator and stairway shall allow access to the Nasmyth platforms from the dome transit ring.

[I-INS/ELT-303] / / / For installation and deinstallation, the Nasmyth Instruments shall be lifted onto the Nasmyth platform using the Nasmyth Platform Crane. The telescope shall provide a clear path for handling and installation.

[I-INS/ELT-304] / / / For maintenance it may be necessary to remove and reinstall subsystems of the Nasmyth Instruments using the Nasmyth Platform Crane. Representative dimensions for such a subsystem (including the handling tool) are W4m x L4m x H4m. The telescope shall provide a clear path for handling. Characteristics of the handling crane are given in a later section of this document.

[I-INS/ELT-305] D/ /I/ The Nasmyth Instruments shall provide interfaces consistent with the above accessibility requirements (e.g. attachment points for lifting equipment)

7.5 Physical Characteristics

[INFO-INS/ELT-307] The mass allocated to each individual instrument will be specified in the corresponding instrument technical specification.

7.6 Vibrations and Acoustic Noise

[I-INS/ELT-309] / / / Under the following conditions:

- observation Alt/Az motion ranges,
- primary environmental conditions (excluding wind inside Dome but assuming wind load on Dome structure, i.e. Dome closed),
- Main Structure tracking,
- Dome tracking synchronously with the Main Structure,
- Air conditioning 'off',
- Cooling liquid running with nominal rates,
- ambient ground or environmental vibration levels,
- hosted units in observing mode

the level of vibration produced by the telescope at the interface with the Nasmyth Instruments shall not exceed the values specified in the table below. The vibration levels are specified as an RMS [µm/s] velocity per one-third octave frequency bands in the frequency ranges indicated in the table below.

	Frequency Range (Hz)		
Unit	1-4.45	4.45-56	56-110
Nasmyth Instruments Vibrations (RMS [µm/s])	3	1	3

Table 14: Maximum RMS velocity [µm/s] per one-third octave frequency bands for different frequency ranges induced by the Telescope

8. Control System Interfaces

8.1 Central Control System

[I-INS/ELT-312] / / / The interface between the E-ELT instruments and the Central Control System will be defined in the Instrument Control System Framework.

8.2 Wavefront Control and Adaptive Optics

[I-INS/ELT-314] / / / Wavefront control interfaces are expected to be according to ESO-265724 version 2, "Wavefront Control Interface between Instrument and E-ELT Central Control System"

8.3 Observing Block Preparation Software

[I-INS/ELT-316] / / / The interface between the E-ELT instruments and the Observing Block Preparation Software will be defined in the Instrument Control System Framework.

8.4 Observatory Data Archive

[I-INS/ELT-318] / / / The interface between the E-ELT instruments and the Observatory Data Archive will be defined in the Instrument Control System Framework.

9. Service Connection Points

[INFO-INS/ELT-320] Service Connection Points are the standard connection points to the E-ELT Observatory service supplies (electric power, compressed air, cooling fluid, communication, safety network and time networks). They are located throughout the observatory.

[I-INS/ELT-321] D/ /I/ The Nasmyth instruments shall be connected to the Observatory infrastructure via Service Connection Points.

[I-INS/ELT-322] / / / The characteristics of service connection points shall comply with the requirements in AD4. The instruments shall be provided with a type A2 SCP.

10. Electrical Interface

10.1 Electric Power Interface

[I-INS/ELT-325] D/ /I/ The electric power interface between the Main Structure and the Nasmyth Instruments shall be through a SCP Part A2 specified in AD4.

[I-INS/ELT-326] D/ / / The electrical power allocation to each specific instrument shall be specified in the corresponding instrument technical specification.

[I-INS/ELT-327] D/ / /T The power factor (lambda) of each Nasmyth instrument shall be greater than or equal to 0.85.

[I-INS/ELT-328] D/ /I/ Access to safety power shall be specifically requested and justified by a proper safety analysis by the Nasmyth Instrument contractor. Authorisation from ESO is required in case of a request for safety power.

10.2 Data Communication Interface

[I-INS/ELT-330] / / / Data communication between the Control System and the Nasmyth Instruments shall be via a SCP part B specified in AD4.

10.3 Equipotential Bonding

[I-INS/ELT-332] D/ /I/T The Nasmyth Instruments shall be equipotentially bonded to the Main Structure according to the requirements in AD2.

11. Fluid Interface

11.1 Cooling Liquid

[I-INS/ELT-335] D/ /I/ The cooling liquid interface between the Main Structure and the Nasmyth Instruments shall be through the SCP part C specified in AD4.

[INFO-INS/ELT-336] The cooling power allocation to each individual instrument will be specified in the corresponding instrument technical specification.

