MBSE at ESA

State of MBSE in ESA Missions and Activities

MBSE SPACE

MBSE2021 Conference

MBSE at ESA: State of MBSE in ESA Missions and Activities

29/09/2021

Jamie Whitehouse, on behalf of ESA TEC-S/MBSE Space Team
with inputs from ESA Mission and Activity representatives

MBSE in ESA Missions Mission Overview

esa

0
concurrent design facility

COMET

A/B1
saga
→ esa-hre

lunar communications and navigation services (lcns)
→ esa-hre

e.deorbit
→ clean space

adrios
→ clean space

e.inspector
→ clean space

ariel
→ esa-sci

envision
→ esa-sci

truths
→ esa-eop

european large logistic lander
→ esa-hre

B2
earth return orbiter
→ mars sample return
→ esa-hre

galileo 2nd gen
→ esa-nav

C/D

euclid
→ esa-sci


plato
→ esa-sci

E

F

COMET (10-25)

Enterprise Architect (SysML)

Cameo Systems Modeler (SysML)

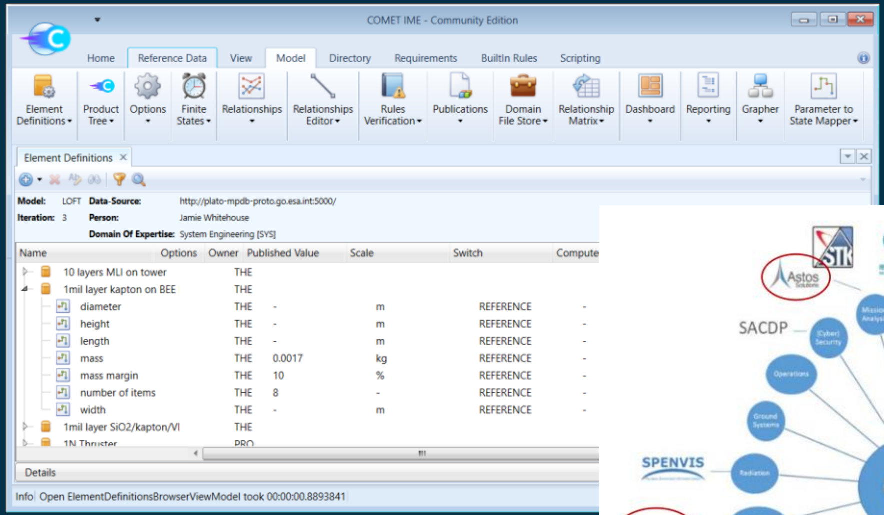
Capella

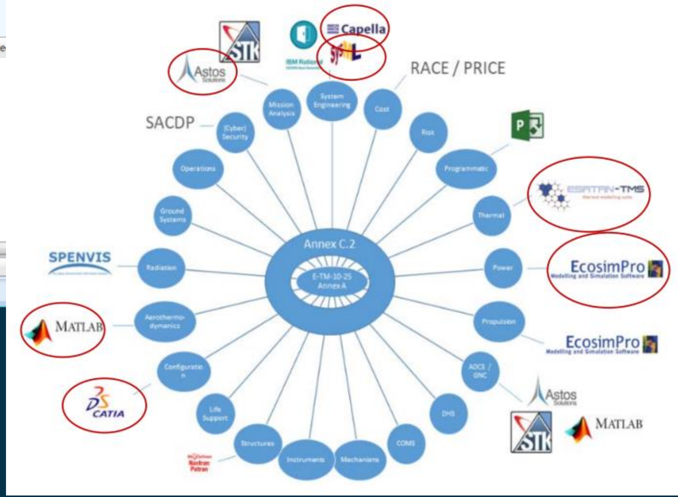
Vitech Genesys

Valispace

MBSE in ESA Missions Phase 0 (CDF)

OCDT Open Concurrent Design Tool + CDP4 COMMUNITY EDITION → COMET

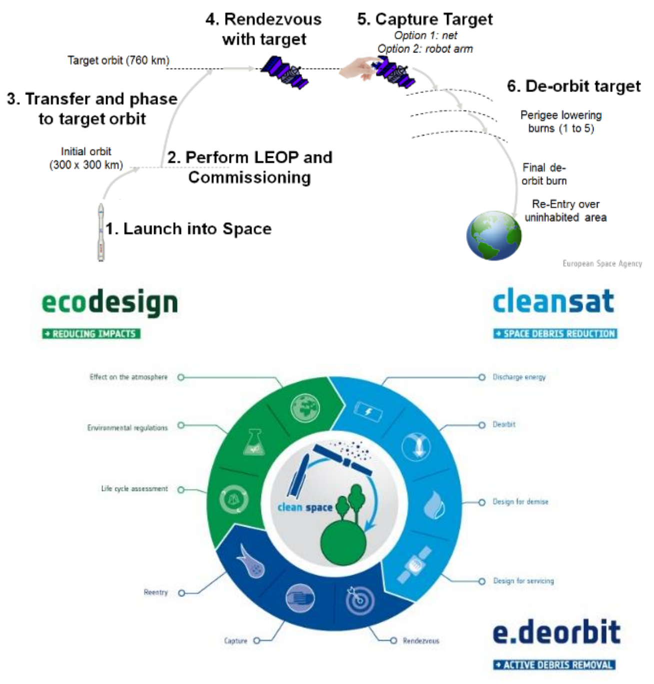




MBSE in ESA Missions Clean Space

e.Inspector

- → Mission to inspect uncontrolled satellite to assess viability of a subsequent deorbiting mission
- → Requirement and Functional modelling in CDF Feasibility Study using SysML/Cameo Systems Modeler (alongside OCDT model)
- → SysML and OCDT models provided as inputs to Phase A
- → *Politecnico di Milano* was selected as Phase A Prime, adopting Capella as MBSE solution



