Model-based instrument review for the Euclid mission for NISP- and VIS CDR

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ABSTRACT

Euclid is the second medium class mission (M2) of the European Space Agency (ESA) Cosmic Vision program. Its primary goal is to determine the nature and distribution of dark matter and dark energy using two main cosmological probes: Weak Lensing (WL) and Galaxy Clustering (GC).

In the last years, the system engineering field is coming to terms with a paradigm change in the approach for complexity management. Different strategies have been proposed to cope with highly interrelated systems and system of systems. In particular, Model Based System Engineering (MBSE) intends to introduce methodologies for a systematic system definition, development, validation, deployment, operation and decommission, based on logical and visual relationship mapping, rather than traditional 'document based' information management.

Euclid is the first attempt to apply an MBSE approach at mission level for a major science project under development in ESA.

Euclid follows the ECSS review lifecycle organized around the V-model. The critical design review (CDR) is held at the end of phase C. The outcome of this review is used to judge the readiness of the project to move into phase D.

The Euclid setup opens up the opportunity to evaluate the benefit of applying MBSE principles to conduct and support reviews at major milestones as defined by the ECSS project lifecycle. In order to facilitate the instrument CDRs it was decided to organize the review around the Euclid model. Specific diagrams derived from the model were used to create a website providing enhanced navigation capabilities through the data pack, supporting the user access and interpretation of relevant information.

The Euclid near infrared spectrophotometer (NISP) and visible imager (VIS) instrument CDRs on Euclid represent the first steps towards a model based review. The lessons learned from these reviews will be presented together with the recommendations for use in future projects.

INTRODUCTION

Due for launch in 2020, ESA's Euclid mission will study the geometry of the Universe by measuring the distribution of dark matter and dark energy with unprecedented accuracy. The satellite will be placed 1.5 million km from Earth in a halo orbit around L2 (the Sun-Earth second Lagrange point). It will use a 1.2m Korsch telescope to measure the shape and redshift of galaxies to z=2 (about 10 billion years of cosmological evolution). Euclid will survey most of the extragalactic sky, combining two observational techniques: measurement of Weak Gravitational Lensing (WL) and measurement of galaxy clustering and hence Baryonic Acoustic Oscillations (BAO).

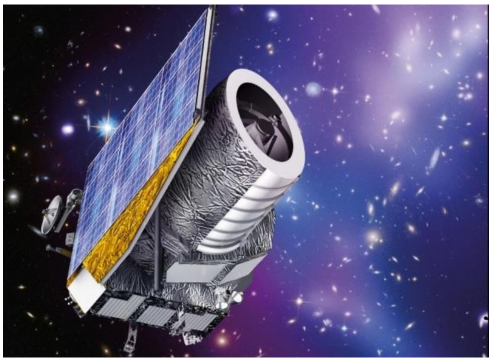

Fig. 1 Euclid S/C

The Weak Lensing measurement comprises a systematic survey of galaxy distortion caused by gravitational light deflection and modified by the expansion of the Universe.

To achieve this, Euclid will carry a large format visible imager called the VIS instrument. VIS will image in a single R+I+Z band from 550-900 nm over a field of view of ~0.5 deg2, reaching a magnitude of mAB=24.5. Analysis of VIS data will measure the effect of Weak Lensing on nearly 1.5 billion galaxies over ~15000 deg2, from which cosmological models may be constrained. VIS will also provide a legacy dataset of unprecedented spatial resolution over most of the extra-Galactic sky.

Baryonic Acoustic Oscillations (BAO) are wiggle patterns imprinted in the clustering of galaxies, which provide a standard ruler to measure dark energy and the expansion in the universe. NISP will provide the high near-infrared spectroscopic capability required by BAO to measure accurately galaxies redshifts at redshifts z>1, and the ability to survey the entire extra-galactic sky. This kind of surveys will also allow the measurements of galaxy clusters and redshift space distortions that will provide additional measurements of the cosmic geometry and structure growth.