11.2 Compressed Air

[I-INS/ELT-338] D/ /I/ The compressed air interface between the Observatory and the Nasmyth Instruments shall be through the SCP part C specified in AD4.

11.3 Cryogenic Fluids

[I-INS/ELT-340] D/ /I/ The cryogenic fluid interface between the Observatory and the Nasmyth Instruments shall be via a dedicated interface connection point separate from the SCP.

[I-INS/ELT-341] / / / The following types of cryogenic fluid shall be supplied by the Observatory as standard:

- liquid nitrogen
- helium gas

The supply of cryogenic fluid shall be agreed on an instrument-specific basis.

[I-INS/ELT-342] / / / Vacuum and cryogenic interfaces are expected to be according to relevant interface information contained in AD5.

12. Cabling and Piping Mechanical Interface

12.1 Cabling and Piping Routing Provided by the Telescope

[I-INS/ELT-345] / / / The *E-ELT System* shall provide cable and pipe routing from the SCPs to the Nasmyth Instruments in the form of a metallic tray for cabling and piping, permanently installed on the Telescope Main Structure, with a minimum cross-section of 400x200 mm. The pipe and cable trays provided by the *E-ELT System* shall not extend into the Nasmyth Instruments design volume.

[I-INS/ELT-346] / / / The *E-ELT System* shall define the routing path for the above cable tray considering the need for maintenance access after first installation.

12.2 Cabling and Piping Provided by the Instruments

[I-INS/ELT-348] D/ /I/ In addition to delivery of the Scientific Instrument, the Nasmyth instrument contractor shall:

- shall procure, deliver and install the cabling and piping including its thermal insulation, between the SCPs and the Nasmyth Instruments.
- shall procure, deliver and install the cabling and piping routing (e.g. metallic trays) inside the instrument design volume.

13. Computer Room Interfaces

[I-INS/ELT-350] / / / The *E-ELT System* shall provide a computer room for the observatory control systems including the instrument control systems (and real-time computers if applicable).

[I-INS/ELT-351] / / / The computer room shall be equipped with cooled electronic racks capable of accommodating units 19 inches wide x 31.5 inches deep.

[I-INS/ELT-352] / / / The computer room shall provide a patch panel connected to the Nasmyth instrument SCPs via dedicated fibre-optic cables.

[I-INS/ELT-353] D/ / /T The instrument control system shall comply with the fibre-optic interface specified in AD4 when connecting to fibre-optic cables.

[I-INS/ELT-354] D/ / /T The instrument control system shall comply with the electrical power and space allocated to the instrument in the computer room. Electrical power and space will be allocated on an instrument-specific basis.

14. Instrument Assembly and Installation

[INFO-INS/ELT-356] The characteristics of the following facilities that might be used by an instrument throughout its life cycle are given in this section:

- E-ELT Auxiliary Building Entrance Hall
- E-ELT Auxiliary Building Instrument Assembly Area
- E-ELT Dome Main Transit Ring
- E-ELT Telescope Nasmyth Platform
- Paranal New Integration Hall

Note that facilities will be allocated on an instrument-specific basis.

14.1 Areas within the E-ELT Dome

14.1.1 Entrance Hall

14.1.1.1 Location and Access

[I-INS/ELT-360] / / / This is the area within the Auxiliary Builiding of the E-ELT Dome at Armazones where instruments will be unloaded after transportation and prepared before moving them into the clean IAA and the dome areas.

[I-INS/ELT-361] / / / The clear cross-section of the access between the outside world and the Entrance Hall shall measure at least 10m x 7.5m (wxh).

14.1.1.2 Use and Function

[I-INS/ELT-363] / / / The Entrance Hall shall be, as a minimum, 32mx10mx8m (lxwxh) in size.

[I-INS/ELT-364] / / / The floor of the Entrance Hall shall be capable of transiting a forklift class FL6 as according to section 6.3 of EN 1991-1-1:2002 Eurocode 1

[I-INS/ELT-365] /// The floor loading capacity of the Entrance Hall shall be classed as Category G as according to section 6.3 of EN 1991-1-1:2002 Eurocode 1

14.1.1.3 Handling Equipment

[I-INS/ELT-367] /// The Entrance Hall shall be equipped with an overhead travelling crane which covers the whole specified area except for the last 2.5m from the walls.

[I-INS/ELT-368] /// The Entrance Hall crane shall provide two crabs with a single hook, each with a capacity of 10 tonnes, and a hoist height from the floor to 7m above floor level.

[I-INS/ELT-369] /// Parallel and also independent operation of both crabs and hooks shall be possible.