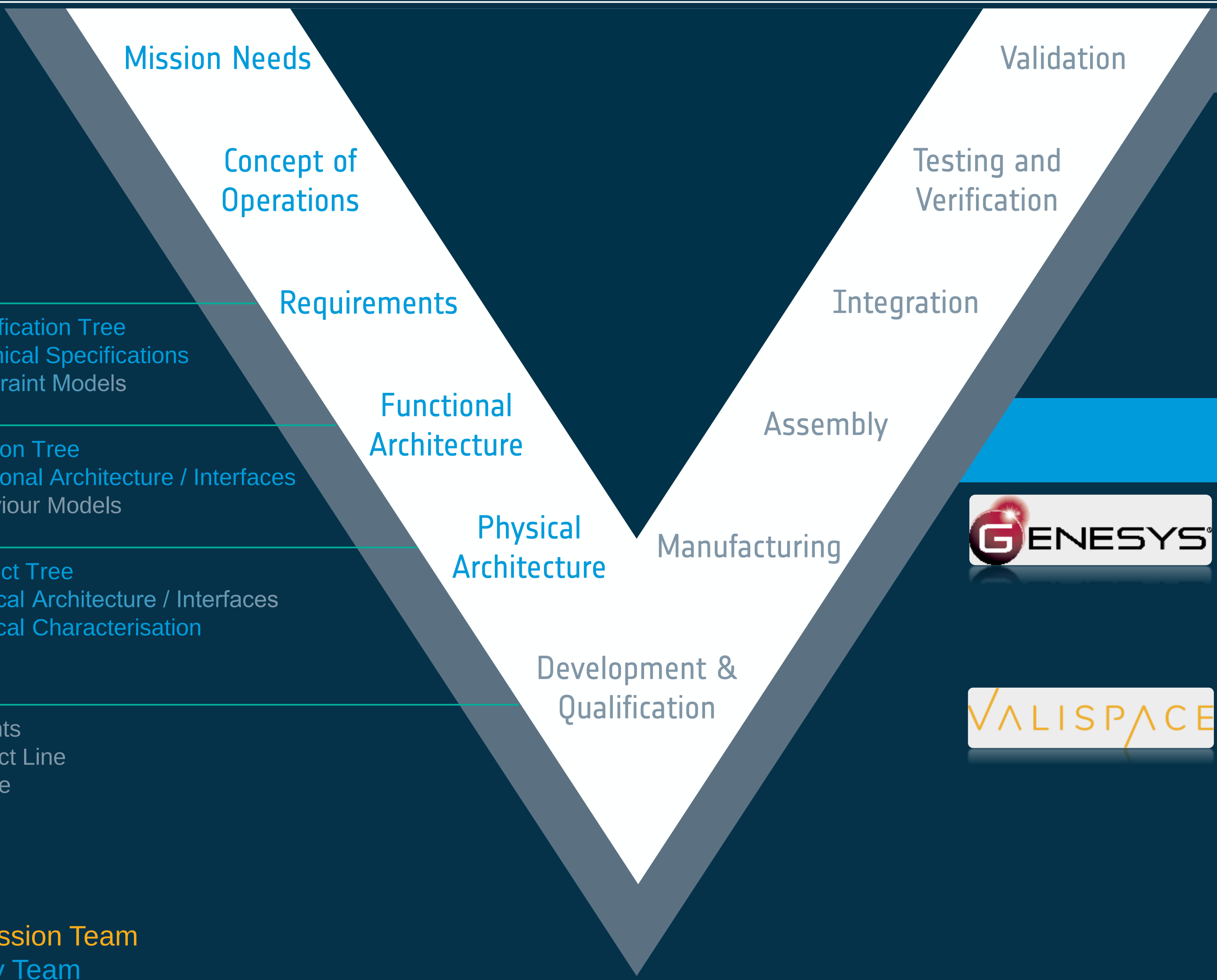
e.Deorbit

- → Active debris removal mission to safely deorbit an uncontrolled target
- → CCN to Phase A SoW to create an MBSE model (i.e. reverse-engineer from phase A)
- → Continuation of MBSE approach in Phase B1 by both consortia
  - ADS using SysML/MagicDraw plus CDP4
  - OHB/TAS using Capella plus IDM-CIC
- → Strong engagement from contractors and lessons learned from different approaches
- → No funding found to continue past Phase B1

MBSE in ESA Missions ADRIOS / ClearSpace-1

Mission Context	
Directorate	TEC / Clean Space
Programme	Space Safety
Project Phase	B1
Launch Date	2025
Objective(s)	The first mission in ESA's Active Debris Removal and In-Orbit Servicing (ADRIOS) project, ClearSpace-1 will rendezvous, capture and bring down for reentry a Vespa payload adapter.
Contractor(s)	ClearSpace (Prime)
Points of Contact	Robin Biesbroek (robin.biesbroek@esa.int) *Mission Performance and Modelling Engineer*

MBSE in ESA Missions ADRIOS / ClearSpace-1



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- → Constraint Models

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- → Physical Characterisation

- → Variants
- → Product Line
- → Re-use

ESA Mission Team
Industry Team
No MBSE implementation currently foreseen

Primary Goals

- → **Full traceability from requirements to functional and physical architectures**
- → Operational/functional modelling informing requirements engineering process, including feared event modelling
- → Performance analysis of system options from physical model