Together, WL and BAO will be able to constraint the dark energy parameters and test accurately the cosmological model. The redshift survey will use emitted emission line galaxies as tracer; in particular, it will be designed to follow the H alpha line distribution in the full sky that are expected to have high density distribution at high redshift.

MBSE

In the last years, the system engineering field is coming to terms with a paradigm change in the approach for complexity management. Different strategies have been proposed to cope with highly interrelated systems and system of systems. In particular, Model Based System Engineering (MBSE) intends to introduce methodologies for a systematic system definition, development, validation, deployment, operation and decommission, based on logical and visual relationship mapping, rather than traditional 'document based' information management.

MBSE is about elevating models in the engineering process to a central and governing role in all phases of the lifecycle of a system. The ultimate goal is to ensure specification completeness and consistency, traceability of requirements and design choices, reuse of design patterns and specifications, and a shared understanding of the designs among users and designers.

Euclid is the first attempt to apply an MBSE approach at mission level for a major science project under development in ESA [3]. The System Modeling Language (SysML) [2] was selected to build a representation of the system and capture the complete traceability of the mission break-down, from science objectives to verification and full life-cycle planning. SysML is a standardized graphical modelling language created to support system level visualization of requirements, architectures, interfaces, verification and behavioural aspects. SysML is based on the Unified Modeling Language (UML) and is in fact a UML profile. As modelling tool Enterprise Architect [5] was used.

ECSS REVIEW LIFECYCLE

Euclid follows the ECSS review lifecycle [1] organized around the V-model. The critical design review (CDR) is held at the end of phase C. The outcome of this review is used to judge the readiness of the project to move into phase D. The figures below show a typical project lifecycle for a space mission (Fig. 2) and the V-model (Fig. 3) respectively.

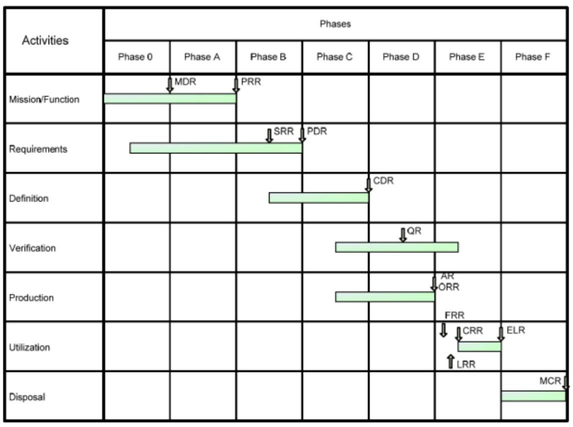

Fig. 2 Project Lifecycle

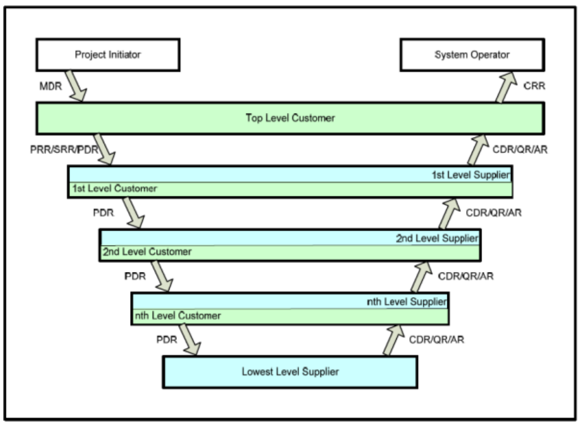

Fig. 3 V-model

NISP AND VIS CDR

The Euclid setup opens up the opportunity to evaluate the benefit of applying MBSE principles to conduct and support reviews at major milestones as defined by the ECSS project lifecycle [1]. In order to facilitate the instrument CDRs it was decided to organize the review around the Euclid model.

The Euclid near infrared spectrophotometer (NISP) and visible imager (VIS) instrument CDRs on Euclid represent the first steps towards a model based review.

