MBSE approach for the Euclid mission: Benefits and lessons learned (so far)

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Mission Complexity definition

**Mission context**

- **High number of requirement interrelations**
- **Scientific complexity**
- **Multiple distributed actors**
- **Organizational complexity**
- **Architectural complexity**

- High number of requirement interrelations
- Multiple distributed actors
- Organizational complexity
- Architectural complexity
- Scientific complexity

- Multiple configured elements

**Mission context**

- Subject
- Ground Network
- Space Environment
- External data
- Mission Stakeholders
- Orbit and Trajectory
- Launch Element
- Space Element
- Science Operations and Data Archiving
- Mission Operations

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Euclid Mission Objectives

The Euclid Mission will measure the universe expansion history and growth of large-scale structure with a precision that will allow to distinguish time-evolving dark energy models from a cosmological constant, and to test the theory of gravity on cosmological scales. In addition it will constrain the initial conditions in the very early Universe, by determining the statistical distribution of the primordial density fluctuations with high precision, on scales that cannot be probed using observations of the cosmic microwave background (CMB).

The mission will address the following four key cosmological questions:

• **Dynamical Dark Energy**: Is the dark energy simply a cosmological constant, or is it a field that evolves dynamically with the expansion of the Universe?

• **Modification of Gravity**: Alternatively, is the apparent acceleration instead a manifestation of a breakdown of General Relativity on the largest scales, or a failure of the cosmological assumptions of homogeneity and isotropy?

• **Dark Matter**: What is dark matter? What is the absolute neutrino mass scale and what is the number of relativistic species in the Universe?

• **Initial Conditions**: What is the power spectrum of primordial density fluctuations, which seeded large-scale structure, and are they described by a Gaussian probability distribution?
WHAT?
Cosmology beyond the Planck mission:
- Dark Matter distribution
- Dark Energy nature

HOW?
- Probed through:
  - BAO
  - Weak Gravitational Lensing

The Mission:
- Large Sky Survey:
  - 15,000 deg2
  - Visible imaging
  - Near-Infrared Photometry
  - Near-Infrared Spectroscopy
Requirement complexity

Baryonic Acoustic Oscillations

**BAO reveals the geometry of the luminous matter:**

- Measure redshifts of galaxies over a large volume
- Obtain the power spectrum for a given redshift bin
- Determine the “wiggles” – the acoustic peaks
- The peaks correspond to a typical scale length

$Z=1100$ from WMAP
Requirement complexity

Weak Lensing

The weak lensing distortion is simply a (very small) change in ellipticity and position angle of a galaxy.

Shear Field

Matter distribution

Gravitational Lensing by Matter
Architectural complexity
Organizational Complexity
MBSE to tackle the problem

- **Model Based System Engineering (MBSE) approach for Euclid**
  - Complex system and requirement interaction
  - Several actors in the system: ESA, Industry, NASA, large/distributed Euclid Consortium
  - Need to manage information exchange and control efficiently and coherently

- Decided to implement a Model Based System Engineering (MBSE) collaborative approach with Euclid Consortium

![Diagram showing MBSE approach with SysML Model and Mission Parameter Database]
MBSE Components

Methodology
- Language / Semantics: SysML, Euclid ontology
- Processes and guidelines

Tools and infrastructure
- Enterprise Architect®, MySQL DB, WebServer
- Mission Parameter Database, DB Viewer, Integration

Modelling Scope / Patterns
- What to model and too which level.
- Information to include in model.

Views / Usability
- ‘Hybrid’ approach: Model vs document
- Dedicated created for different stakeholders
Euclid System Model deployment and collaboration

Data exchange (in works) based on ECSS-E-TM-E-25A

Model HTML export for external viewers
Euclid Mission Parameters Database

Consistent assumptions for all analysis, studies and software development: Mission Database (MDB):

- Contains performance parameters for all mission elements and inputs.
- Maintained by European Consortium. Viewers implemented by ESAC.
- Change controlled by CCB with Mission System Engineering Working Group members participation.