Technical Solution

GENESYS

- → Use of Vitech GENESYS since K/O (2020)
  - → Operational activities, function modelling, requirements
- → Exchanges with ESA team via HTML Export

VALISPACE

- → Recent move away from GENESYS to Valispace
  - → More focus on product tree/physical aspects of model
  - → Operational and functional flows still implemented and traced
- → Platform allows for quick option analysis/budgeting
- → Access given directly to ESA team

MBSE in ESA Missions Ariel

Mission Context		
Directorate	SCI	
Programme	Cosmic Vision M4	
Project Phase	B1	
Launch Date	2029	
Objective(s)	Ariel will study what exoplanets are made of, how they formed and how they evolve, by surveying a diverse sample of about 1000 extrasolar planets, simultaneously in visible and infrared wavelengths.	
Points of Contact	Salma Fahmy (salma.fahmy@esa.int)	*Mission, Payload & AIV Manager*
	Alberto Gonzalez Fernandez (alberto.gonzalez.fernandez@esa.int)	*MBSE Support*

MBSE in ESA Missions   Ariel

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Primary Goals

ESA Mission Team

- → Requirements Engineering/Management, including generation of requirement documents from model (migration from Excel-based approach)
- → Full traceability from requirements, functional and physical architectures
- → **Single source of truth for ESA, Industry and Consortia (minimisation of explicit exchanges)**
- → Methods for accommodating confidential/IPR restricted data

Technical Solution

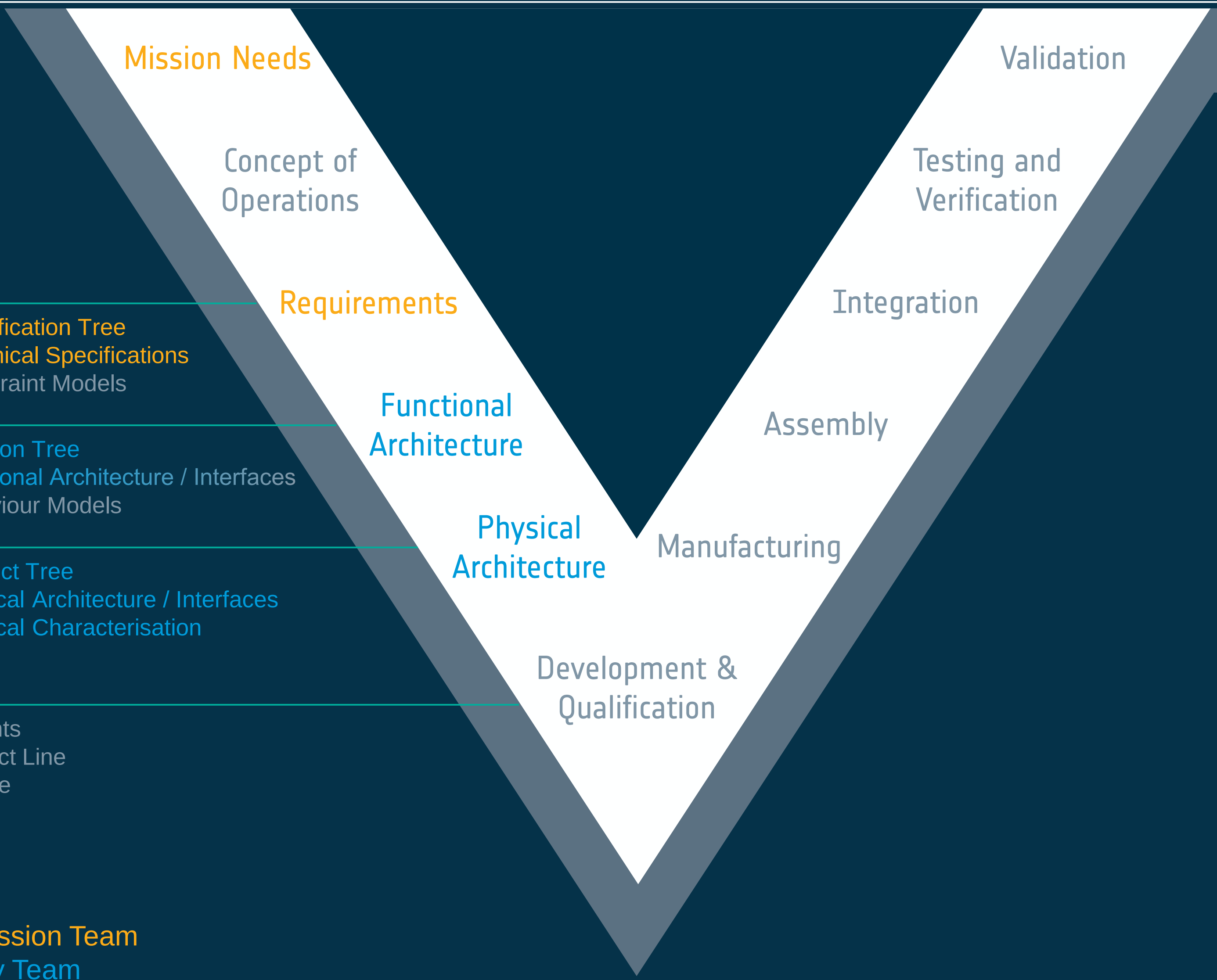
- → Enterprise Architect with collaborative model server and web interface
  - → Reuse of SCI MBSE infrastructure and Euclid/PLATO heritage (see Euclid/PLATO slides)
  - → ESA SysML Toolbox
  - → Web interface for “general user” access with no setup