APPROACH

In order to facilitate the instrument CDRs it was decided to organize the review around the Euclid model. Existing diagrams basically taken "as is" from the model as well as diagrams specifically created to support the review were used to create a website providing enhanced navigation capabilities through the data pack, supporting the user access and interpretation of relevant information. The diagrams are decorated with text, images and hyperlinks.

Structure Website

The image below (Fig. 4) gives an overview of the website which is further elaborated below.

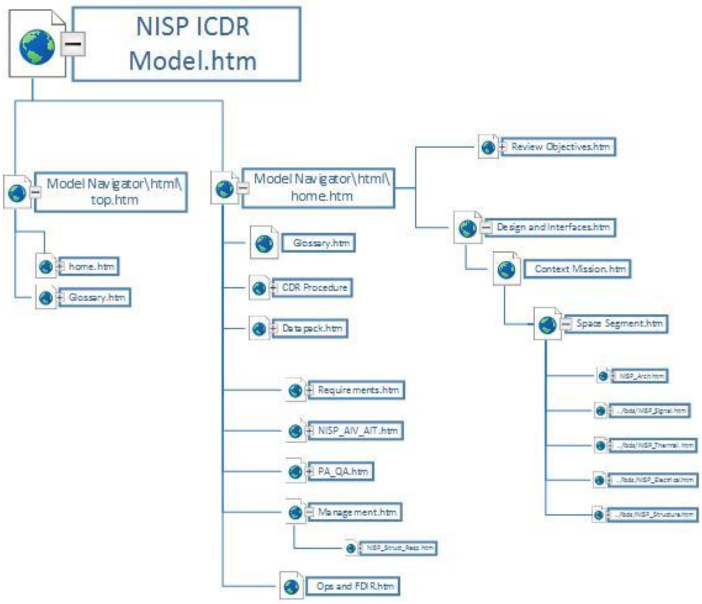

Fig. 4 Website Map

Welcome page

The welcome page (Fig. 5) is the main starting point for navigation and contains links to:

1. The Instrument CDR procedure
   A hyperlink to the document in Eclipse, ESA's Document Configuration and Change Management (DCCM) system.
2. Instrument Datapack
   A hyperlink to a web page containing a categorized list of all documents under review (the traditional "excel view" of the Datapack) as well as a link to an additional web page containing a list of all reference documents.
3. Glossary/ List of Acronyms
   A searchable list of used terminology and acronyms in the project.
4. Review Objectives
   A hyperlink to a web page containing all review objectives.

Links to the main sections of the website described hereunder.

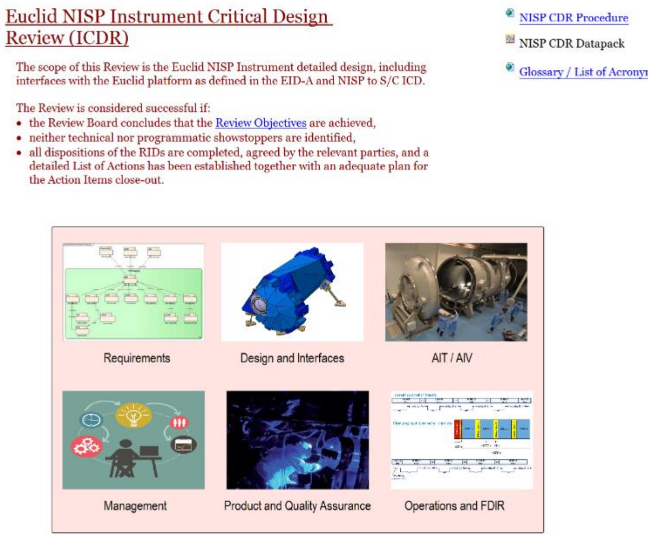

Fig. 5 Starting Page

Requirements

The requirements section (Fig. 6) contains the instrument's requirements tree with links to the applicable high-level requirements specifications, e.g. PERD (Payload Element Requirements Document), and all derived requirements specifications, e.g. NI-CU (NISP Calibration Unit) Requirement Specification.