![Euclid Mission Parameters Database](image-url)
Euclid Mission Model: This model is designed to support System Engineering activities.

It aims at containing the suitable information to ensure that the Euclid Mission is designed, built and verified to comply with its mission needs.

Lifecycle package contains description of the different steps in the life of the Euclid Mission from selection to scientific analysis of the processed data. Status: empty

Actor package describes the different structure and key people contributing to the Euclid Mission. Status: preliminary

Architecture package describes the design architecture of the mission, including the Mission product tree, the Mission environment and the Mission interface. Status: advanced

Requirement package contains the requirement specification flow down from top level Science Requirements to implementation. Status: Advanced

Verification package contains the test cases and verification approach description that allow verifying that current mission implementation meet the expected needs. Status: empty

Model Library contains reference definition, profiles and stereotypes used in the model. Status: advanced
Requirements modelling

Euclid ontology definition

Full traceability and justification

Custom MRD-WL-017: additive bias knowledge_OK

Link to verification
Maintenance and traceability

> From Euclid Mission Model: Example of requirements traceability and documentation.

Generation of “Traditional” views provided in reviews:
- Reqs documents
- Traceability matrix
- Verification matrix
- ...

Legend
- SD/DR Requirement
- PERD Requirement
- MRD Requirement
- MOCD Requirement
- GDPRD Requirement
- SIRD Requirement
- EID-A Requirement
- SciRD Requirement
- MIRD Requirement
- GDPM-004: VIS FPA planarity tolerance +/-60um
- SRD-PLM-04: VIS FPA & TA optical IF
- SRD-PLM-22: VIS FPA flatness tolerance +/-60um
- SRD-PLM-26: Telescope VIS Ch R2 < 0.055 over 700s
- R-VIS-F-002: VIS shutter required
- R-VIS-P-006: VIS Inst R2 <0.002
- R-VIS-F-008: VIS Inst R2 < 0.012
- R-VIS-P-005: VIS instrument ellipticity <0.156
- R-VIS-P-003: VIS Instrument/PSF FWHM <1.6um
- MRD-WL-004: VIS Channel Ellipticity < 0.15
- MRD-WL-005: VIS Channel (Rpsf/Rref)^2 <4
- MRD-WL-002: VIS PSF FWHM < 0.18''
- MRD-WL-003: VIS PSF FWHM < 0.18''
- SRD-PLM-25: Telescope PSF ellipticity < 0.14 over 700s
- SRD-PLM-06: Telescope VIS FWHM < 0.155 arcsec over 700s
- SRD-PLM-36: Telescope VIS Ch R2 < 0.055 over 700s
- SRD-PLM-29: Telescope PSF ellipticity < 0.13 over 700s
- SRD-PLM-28: Telescope VIS Ch R2 < 0.055 over 700s
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Requirements modelling

Requirement Diagram view

Requirement browser

Up-link

Down-link

Traceability window

Req. text and properties window
Requirements modelling

• **Benefits:**
  Start from Ops Concept at Phase A/B1 and systematic analysis of requirements and relationships:
  • Top level requirements reduced to 40 (from over 200...).
  • Clearly differentiated needs from assumed architectural choices.
  • Knowledge Management: Systematic documentation for justification for all requirements – central project knowledge
  • Change Assessment: Quick and complete assessment of impact of changes to all levels. Change control processes driven by the model: annotated issues, request for changes, etc.
  • Mission Requirements Review very successful.

• **Lessons learned / Open Work:**
  • Seamless with classic requirements management (DOORS): Easy import, difficult to maintain linkage. Tool issue.
  • Need to establish **baselines** at regular time intervals for contractual reasons.
The Euclid mission requires external data to achieve their scientific objectives at Level-0 and Level-1 as expressed in the SciRD.
Architecture modelling
Architecture modelling

FPA detectors and the NI-DCU is described in:

Ni-DCU (for NI-SCS)I

Communication between the ICU and the DPU is described in the DPU ASW ICD and the electrical ICD Ni-DPU ASW ICD

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Architecture modelling

• **Benefits:**
  - Systematic identification/definition of all interfaces.
  - Coherent view of functions and allocation.
  - Definition of clear blocks for reusability.
  - Allows completeness in assessment of non nominal conditions and failures.