[I-INS/ELT-370] /// The crane shall have a load indication with a minimum accuracy of 2% of the maximum load with remote readout.

[I-INS/ELT-371] /// The lateral speed shall be adjustable from 9mm/sec to 80mm/sec and will allow a minimum step of 2mm.

[I-INS/ELT-372] /// The vertical speed shall be adjustable from 1mm/sec to 50mm/sec and will allow a minimum step of 0.5mm.

14.1.1.4 Services

[INFO-INS/ELT-374] The Entrance Hall shall be equipped with Service Connection Points Parts A2-B-C as defined in AD4.

[I-INS/ELT-375] /// The Entrance Hall shall be equipped with a hot and cold water supply

[I-INS/ELT-376] /// The Entrance Hall shall be equipped with a drainage connection.

[I-INS/ELT-377] /// The Entrance Hall shall be equipped with two standard compressed air supply points.

[I-INS/ELT-378] /// The Entrance Hall shall be equipped with 15x 230V (16A) electrical sockets.

[I-INS/ELT-379] /// The Entrance Hall shall be equipped with a single telephone socket.

[I-INS/ELT-380] /// The Entrance Hall shall be equipped with 8x RJ45 outlets.

[I-INS/ELT-381] /// The illumination level of the Entrance Hall shall be 500 Lux.

14.1.2 Instrumentation Assembly Area

14.1.2.1 Location and Access

[I-INS/ELT-384] /// This is the area within the Auxiliary Building of the E-ELT Dome at Armazones where an instrument can be assembled and test before integration on the Telescope. This area includes:

- instrument assembly area
- instrument assembly area auxiliary room
- instrument electronics maintenance area

The auxiliary room will house the instrument control electronics and test equipment during integration and test.

[I-INS/ELT-385] /// The Instrumentation Assembly Area shall be connected to the Entrance Hall via an access path having a clear cross-section of at least 10x7.5m (wxh).

[I-INS/ELT-386] /// The Instrumentation Assembly Area shall be connected to the Instrument Assembly Area Auxiliary Room via an access path having a clear cross-section of at least 2x2.5m (wxh).

[I-INS/ELT-387] /// The Instrumentation Assembly Area shall be connected to the Instrument Electronics Maintenance Area via an access path having a clear cross-section of at least 2x2.5m (wxh).

14.1.2.2 Use and Function

[I-INS/ELT-389] /// The volume available to instruments within the Instrumentation Assembly Area shall be, as a minimum, 22x10x8m (lxwxh) in size.

[I-INS/ELT-390] /// The floor of the Instrumentation Assembly Area shall be capable of transiting a forklift class FL6 as according to section 6.3 of EN 1991-1-1:2002 Eurocode 1

[I-INS/ELT-391] /// The floor loading capacity of the Instrumentation Assembly Area shall be classed as Category E2 as according to section 6.3 of EN 1991-1-1:2002 Eurocode 1

[I-INS/ELT-394] /// The instrument assembly area shall be equipped to reach ISO class 8 (100,000) cleanliness.

[I-INS/ELT-395] /// The Instrumentation Assembly Area Auxiliary Room shall be, as a minimum, 6x5x3m (wxlxh) in size.

[I-INS/ELT-396] /// The Instrumentation Electronics Maintenance Area shall have a floor area of at least 30 square metres.

14.1.2.3 Handling Equipment

[I-INS/ELT-398] /// The Instrumentation Assembly Area shall be equipped with an overhead travelling crane which covers the whole specified area except for the last 2.5m from the walls.

[I-INS/ELT-399] /// The Instrumentation Assembly Area crane shall provide a bridge crane with two hooks, each with a capacity of 12 tonnes, and a hoist height from the floor to 7.5m above floor level.

[I-INS/ELT-400] /// The lateral speed shall be adjustable from 9mm/sec to 80mm/sec and will allow a minimum step of 2mm.

[I-INS/ELT-401] /// The vertical speed shall be adjustable from 1mm/sec to 50mm/sec and will allow a minimum step of 0.5mm.

14.1.2.4 Services

[I-INS/ELT-403] /// The Instrumentation Assembly Area shall be equipped with 2 Service Connection Points Parts A2-B-C as defined in AD4.

[I-INS/ELT-404] /// The Instrumentation Assembly Area shall be equipped with a supply of cryogenic fluids as specified in #340,#341 and #342.

[I-INS/ELT-405] /// The Instrumentation Assembly Area shall be equipped with a hot and cold water supply and drainage connection.

[I-INS/ELT-406] /// The Instrumentation Assembly Area shall be equipped with two standard compressed air supply points.