ESA Mission Team
Industry Team
No MBSE implementation currently foreseen

MBSE in ESA Missions EnVision

Mission Context		
Directorate	SCI	
Programme	Cosmic Vision M5	
Project Phase	B0 (B1 K/O Nov 2021)	
Objective(s)	EnVision is a Venus orbiter mission that will determine the nature and current state of Venus' geological evolution and its relationship with the atmosphere, to understand how and why Venus and Earth evolved so differently.	
Contractor(s)	TAS / ADS (Competitive)	
Points of Contact	Robert Buchwald (robert.buchwald@esa.int)	*System Engineer*
MBSE2021 Presentations	Application of Digital Exchanges Between Project Partners in the Frame of Envision Project (Gerald Garcia, TAS)	Wed 29/09/2021 @ 12:25CET

MBSE in ESA Missions EnVision



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Primary Goals

ESA Mission Team

- → Reuse of heritage infrastructure from Euclid/PLATO, investigate use for Phase A
- → **Requirements Engineering/Management, including generation of requirement documents from model**

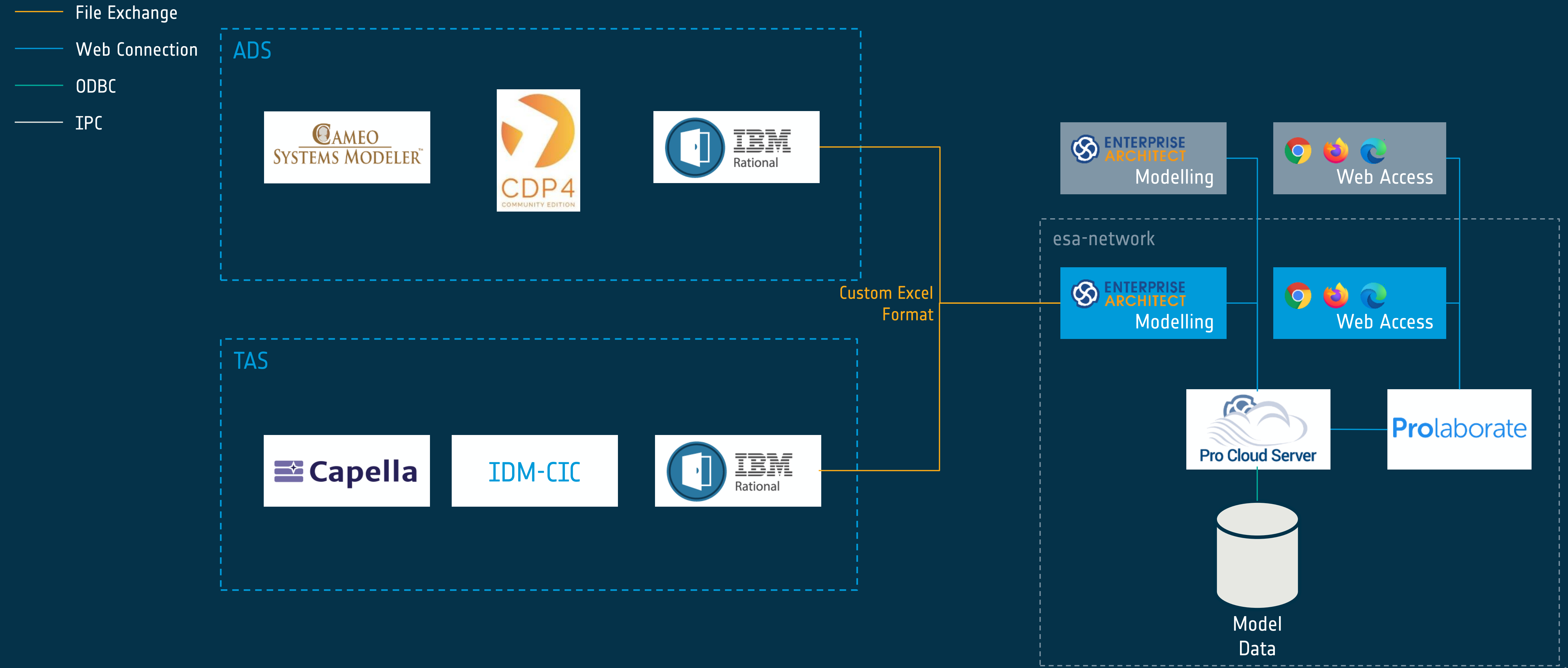
Industry Teams

- → Physical modelling and requirement traceability to support justification of design w.r.t. mission performance requirements
- → System budget reporting from model
- → Dashboard with trend reports of system budgets and evolution of key system parameters

ESA Mission Team
Industry Team
No MBSE implementation currently foreseen

MBSE in ESA Missions EnVision

MBSE Architecture



MBSE in ESA Missions EnVision

Takeaways

Key Capabilities

- Exploitation of model (e.g. doc generation, consistency checks)
- “Intelligent VCD”
- Easier exchange formats for Industry
- Interactive web viewer supports discussions internally and externally