• **Lessons learned / Open Work:**
  - Level of modelling: When to stop?
  - Maintenance of history of changes and evolution for easy access, tracing of decisions for change.
  - Modelling of variants: how to model trade-offs? → Currently employing cloned branches of the model
  - Interfaces modelling in SysML: Use of Ports and Association blocks still cumbersome. Association of requirements and behaviour to interfaces not immediate.
From Architecture to Verification modelling

Hierarchy of verification activities to group into “traditional” verification plans.
Verification modelling

Systematic assignment of verification to interfaces.

Automated search allows to quickly identify gaps, progress in verification.
Verification modelling

**ACT [Package] End to end verification [VIS Radiometric Calculation]**

- **VIS Channel Spectral Response**: Real
- **VIS Channel System NDI**: NDI
- **VIS PSF, PSF**: 
- **Radiometric Aperture**: Integer
- **Signal Input Flux**: Real
- **SNR**: Real
- **CCD read noise**: Real

**Analysis**

- **Calculate Radiometric Calculation**
- **Calculate Zodi level**
- **Calculate Straight Background**
- **Calculate VIS SNR**

**EOM Test Campaign [NISP EOM Test Campaign]**

**Mechanical Verification**

- **Identify external constraints**
- **Calculate structure response and characteristics (FEM Model)**
- **Predict mechanical environment for subsystems**
- **FEM Update and correlation**
- **PLM STM Campaign**
- **SVM STM Campaign**
- **SC STM Campaign**
- **FEM Update and correlation**

**NISP Verification Program**

- **NISP Facilities**
- **NISP GSE**
- **NISP DM AIT Campaign**
- **NISP STM Test Campaign**
- **NISP EQM Test Campaign**

**Verification Plan**

- **NISP Verification Program**
- **NISP Facilities**
- **NISP GSE**
- **NISP DM AIT Campaign**
- **NISP STM Test Campaign**
- **NISP EQM Test Campaign**

**Test Campaign**

- **PLM STM Campaign**
- **SVM STM Campaign**
- **SC STM Campaign**
- **FEM Update and correlation**

**Reduced Functional Test**

- **NISP Metrology**
- **Sine Test**
- **Random vibration test**

**Signal Level**

- **Calculate Signal Level**
- **Calculate Zodiacal level**
- **Calculate VIS SNR**

**Channel Spectral Response**: Real
**VIS Channel System NDI**: NDI
**Radiometric Aperture**: Integer
**Signal Input Flux**: Real
**SNR**: Real
**CCD read noise**: Real
Verification modelling

Mission verification tasks are linked to expressions or requirements that are implemented in code. **No automation, just representation in SysML Model.**

Inputs, products and processing functions maintained in **Mission Parameters Database**

Telescope PSF
(9 field points, 4µm sampling)
Behaviour modelling

sd [Package] VIS Linearity Sequence [VIS Linearity Sequence]

PUS[8,1] TC-PERFORM-FUNCTION: Set Operations ID (OpsID)

PUS[8,1] TC-PERFORM-FUNCTION: Execute Linearity Sequence (Tint1, Tint2, Tint3, Tint4)

1485 = 1495s - 10s

RSU_MOVE()

Science Data Transfer to MMU()

Open File(FileName)

STM State Machine VIS ROE

Flushing

Initial ROE

Iddle

Reading Completed

Command Read /Stop periodic HK polling(int)

Command Read /Stop periodic HK polling()

ROE

ROE_RW5

CCDOper(FLUSH)

Ack and Reply CCD Operation()

<problemimiento>

The SW uses a single address for the ROEs (0x11) on its commands. Are these multiplexed? Or treated as a 'single' interface.

=> COMMANDED ONE BY ONE.