[I-INS/ELT-407] /// The Instrumentation Assembly Area shall be equipped with 15 x 230V (16A) electrical sockets, 5 x 230V (16A) Safety Power Sockets and 5 x 400V (32A/phase) electrical sockets.

[I-INS/ELT-408] /// The Instrumentation Assembly Area shall be equipped with 2x telephone sockets.

[I-INS/ELT-409] /// The Instrumentation Assembly Area shall be equipped with 8x RJ45 outlets.

[I-INS/ELT-410] /// The illumination level of the Instrumentation Assembly Area shall be 750 Lux.

[I-INS/ELT-411] /// The Instrumentation Electronics Maintenance Area shall be equipped with a Service Connection Point Parts A2-B-C as defined in AD4.

14.1.3 Main Transit Ring

14.1.3.1 Location and Access

[I-INS/ELT-414] / / / This is the area between the Telescope Pier and the Dome Foundation. It shall permit the hosted units to be manoeuvred into a position where they can be accessed by the Dome cranes.

[I-INS/ELT-415] / / / The Main Transit Ring shall be connected to the Entrance Hall as well as various other functional rooms within the Auxiliary Building of the Dome.

[I-INS/ELT-416] / / / The access path between the Main Transit Ring and the Entrance Hall shall have a clear cross-section of at least 10mx7.5m (wxh).

14.1.3.2 Use and Function

[I-INS/ELT-418] / / / The floor of the Main Transit Ring shall be capable of transiting a forklift class FL6 as according to section 6.3 of EN 1991-1-1:2002 Eurocode 1.

[I-INS/ELT-419] / / / The floor loading capacity of the Main Transit Ring shall be classed as Category E2 as according to section 6.3 of EN 1991-1-1:2002 Eurocode 1.

[I-INS/ELT-420] / / / The floor of the Main transit ring in the dome shall be designed for a rubber tired vehicle with a total weight of 30 tonnes and supported on 4 wheel pairs spaced minimum 3m x 3m.

14.1.3.3 Handling Equipment

[INFO-INS/ELT-422] The characteristics of the Nasmyth platform crane are given in the corresponding section later in this document.

14.1.3.4 Services

[I-INS/ELT-424] / / / The Main Transit Ring shall be equipped with 4 Service Connection Points Parts A2-B-C as defined in AD4.

[I-INS/ELT-425] / / / The Main Transit Ring shall be equipped with a drainage connection.

[I-INS/ELT-426] / / / The Main Transit Ring shall be equipped with a 230V double Socket every 10 to 15m on both the Telescope Pier wall and Dome Foundation Wall.

[I-INS/ELT-427] / / / The Main Transit Ring shall be equipped with a 400V 32A CEE 5 pole socket every 10 to 15m on both the Telescope Pier wall and Dome Foundation Wall.

[I-INS/ELT-428] / / / The Main Transit Ring shall be equipped with 4x telephone sockets equispaced around the circumference.

[I-INS/ELT-429] / / / The Main Transit Ring shall be equipped with 12x RJ45 outlets equispaced around the circumference.

[I-INS/ELT-430] / / / The general illumination of the Telescope Chamber shall deliver a lighting level of 200lux measured at the level of the floor except in those areas where maintenance is required where the lighting level is of 300lux. Where specialized maintenance activities are expected, the task lighting level will be determined by the maintainability analysis.

[I-INS/ELT-431] / / / In case of power outage, the emergency lighting and signage shall be automatically and immediately activated. All the devices shall have battery support for 1.5h in case of total power blackout.

[I-INS/ELT-432] / / / It shall be possible to switch off completely all (non-emergency) lighting equipment locally, or in a centralised manner.

14.1.4 Nasmyth Platform

14.1.4.1 Location and Access

[INFO-INS/ELT-435] The Nasmyth Platforms are located on the either side of the Azimuth Structure of the telescope Main Structure.

[INFO-INS/ELT-436] The floor of the Nasmyth Platforms are at a height of 27m above the floor of the Main Transit Ring.

[I-INS/ELT-437] / / / An access category D (elevator access) shall be provided for both Nasmyth platforms.

[I-INS/ELT-438] / / / In addition, an access category C (stair) shall be provided for both Nasmyth platforms.

[I-INS/ELT-439] / / / An access category A shall be provided for the circumference of both Nasmyth Platforms.

[I-INS/ELT-440] / / / A category A access shall bring persons and material to the specified locations with the use of an aerial work platform.

14.1.4.2 Use and Function

[I-INS/ELT-442] / / / The floors of the Nasmyth Platforms shall be capable of transiting a forklift class FL3 as according to section 6.3 of EN 1991-1-1:2002 Eurocode 1.