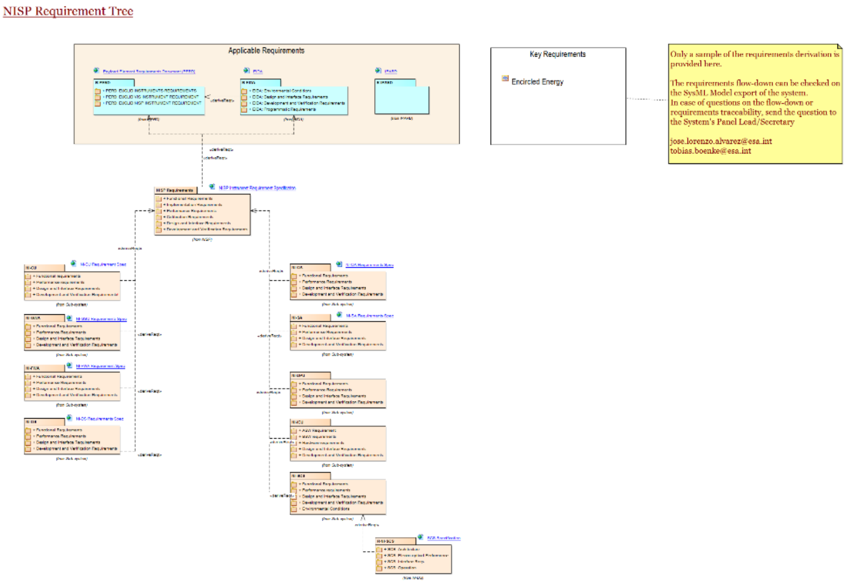

Fig. 6 Requirements section

Design and Interfaces

A collection of web pages reflecting the high-level architecture and decomposition, containing diagrams at various levels. This was modelled with the help of SysML Block Definition Diagrams (BDDs) used for decomposition and characterization of (parts of) the system.

From Mission to Space Segment (Fig. 7), the architectural context with links to the Euclid Mission Architecture Description Document. The diagram indicates to the user where to click in order to navigate the model.

Next a decomposition of the instrument/Product Structure (Fig. 8) down to payload subsystems. A detailed overview of the NISP architecture resembling the product tree. Leafs in the tree link to specific lower-level diagrams linking to the relevant documentation at that level.

A separate section for Interfaces provided links to the various interface perspectives (Structural/Mechanical, Electrical, Signal, Thermal).Those were modelled as SysML Interface Block Diagrams (IBDs) depicting the interconnection of blocks, e.g. interface specifications. See (Fig. 9) for an example of the thermal perspective.