Time stamps are generated by the ASW. An event will be generated at the end of the flush including the Delta T from all 12 ROE units.

1495s + Tproc (~300s) - 10s

RSU_END_MOVE()

SC_FGS treatment RSU movement - close

Close File()

Stm [StateMachine] VIS ROE stm [ROE Classifier Behaviour]
Mission Operational model for the complete lifecycle.
For Official Use

End of SpW data transfer to MMU for science exposures during Dither 4.

Start sequence "Nominal science().

NISP

End of RWL-controlled slew.

End of data run TC file (File name: "Dither 1")

End of dark

Raise RSU flag

Synchronous CMU command (Wheel = GWA, Movement = OPEN to DITHER 1)

AASW

Synchronous CMU command (Wheel = FWA, Movement = CLOSED to OPEN)

Load DITH_CONFIG_TAB (Dither = 1, Full content of SITH_CONFIG_TAB)

Transfer dither configuration tables for Dither 1 to active DPU's.

Start CCD flushing.

VIS

Set CMU parameters

Start of RSU movement

Suspend use of Dither 1 TC File
Verification and behaviour modelling

- **Benefits:**
  - Completeness of verification by full coverage check of requirements (incl. functions) and interfaces.
  - Identification of common/repeated tasks: better use of synergies between analysis and tests, reducing duplication and optimizing flow.
  - Key for communication between different players to develop verification plans:
    - Commonly agreed analysis flows, sequences, etc instead of documents.

- **Lessons learned / Open Work:**
  - Integration of model with operations and science operations groups models: currently separate activities
  - Link with verification results: currently we link to test, analysis reports. Appropriate for the use in Euclid. For future missions it should be incorporated in System Knowledge Database.
Views / Communication

- SysML model is in essence a DB with object and connections between them.
  - Knowledge of the semantics allows custom searches and visualizations (both in tool or with external data display applications).
  - Integration into generic project Dashboards:

Currently working on integration of model metrics into system Management Dashboard.
Views / Communication

Dedicated views created for reviews in HTML, integrating model and the traditional document based ESA review process

NISP Instrument Control Unit (NI-ICU) Summary View

The NI-ICU handles all the NISP control functionalities, and interfaces the NISP instrument to the S/C control system for TM/TC tasks.
- Exchanges TM/TC data with the NI-DPU using a dedicated intra-instrument interface.
- Provides the control electronics for the NI-FWA, the NI-GWA, and the NI-ICU.
- It is responsible for monitoring the NI-OMADA temperature sensors and powering the heaters, and it maintains HK data of the NISP warm electronics (NI-WE).

The NI-ICU generates the secondary power supplies which are needed to perform all these functions except from the DPU, DCU, whose main power supply and secondary power needs are self-provided.

Requirements
- NI-ICU Requirement Spec
- NI-ICU VCD

Design
- NI-ICU Design Definition Document
- NI-ICU ASPV Design Definition Document
- NI-ICU Design Justification File

Relevant Analysis
- NI-ICU Worst Case Analysis
- NI-ICU Radiation Analysis
- ICU PW / Root SW and ASPV Integration Report
  - Preliminary Tests on ICU DPU Communication

Communication between the ICU and the DPU is described in the DPU ASPV ICD and the electrical ICD
- NI-DPU ASPV ICD

The agreement on the interface is controlled in the S/C to NISP ICD.
- FMS NISP to Spacecraft ICD

The TM/TC details are described in the TM/TC list and the ICU ASPV ICD
- NI-ICU ASPV ICD
- NISP TM/TC List
- NI-ICU HW/SW ICD

The electrical interface between the ICU and the different subsystems is reflected in the ICU Electrical ICD.

Click on a specific unit to see details on their side of the interface.
- NI-ICU Electrical ICD
Main Lessons learned

- Use modeling as Systems Thinking “lighthouse”
- Define and document a clear modeling approach
- Start early: Phase A/B1
- Identify to what level is necessary to model
- Facilitate Sharing and usage: Observers don’t want to know you have a ‘model’
Thanks!