This value defines also the maximum floor capacity for concentrated loads.

For the estimation of the allowable exerted load a safety factor SF=1.5 shall be considered in all load cases, including survival and accidental load cases. This safety factor shall be considered in lieu of the safety factor for allowable stress and material safety factor defined in ESO Engineering Analysis Standard (ESO-191462), those do not apply for the calculation of the exerted load.

[I-INS/ELT-443] / / / The floor loading capacity of the Nasmyth Platforms shall be qk=10 000 N/m^2 as according to section 6.3 of EN 1991-1-1:2002 Eurocode 1.

For the estimation of the allowable exerted load a safety factor SF=1.5 shall be considered in all load cases, including survival and accidental load cases. This safety factor shall be considered in lieu of the safety factor for allowable stress and material safety factor defined in ESO Engineering Analysis Standard (ESO-191462), those do not apply for the calculation of the exerted load.

14.1.4.3 Handling Equipment

[I-INS/ELT-445] / / / The Dome shall provides a crane with a single crane hook which can move loads between the Nasmyth platform and the Main Transit Ring when the Telescope is parked in zenith and in horizon pointing.

[I-INS/ELT-446] / / / The crane range shall cover the complete area of both Nasmyth platforms.

[I-INS/ELT-447] / / / The capacity of the crane shall be at least 20 tonnes.

[I-INS/ELT-448] / / / The crane shall have a load indication with a minimum accuracy of 2% of the maximum load with remote readout.

[I-INS/ELT-449] / / / The crane hook shall be capable of being placed at any height from 0 to 15m above the surface of the Nasmyth platforms or the main Transit Ring up to a radius of 29m measured from the Azimuth axis. Beyond this radius and up to the edge of the Nasmyth platforms, the height can be reduced linearly from 15m down to 12m, between 29m radius and 32.4 m radius.

[I-INS/ELT-451] / / / Load attachment shall be with commercial slings with an angle between slings of maximum 45deg..

[I-INS/ELT-452] / / / The transport route shall allow the passage of a volume of 7x7x6m (L x W x H).

[I-INS/ELT-453] / / / The lateral adjustment shall allow a minimum step of 1cm and minimum speed of 1cm/sec.

The vertical adjustment shall allow a minimum step of 1.5mm and a minimum speed of 2.5mm/s.

[I-INS/ELT-454] / / / The crane drives shall be equipped with adjustable acceleration and deceleration ramps which allow the adjustment of the acceleration and deceleration rates for a smooth start and stop of movements when delicate equipment like optics is handled. The acceleration or deceleration from stop to any speed in the given speed range is linearly adjustable in a range from 0.5s to 5s minimum.

[I-INS/ELT-455] /// The crane transfer time from the main transit ring to the Nasmyth platform shall be no longer than 10min.

14.1.4.4 Services

[I-INS/ELT-457] /// The Nasmyth Platforms shall be equipped with 5 Service Connection Points Parts A2-B-C on each platform.

[I-INS/ELT-458] /// The Nasmyth Platforms shall each be equipped with a drainage connection.

[I-INS/ELT-459] /// The Nasmyth Platforms shall be equipped with 2x telephone sockets per platform.

[I-INS/ELT-460] /// The Nasmyth Platforms shall each be equipped with 8x RJ45 outlets and WIFI Access.

[I-INS/ELT-461] /// The illumination level of the Nasmyth Platforms shall be 300 Lux.

14.2 Paranal New Integration Hall

14.2.1 Location and Access

[I-INS/ELT-464] /// Characteristics of the Paranal new integration hall are given below. This is an area at Paranal observatory close that shall be used for instrument unpacking, reintegration and test prior to transport to the E-ELT telescope.

[I-INS/ELT-465] /// The door and access path between the Packing Area and the outside shall have a clear width of 4.7m x 4.8m high

[I-INS/ELT-466] /// The Packing Area has a main working area with approximate dimensions 5.4m x 7.4m

[I-INS/ELT-467] /// The door and access between the Packing Area and the instrument assembly hall shall have a clear width of 4.7m x 4.8m high

[I-INS/ELT-468] /// The instrument assembly hall has approximate dimensions of 14.7m x 9.2m.

[I-INS/ELT-469] /// Adjacent to the integration area are a number of offices and small work areas which can be used during the integration.

14.2.2 Use and Function

[I-INS/ELT-471] /// The Paranal new integration hall does not provide a specified level of cleanliness. Instruments requiring a specific level of cleanliness shall provide the means for achieving it (e.g. clean tents).