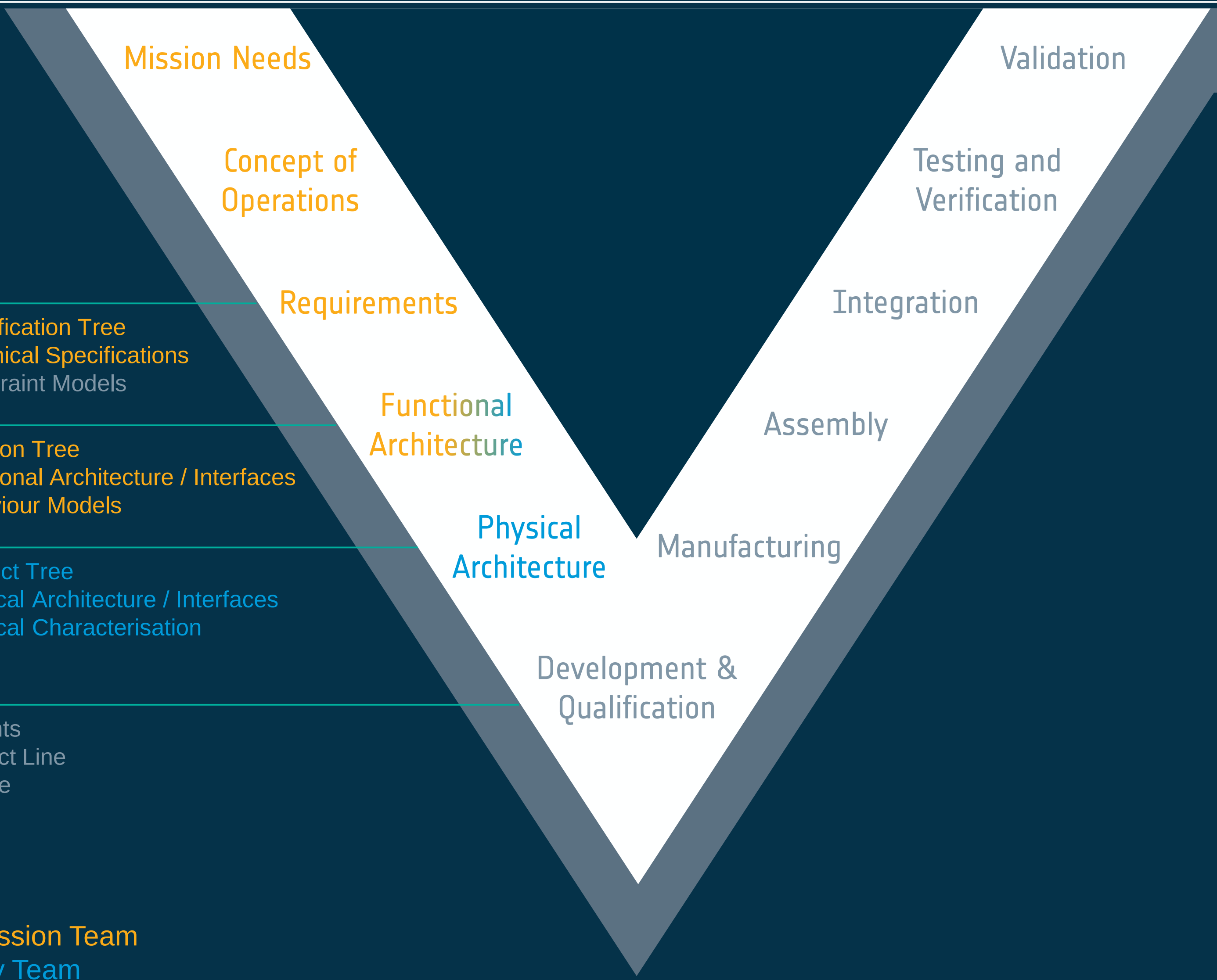
Lessons Learned

- Reuse of existing infrastructure → quick to establish model and start working
- **Multi-media in requirements (images, tables) → significant challenges with EA and exchanging with other systems (e.g. DOORS)**
- Overhead from input/output in various document-based formats
- Start early
- Identify owners of model sections (i.e. book captains), enforce work through model
- Interoperability with Industry using different modelling tools - common formats needed to simplify work on ESA team

MBSE in ESA Missions TRUTHS

Mission Context		
Directorate	EOP	
Programme	Earth Watch	
Project Phase	B1	
Objective(s)	Creation of a space-based climate and calibration observatory that will improve confidence in climate change forecasts and support net zero mitigation strategies and their impact.	
Contractor(s)	ADS (Prime)	
Points of Contact	Andrea Marini (andrea.marini@esa.int)	*TRUTHS Project Manager*
	Eric Joffre (eric.joffre@esa.int)	*SE Support*

MBSE in ESA Missions TRUTHS



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Primary Goals

- → General benefits of Model-Based approach: towards digital continuity, single source of truth, communication with stakeholders, eased model navigation and access to information etc.
- → Requirements traceability to functional and operational architectures, allowing for change impact analysis
- → **Special focus on payload calibration operations**
- → FMEA, as input to FDIR design
- → Engineering data, and technical budgets, including performance
- → Metrological verification (TBC, with NPL)

