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Project: **ELT MCAO Construction – MORFEO**

FEM Analysis Strategy and Verification Plan

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Table of Contents

Contents

1.Applicable Documents

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 the others.

AD1. Common ICD between the ELT Nasmyth Instruments and the Rest of the ELT System ESO-253082 issue 4

AD2. Common Requirements for ELT Instruments ESO-254547

AD3. ESO Mechanical Standards ESO-192984 Version 2

AD4. ESO-191462 ESO Engineering Analysis Standard, issue 2

AD5. Nasmyth Platform Interfaces ESO-286456 (CAD-135139) Revision 1

2. Introduction

This document defines the Finite Element Modelling (FEM) analysis strategy adopted for the structural verification of the instrument. It outlines the modelling philosophy, the different FEM configurations used during the project, and their application to analyses across the instrument's life phases, from design verification to safety assessment.

The strategy aims to ensure coherent, traceable, and efficient use of FEM analyses, providing sufficient accuracy to demonstrate compliance with ESO structural and performance requirements, while maintaining an appropriate level of model complexity for each task. A hierarchical modelling approach is adopted: simplified models assess global behaviour (stiffness, mass distribution, interface loads), while higher-fidelity representations are reserved for critical subsystems or interfaces.

FEM analyses support both performance-driven verifications (e.g., optical stability, line-of-sight preservation, eigenfrequency requirements) and safety-driven verifications (e.g., strength, stability, transport, and seismic survival). The same modelling framework is applied across all life phases—including Assembly, Integration and Verification (AIV), Transport, Operation, and Maintenance—with appropriate adjustments to loads, boundary conditions, and model configurations.

This document clarifies the assumptions behind each model type, the choice of element formulations (1D, 2D, 3D), and the rationale for their use. In any case, if inconsistencies arise between this document and ESO-192984 (ESO Mechanical Standards), ESO-191462 (ESO Engineering Analysis Standard), or the PM0 Technical Specifications, those documents take precedence.

3. FEM Model Definitions

This chapter expands the definition of the FEM models introduced in the overview, clarifying the main assumptions adopted for each model type and the corresponding choice of element formulation (1D, 2D, 3D). The intent is to ensure consistency across analyses while maintaining an appropriate balance between model fidelity and computational efficiency.

3.1. General Modelling Assumptions

Across all FEM configurations, the following general assumptions apply:

• Linear elastic material behaviour is assumed for all structural components, unless otherwise specified for local checks (e.g. bolted joints or weld verification).

• Small displacement and small strain hypotheses are adopted for all performance analyses. Non-linear effects are only considered where explicitly required (e.g. buckling verification).

• Mass distribution is verified to be representative of the actual configuration for each life phase, including appropriate lumped masses for components not explicitly modelled.

3.2. Model A – Preliminary / Simplified Model

Model A is intended for early final design phases or rapid trade-off studies. The primary objective is to capture the global stiffness and mass distribution with minimal modelling effort.

3.2.1. Assumptions:

- Geometry is simplified, neglecting secondary structural details that have limited impact on global behaviour.
- Interfaces are represented as ideal constraints or simplified spring elements.
- Local stress results are not considered representative and are not used for verification.

3.2.2. Element Types:

- 1D beam elements are used for primary load-carrying members (frames, trusses), with equivalent cross-sectional properties.
- Lumped mass elements are used to represent major subsystems, optics, or equipment where geometric fidelity is not required.

This model is mainly used to support concept validation, preliminary frequency estimates, and sensitivity analyses.

3.3. Model B – Main Structural Model (Skeleton / Frame)

Model B represents the reference structural model for most performance verifications. It captures the main load paths and structural stiffness of the instrument.

3.3.1. Assumptions:

- The primary structure is modelled with sufficient geometric fidelity to correctly predict global deformations and eigenfrequencies.
- Secondary components that do not significantly contribute to stiffness are simplified or represented through equivalent masses.
- Interfaces between major assemblies are modelled with realistic boundary conditions consistent with the relevant life phase.

3.3.2. Element Types:

- 1D beam elements for frames, struts, and stiffeners where the slenderness ratio justifies beam theory.
- 2D shell elements for plates, panels, and structural walls where bending behaviour is relevant.
- Rigid elements (e.g. RBE-type elements) are used to connect distributed masses or to enforce kinematic constraints at interfaces.

Model B is used for quasi-static, vibration (modal), and operational performance analyses, with particular focus on optical stability and line-of-sight preservation.

3.4. Model C – Detailed Subsystems / Payloads

Model C provides a higher level of detail for selected subsystems or payloads (e.g. beams joints, …) that are critical either in terms of mass, stiffness, or interface loads.