14.2.3 Handling Equipment

[I-INS/ELT-473] /// The Packing Area crane shall have a load capacity of 1x 10 tonnes tonnes, a crane hook height of 5.6m above floor level, and a minimum vertical speed of 10mm/sec.

[I-INS/ELT-474] /// The instrument assembly hall crane shall have a load capacity of 1x 10 tonnes and a hook height of 5.6m above floor level.

14.2.4 Services

[I-INS/ELT-476] /// The Paranal NIH instrument assembly area shall be equipped with at least one SCP as specified in AD4.

[I-INS/ELT-477] /// The Paranal NIH instrument assembly area shall be equipped with a supply of cryogenic fluids as specified in #,#341 and #342.

14.3 General Handling Equipment

14.3.1 Internal Transporter

[I-INS/ELT-480] /// ESO shall provide a general transporter for use within the buildings of the E-ELT Dome

[I-INS/ELT-481] /// The internal transporter shall have a load carrying capacity of 20 tonnes.

[I-INS/ELT-482] /// The load carrying surface of the internal transporter shall measure 3m x 6m (lxw).

[I-INS/ELT-483] /// The height of the load carrying platform shall be adjustable in the range 0.8m - 1.0m

[I-INS/ELT-484] /// Objects being moved by the internal transporter shall be secured by means of commercially available cargo straps.

[I-INS/ELT-485] /// The internal transporter shall provide a number of attachement points for restraining straps.

15. Verification

[I-INS/ELT-487] D/ / / The interface characteristics defined in this ICD and identified for verification by the instrument shall be verified according to a verification plan to be agreed by ESO. This plan should take into account the suggested verification tag specified for the requirements.

[I-INS/ELT-488] / / / The table below specifies which side of the ICD is responsible for verifying each requirement:

ID	Validator	ID	Validator	ID	Validator
43	ESO Instrument Consortia	222	ESO	360	ESO
62	ESO	223	ESO	361	ESO
64	ESO	509	ESO	363	ESO
67	ESO	225	ESO	364	ESO
68	ESO Instrument Consortia	226	ESO	365	ESO
70	ESO	229	ESO	367	ESO
71	ESO	230	ESO	368	ESO
72	ESO	231	ESO	369	ESO
78	ESO	497	ESO Instrument Consortia	370	ESO
79	ESO	234	Instrument Consortia	371	ESO
80	ESO	235	Instrument Consortia	372	ESO
81	ESO	236	Instrument Consortia	375	ESO
83	ESO	237	Instrument Consortia	376	ESO
84	ESO	240	Instrument Consortia	377	ESO
85	ESO	241	ESO	378	ESO
88	ESO	498	ESO Instrument Consortia	379	ESO
89	ESO	242	Instrument Consortia	380	ESO
90	ESO	243	ESO Instrument Consortia	381	ESO
91	ESO	245	Instrument Consortia	384	ESO
92	ESO	246	ESO	385	ESO

93	ESO	249	ESO	386	ESO
518	ESO	250	ESO	387	ESO
94	ESO	253	ESO	389	ESO
96	ESO	254	ESO	390	ESO
100	ESO	499	ESO	391	ESO
102	ESO	257	ESO	394	ESO
103	ESO	258	ESO	395	ESO
106	ESO	261	ESO Instrument Consortia	396	ESO
107	ESO	262	ESO Instrument Consortia	398	ESO
109	ESO	263	ESO Instrument Consortia	399	ESO
110	ESO	264	ESO Instrument Consortia	400	ESO
115	ESO	265	ESO Instrument Consortia	401	ESO
117	ESO	266	ESO Instrument Consortia	403	ESO
118	ESO	267	ESO Instrument Consortia	404	ESO
119	ESO	268	ESO Instrument Consortia	405	ESO
120	ESO	269	ESO Instrument Consortia	406	ESO
123	ESO	270	ESO Instrument Consortia	407	ESO
125	ESO	271	ESO Instrument Consortia	408	ESO
127	ESO	272	ESO Instrument Consortia	409	ESO
129	ESO	273	ESO Instrument Consortia	410	ESO
132	ESO	274	ESO Instrument Consortia	411	ESO
134	ESO	275	ESO Instrument Consortia	414	ESO
136	ESO	276	ESO Instrument Consortia	415	ESO