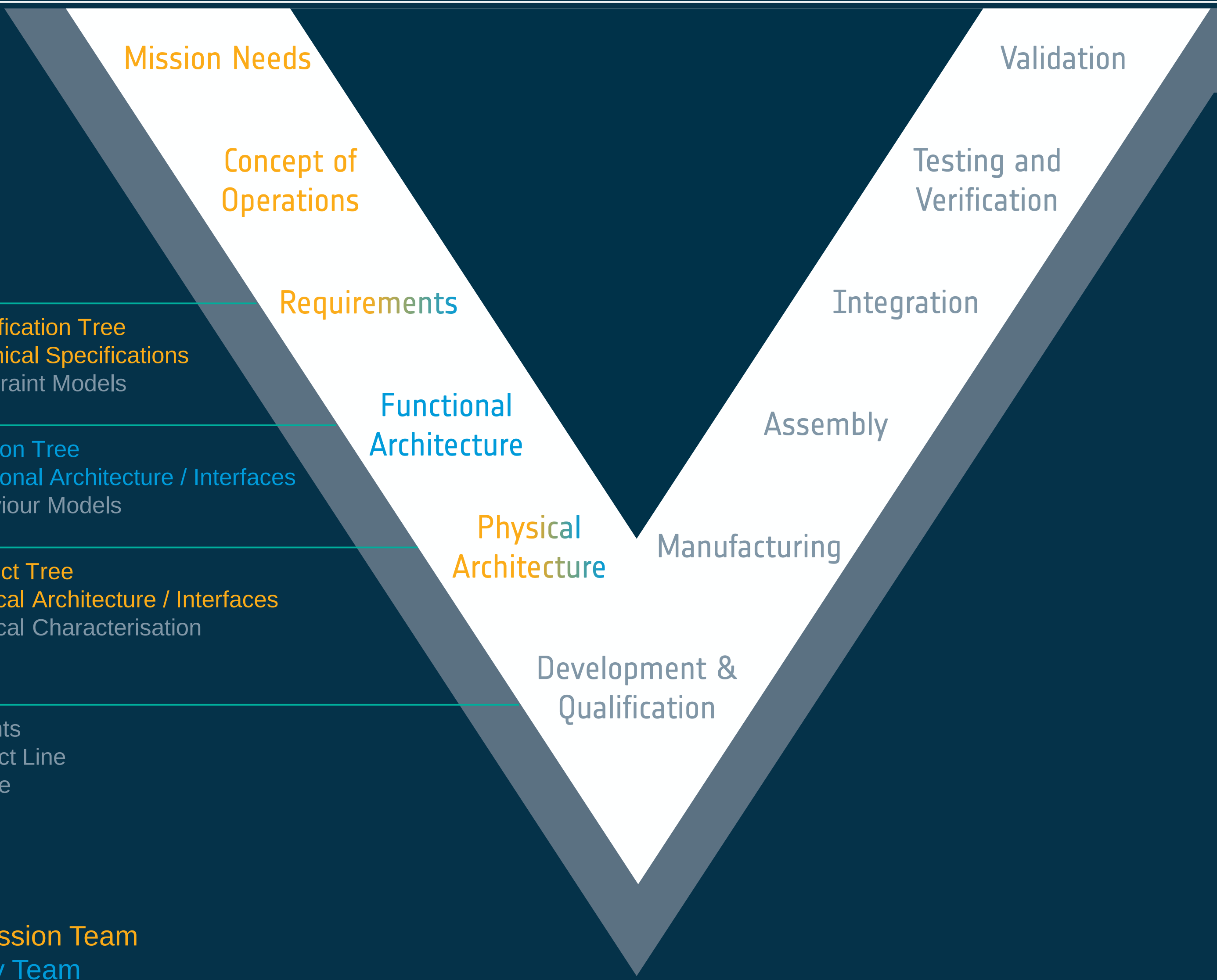
* Technical solution TBD, intend to adopt ADS MOFLT methodology within ESA/Industry teams

ESA Mission Team
Industry Team
No MBSE implementation currently foreseen

MBSE in ESA Missions EL3

Mission Context		
Directorate	HRE	
Project Phase	B1	
Launch Date	2029	
Objective(s)	European Large Logistics Lander (EL3), designed to allow a series of different missions to the lunar surface with different options for its payload.	
Contractor(s)	ADS / TAS (Competitive)	
Points of Contact	Ludovic Duvet (ludovic.duvet@esa.int)	*Sr. System Engineer*
	Alberto Gonzalez Fernandez (alberto.gonzalez.fernandez@esa.int)	*MBSE Support*

MBSE in ESA Missions EL3



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Primary Goals

ESA Mission Team

- → Single source of truth for ESA, Industry and Consortia (minimisation of explicit exchanges)
- → Requirements Engineering/Management, including generation of requirement documents from model (migration from Excel-based approach)
- → Physical architecture including parameter characterisation for reference configuration baseline
- → **Move from to model-centric review process with Industry**
- → Identify efficient exchanges with Industry of model data