3.4.1. Assumptions:

• Only subsystems with a direct impact on performance or safety are modelled in detail.

- Internal details are simplified where possible, provided that equivalent stiffness and mass properties are preserved.
- Local coordinate systems are used to ensure correct load transfer at interfaces.

3.4.2. Element Types:

- 2D shell elements for housings, panels, and thin-walled components.
- 3D solid elements for locally thick or highly stressed regions, such as flanges, interface blocks, or load introduction points.
- Connector elements (springs, bushings) may be used to represent flexible mounts or isolators.

3.5. Combined Model B + C – Full Integrated Assembly

The combined Model B + C represents the full integrated instrument configuration and is used for analyses where global behaviour and total mass effects must be captured simultaneously.

3.5.1. Assumptions:

- Consistency between Model B and Model C is ensured through aligned interfaces and compatible mesh density.
- Submodel interactions do not introduce artificial stiffness due to over-constraining.

3.5.2. Element Types:

- A mixed formulation combining 1D, 2D, and 3D elements, used according to the level of detail required for each subsystem.

This integrated model is used for earthquake, transport, and thermoelastic analyses, as well as for the evaluation of interface reaction forces and global safety margins.

Model ID	Description	Usage Context
Model A	Preliminary/Simplified model (Context implied).	Early design phases or specific sub-component checks.
Model B	Main Structural Model (Skeleton/Frame).	Used for **Static (QS)** and **Vibration (Frequency)** analyses where the primary structural stiffness and optic displacements are the focus.

Model C	Detailed Subsystems/Payloads (e.g., Optics, Cabinets).	Combined with Model B to create the full assembly representation.
Model B + C	**Full Integrated Assembly.**	Used for **Earthquake (QS)**, **Transport** (packed configuration), and **Thermoelastic** analyses to capture total mass effects and reaction forces.

Table 1 Summary of model types

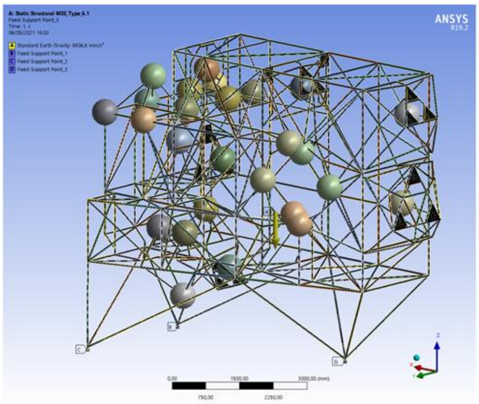

Figure 2 Model A type

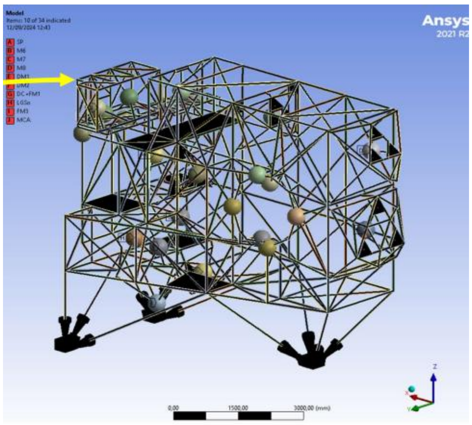

Figure 3 Model B type

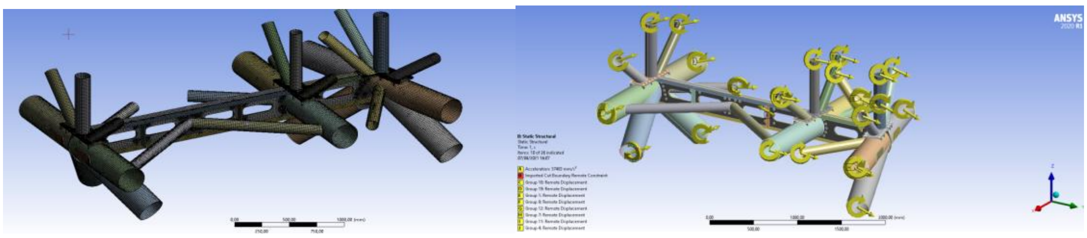

Figure 4 Model C type

4. Analysis deployment

4.1. Analysis Types and Objectives

The following table details the specific analyses to be performed, the physical phenomena investigated (Probing), and the relevant ESO requirements applicable to the verification.