137	ESO	277	ESO Instrument Consortia	416	ESO
138	ESO	278	ESO Instrument Consortia	418	ESO
146	ESO	279	ESO Instrument Consortia	419	ESO
150	ESO	280	ESO Instrument Consortia	420	ESO
151	ESO	281	ESO Instrument Consortia	424	ESO
153	ESO	282	ESO Instrument Consortia	425	ESO
154	ESO	283	ESO Instrument Consortia	426	ESO
155	ESO	284	ESO Instrument Consortia	427	ESO
156	ESO	285	ESO Instrument Consortia	428	ESO
157	ESO	286	ESO Instrument Consortia	429	ESO
159	ESO	287	ESO Instrument Consortia	430	ESO
160	ESO	288	ESO Instrument Consortia	431	ESO
161	ESO	289	ESO Instrument Consortia	432	ESO
163	ESO	290	ESO Instrument Consortia	437	ESO
500	ESO	291	ESO Instrument Consortia	438	ESO
501	ESO	292	ESO Instrument Consortia	439	ESO
502	ESO	293	ESO Instrument Consortia	440	ESO
503	ESO	294	ESO Instrument Consortia	442	ESO
170	ESO	295	ESO Instrument Consortia	443	ESO
171	ESO	296	ESO Instrument Consortia	445	ESO

173	ESO	297	ESO Instrument Consortia	446	ESO
174	ESO	298	ESO Instrument Consortia	447	ESO
504	ESO	300	ESO Instrument Consortia	448	ESO
505	ESO	301	ESO	449	ESO
506	ESO	302	ESO	451	ESO
510	ESO	303	ESO Instrument Consortia	452	ESO
511	ESO	304	ESO	453	ESO
512	ESO	305	Instrument Consortia	454	ESO
176	ESO	309	ESO	455	ESO
177	ESO	312	ESO Instrument Consortia	457	ESO
178	ESO	314	ESO Instrument Consortia	458	ESO
181	ESO	316	ESO Instrument Consortia	459	ESO
182	ESO	318	ESO Instrument Consortia	460	ESO
183	ESO	321	Instrument Consortia	461	ESO
184	ESO	322	ESO	464	ESO
185	ESO	325	Instrument Consortia	465	ESO
186	ESO	326	Instrument Consortia	466	ESO
514	ESO	327	Instrument Consortia	467	ESO
515	ESO	328	Instrument Consortia	468	ESO Instrument Consortia
517	ESO Instrument Consortia	330	ESO	469	ESO
200	ESO	332	Instrument Consortia	471	ESO
201	ESO	335	Instrument Consortia	473	ESO
203	ESO	338	Instrument Consortia	474	ESO
207	Instrument Consortia	340	Instrument Consortia	476	ESO
209	ESO Instrument Consortia	341	ESO	477	ESO Instrument Consortia
212	ESO	342	ESO Instrument Consortia	480	ESO

213	ESO	345	ESO	481	ESO
214	ESO	346	ESO	482	ESO
215	ESO	348	Instrument Consortia	483	ESO
216	ESO	350	ESO	484	ESO
217	ESO	351	ESO	485	ESO
219	ESO	352	ESO	487	Instrument Consortia
220	ESO	353	Instrument Consortia	488	ESO Instrument Consortia
221	ESO	354	Instrument Consortia		

16. Appendix

[INFO-INS/ELT-490] A zemax optical design listing for the five mirror telescope is given below.

[INFO-INS/ELT-491] **GENERAL LENS DATA:**

```
Surfaces                : 11
Stop                    : 1
System Aperture         : Entrance Pupil Diameter = 38542
Glass Catalogs          : SCHOTT
Ray Aiming              : Real Reference, Cache On
X Pupil Shift           : 0
Y Pupil Shift           : 0
Z Pupil Shift           : 0
X Pupil Compress        : 0
Y Pupil Compress        : 0
Apodization             : Uniform, factor =   0.00000E+000
Temperature (C)         :    2.00000E+001
Pressure (ATM)          :    1.00000E+000
Adjust Index Data To Environment  : Off
Effective Focal Length  :        684021.6 (in air at system temperature and pressure)
Effective Focal Length  :        684021.6 (in image space)
Back Focal Length       :       -29872.34
Total Track             :        33392.98
Image Space F/#         :        17.74743
Paraxial Working F/#    :        17.74743
Working F/#             :        17.74733
Image Space NA          :      0.02816191
Object Space NA         :     1.9271e-006
Stop Radius             :           19271
Paraxial Image Height   :        994.8697
Paraxial Magnification  :               0
Entrance Pupil Diameter :           38542
Entrance Pupil Position :               0
Exit Pupil Diameter     :        2133.694
Exit Pupil Position     :       -37867.54
Field Type              : Angle in degrees
Maximum Radial Field    :      0.08333333
Primary Wavelength      :               1 µm
Lens Units              :    Millimeters
Angular Magnification   :         18.0635
```