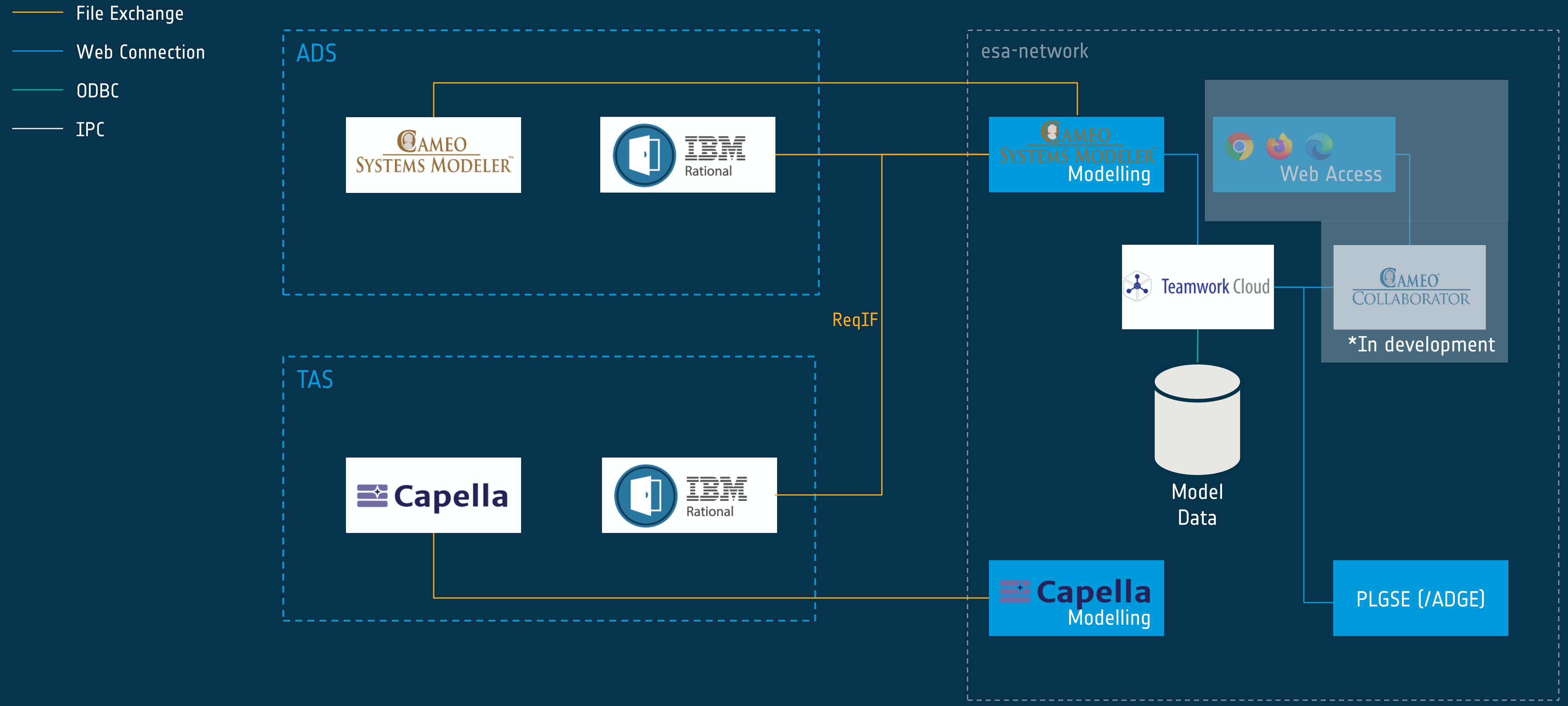
Industry Teams

- → Full traceability from requirements to functional and physical architectures
- → Functional analysis
- → System budget reporting from model