Table 2 Analysis types and objectives

Analysis Type	Objectives & Probing Targets	Applicable Models	Reference Requirements
Earthquake (Quasi-Static)	**Safety & Integrity** • Stresses (Yield/Ultimate) • Reaction Forces (Interface Loads) • Deformation (Survival) • Buckling analysis • Bolt/Interface checks • Welding checks	**Model B + C**	**[I-INS/ELT-245]:** Max load on flanges (SF=1.5[6]). **[R-INS-1244]:** Quasi-static acceleration based on eigenfrequency. **[I-INS/ELT-246]:** Interface Stiffness.
Static (Quasi-Static)	**Performance:** • Optics displacements (Line of Sight, Stability) • Internal displacements under Gravity and Wind load.	**Model B**	**[I-INS/ELT-253]:** Structural Deflection limits under operational conditions **[I-INS/ELT-257/258]:** Combined motion relative to focal plane.
Vibration (Frequency)	**Dynamic Stiffness** • Calculation of Eigenfrequencies • Optics displacements under vibration (internal and from the telescope). • Assessment of vibration transmission to telescope.	**Model B**	**[R-INS-1187]:** Lowest eigenfrequency > 7Hz. **[I-INS/ELT-309]:** Vibration levels induced by telescope.
Thermoelastic	**Environmental Effects:** • Stresses induced by temperature changes. • Deformation/Optical stability under thermal gradients.	**Model B + C**	**[R-INS-755/757]:** Thermal requirements (day/night surface temp differences). **[I-INS/ELT-253]:** Thermal expansion subtraction allowed.
Transport	**Logistics Safety:** • Stresses on packed elements.	**Model B + C** (of the Packed elements)	**[R-INS-1250]:** Quasi-static accelerations during transport (Road/Sea/Air).

[6] MORFEO has agreed on 1.3

	• Deformation of transport containers/frames.		**[R-INS-879]:** PSD accelerations for transport.

4.2. Life Phases and Analysis Matrix

The analysis strategy is tailored to the specific Life Phase of the instrument, ranging from Transport to Operation. The configuration of the FEM and the loads applied vary accordingly.

Life Phase	Location	Model Configuration	Required Analyses	Constraints & Notes
AIV (Assembly, Integration, Verification)	**IAA**[7] (Instrument Assembly Area)	**Model B + C** (Various Configs): 1. Fully integrated structure 2. Config 1+ Panels 3. Config 2 without payloads + all access structures 4. Config 3 + all the payloads	• ***Earthquake*** • ***Static*** • ***Vibration*** • ***Thermoelastic***	Access and handling loads must comply with **[I-INS/ELT-399]** (Crane capacity 12t) and **[I-INS/ELT-391]** (Floor Category E2).
Transport	SS integration sites to Bologna Bologna to Chile Telescope to Recoating sites	**Subsystems** (as per packing list)	• ***Transport Loads***	Analysis performed only for critical components. Loads defined in ESO-254547.
Operation	**Nasmyth Platform**	**Model B + C** (Complete MORFFEO Assembly)	• ***Earthquake*** • ***Static*** • ***Vibration*** • ***Thermoelastic***	Full operational loads (Gravity, Wind, Temperature). Interface loads must respect **[I-INS/ELT-245]**.
Maintenance	**Nasmyth Platform**	**Model B + C** (Without all payloads + all Access structures)	***Earthquake***	**Derating Factor:** 0.5 on loads applied during maintenance phase. Access must comply with **[I-INS/ELT-442]** (Floor load limits)

[7] Nasmyth already covered by Operation and Maintenance

4.3. Specific Load & Boundary Conditions

- **Nasmyth Constraints:**
  - For **Operational** and **Maintenance** phases, the model is constrained at the Nasmyth interface points defined in **AD5** (ESO-286456).
  - **[I-INS/ELT-240]** dictates the use of standard mounting interfaces.
  - Additional support points, if used, must follow **RD1** and **RD2** and be agreed upon with ESO.
- **IAA Constraints:**
  - For the **AIV** phase, constraints are "TBD" or "Not Foreseen" for static/vibration in SE0, but must physically correspond to the integration stands or crane hooks used in the Instrument Assembly Area.
- **Derating Factors:**
  - During **Maintenance**, a load derating factor of **0.5** is applied to Earthquake analysis, acknowledging the reduced probability of a major seismic event during the limited duration of maintenance windows.
- **Safety Factors (SF):**
  - For the calculation of forces on flanges (Reaction Forces), a **Safety Factor SF=1.5**[1] must be used for all load cases (including survival/accidental), replacing standard material safety factors.
- **Load Combination shall be defined according to :**
  - To determine the Load Combination factors, section 4.3 of ESO-254547 shall be considered