Fields : 5

Field Type : Angle in degrees

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	100.000000
2	0.041667	0.000000	5.000000
3	0.083333	0.000000	1.000000
4	0.000000	0.041667	5.000000
5	0.000000	0.083333	1.000000

SURFACE DATA SUMMARY:

Surf	Type	Radius	Thickness	Glass	Diameter	Conic	Comment
OBJ	STANDARD	Infinity	Infinity		0	0	
STO	STANDARD	Infinity	-2704		38542	0	Entrance pupil
2	STANDARD	68685	30829.45	MIRROR	38542	-0.996473	M1
3	EVENASPH	8810	-17308.85	MIRROR	4101.065	-2.208857	M2
4	STANDARD	Infinity	-33.935		503.4258	0	M4 vertex location
5	STANDARD	Infinity	-13166.07		502.8282	0	Intermediate focus
6	EVENASPH	21089.53	13200	MIRROR	3784.723	0	M3
7	STANDARD	Infinity	-2004.813	MIRROR	2394.244	0	M4
8	STANDARD	Infinity	-7995.187		2137.317	0	Exit pupil
9	STANDARD	Infinity	2672.384	MIRROR	2649.173	0	M5

```
  10 STANDARD   Infinity      27200           2094.949          0 Intersect Alt-Az
 IMA STANDARD  -9884.164                      1987.118          0 Focus
```

SURFACE DATA DETAIL:

```
Surface OBJ STANDARD
Surface STO STANDARD Entrance pupil
Aperture       : Circular Aperture
Minimum Radius :          5476
Maximum Radius :         19271
Surface   2 STANDARD M1
Mirror Substrate :Curved, Thickness = 7.70840E+002
Aperture       : Circular Aperture
Minimum Radius :          4709
Maximum Radius :         19573
Surface   3 EVENASPH M2
Mirror Substrate :Curved, Thickness = 8.20213E+001
Coeff on r  2  :                 0
Coeff on r  4  :  -5.1981957e-016
Coeff on r  6  :                 0
Coeff on r  8  :                 0
Coeff on r 10  :                 0
Coeff on r 12  :                 0
Coeff on r 14  :                 0
Coeff on r 16  :                 0
Aperture       : Circular Aperture
Minimum Radius :           475
Maximum Radius :        2077.5
Surface   4 STANDARD M4 vertex location
Surface   5 STANDARD Intermediate focus
Surface   6 EVENASPH M3
Mirror Substrate :Curved, Thickness = 7.56945E+001
Coeff on r  2  :                 0
Coeff on r  4  :  -8.2721626e-015
Coeff on r  6  :   -8.925957e-024
Coeff on r  8  :                 0
Coeff on r 10  :                 0
Coeff on r 12  :                 0
Coeff on r 14  :                 0
Coeff on r 16  :                 0
Aperture       : Circular Aperture
Minimum Radius :            31
Maximum Radius :          1910
Surface   7 STANDARD M4
Mirror Substrate :Curved, Thickness = 4.78849E+001
Tilt/Decenter  :      Decenter X  Decenter Y     Tilt X  Tilt Y  Tilt Z          Order
Before surface :               0           0          0   -7.75        0Decenter, Tilt
After surface  :               0           0          0   -7.75        0Decenter, Tilt
Aperture       : Circular Aperture
Minimum Radius :           270
Maximum Radius :        1193.5
Surface   8 STANDARD Exit pupil
Surface   9 STANDARD M5
Mirror Substrate :Curved, Thickness = 5.29835E+001
Tilt/Decenter  :      Decenter X  Decenter Y     Tilt X  Tilt Y  Tilt Z          Order
Before surface :               0           0          0  -37.25        0Decenter, Tilt
After surface  :               0           0          0  -37.25        0Decenter, Tilt
Aperture       : Elliptical Aperture
X Half Width   :        1332.5
Y Half Width   :        1062.5
Surface  10 STANDARD Intersect Alt-Az
Surface IMA STANDARD Focus
```

[INFO-INS/ELT-492] The general equation of an even, axisymmetrical asphere is:

$$z(r) = \frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}} + a_2r^2 + a_4r^4 + a_6r^6 + \ldots$$

[INFO-INS/ELT-493] where z(r) is the surface sag. r is the radial coordinate, and c=1/R is the curvature (R being the paraxial radius of curvature at the vertex of the concerned surface). k is dimensionless, while a_i has the dimension of $r^{(1-i)}$.

[INFO-INS/ELT-494] Note that z(r) and c=1/R shall follow the same sign convention. R shall be counted from surface vertex to centre of curvature. With the origin of the z-axis at the vertex of the concerned surface, if the centre of curvature is on the negative side of the z-axis, then R shall be negative.

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