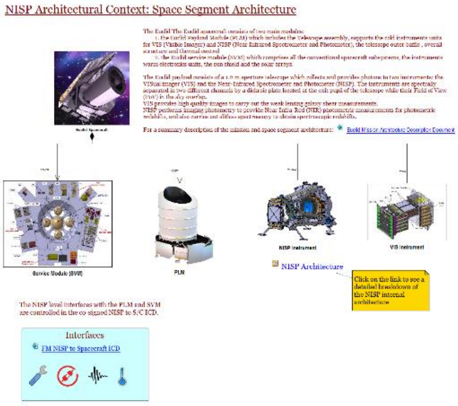

Fig. 7 Context NISP Space Segment

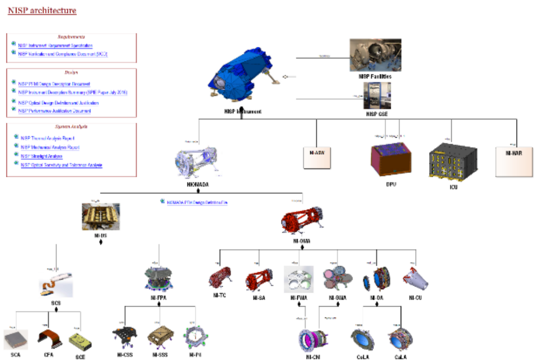

Fig. 8 NISP product Tree

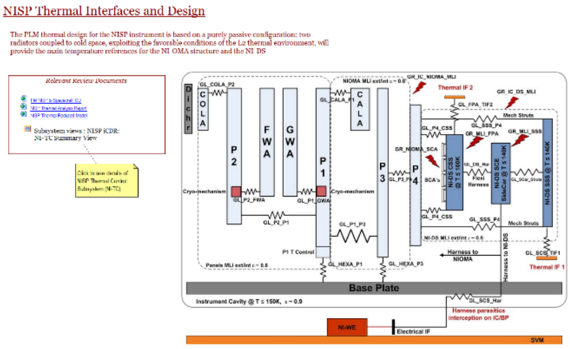

Fig. 9 Thermal Interfaces and Design

AIT / AIV

A section with categories containing all relevant AIT/AIV documentation (Fig. 10).

Management

Management documentation and a link to a responsibilities diagram (Fig. 11), a diagram presenting member institutes and organizations of the Euclid Consortium [4] at different levels. The various elements in the diagram are linked to specific diagrams.

Product and Quality Assurance

Categorized lists of relevant PA/QA documents.

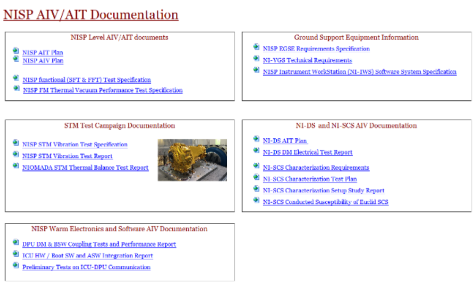

Fig. 10 AIV/AIT

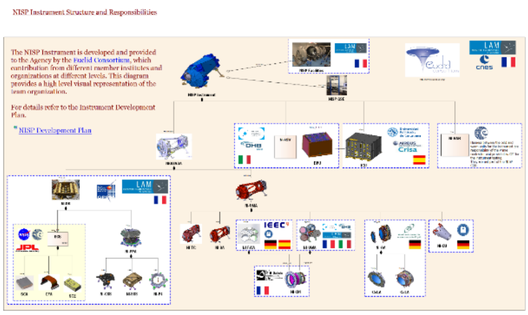

Fig. 11 Instrument Structure and Responsibilities

LESSONS LEARNED

In the next bullets, we summarize what we consider the main lessons learned:

- *The Model based review was well received.* Doing things differently compared to the traditional Datapack was received very positively by the reviewers. It enables users to easily navigate the data pack, find the relevant document(s) and put them in the proper context.
- *If you are doing MBSE the effort involved organizing the review around the model is modest.* You can leverage the existing model and decorate it with a few review specific diagrams utilizing existing model elements in order to support the review.
- *Reporting functionality of the modelling tool can be used.* Reporting functionality of Enterprise Architect was used to generate a set of documentation in html format. This fed into the website, only a small manual tweak was required in order to make it more user friendly.
- *Keep it Simple.* You have to provide the right level of detail to the reviewers. The Euclid model is fairly detailed and it is important to find the right balance between providing a meaningful context and overloading the user with details of the model.

RECOMMENDATIONS

Continue and expand the usage of models for supporting major milestone reviews. In the course of time the transition to a fully model based review, i.e. where the model is subject to review, can be made.

REFERENCES

[1] ESA Requirements and Standards Division, *Space project management - Project planning and implementation*, (16 March 2009), ECSS-M-ST-10C Rev.

[2] "SysML Open Source Specification Project", SysML v1.4 (http://sysml.org/docs/specs/OMGSysML-v1.4-15-06-03.pdf)

[3] Lorenzo Alvarez, J., et. al., Model-based system engineering approach for the Euclid mission to manage scientific and technical complexity(2016), [9911-12]

[4] "Euclid Consortium", http://www.euclid-ec.org/

[5] "Enterprise Architect", http://www.sparxsystems.com/