ESA Mission Team
Industry Team
No MBSE implementation currently foreseen

MBSE in ESA Missions EL3

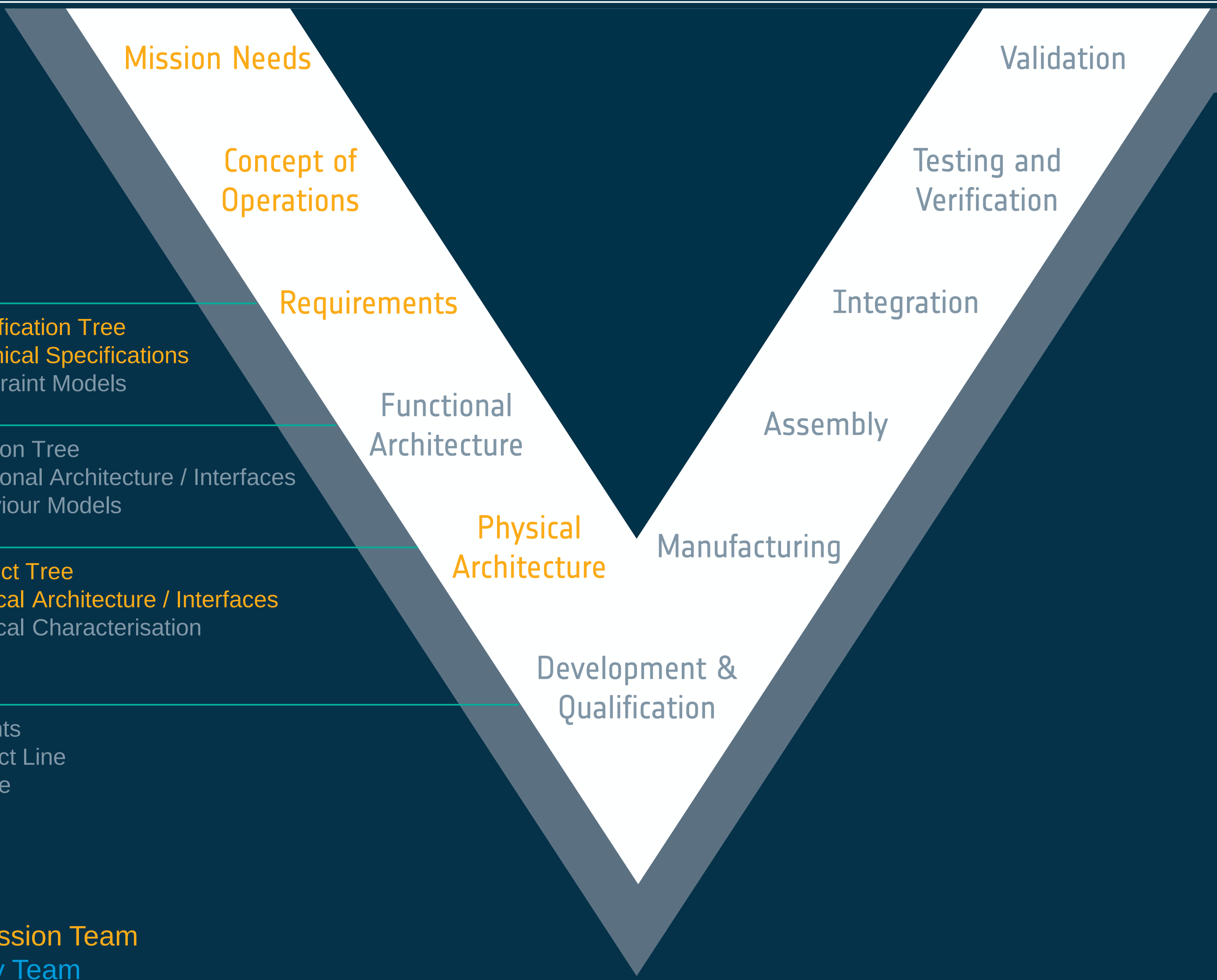
MBSE Architecture



MBSE in ESA Missions Euclid

Mission Context		
Directorate	SCI	
Programme	Cosmic Vision M2	
Project Phase	D	
Launch Date	2023 Q1	
Objective(s)	To understand the nature of dark energy and dark matter by accurate measurements of both the accelerated expansion of the Universe and the strength of gravity on cosmological scales.	
Contractor(s)	TAS-IT (Prime, SVM), ADS-FR (PLM)	
Points of Contact	Tobias Boenke (tobias.boenke@esa.int)	*Mission System Engineer*
	Jamie Whitehouse (jamie.whitehouse@esa.int)	*MBSE Support*

MBSE in ESA Missions   Euclid



Primary Goals

→ **Assess benefit and usage of MBSE in real mission in development and assess scalability**
→ Control subset of SE areas at mission level using MBSE approach

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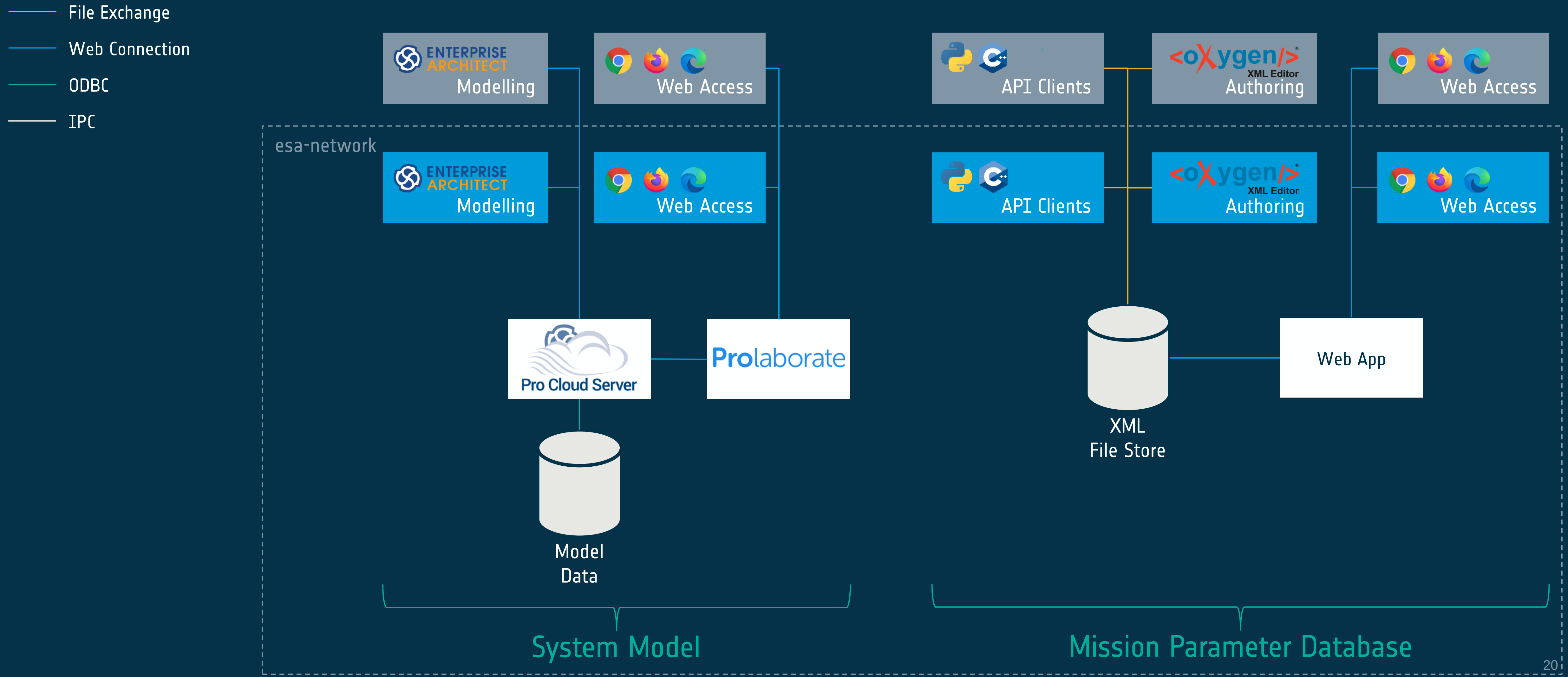
ESA Mission Team
Industry Team
No MBSE implementation currently foreseen

MBSE in ESA Missions   Euclid

MBSE Architecture



MBSE in ESA Missions   Euclid

Takeaways

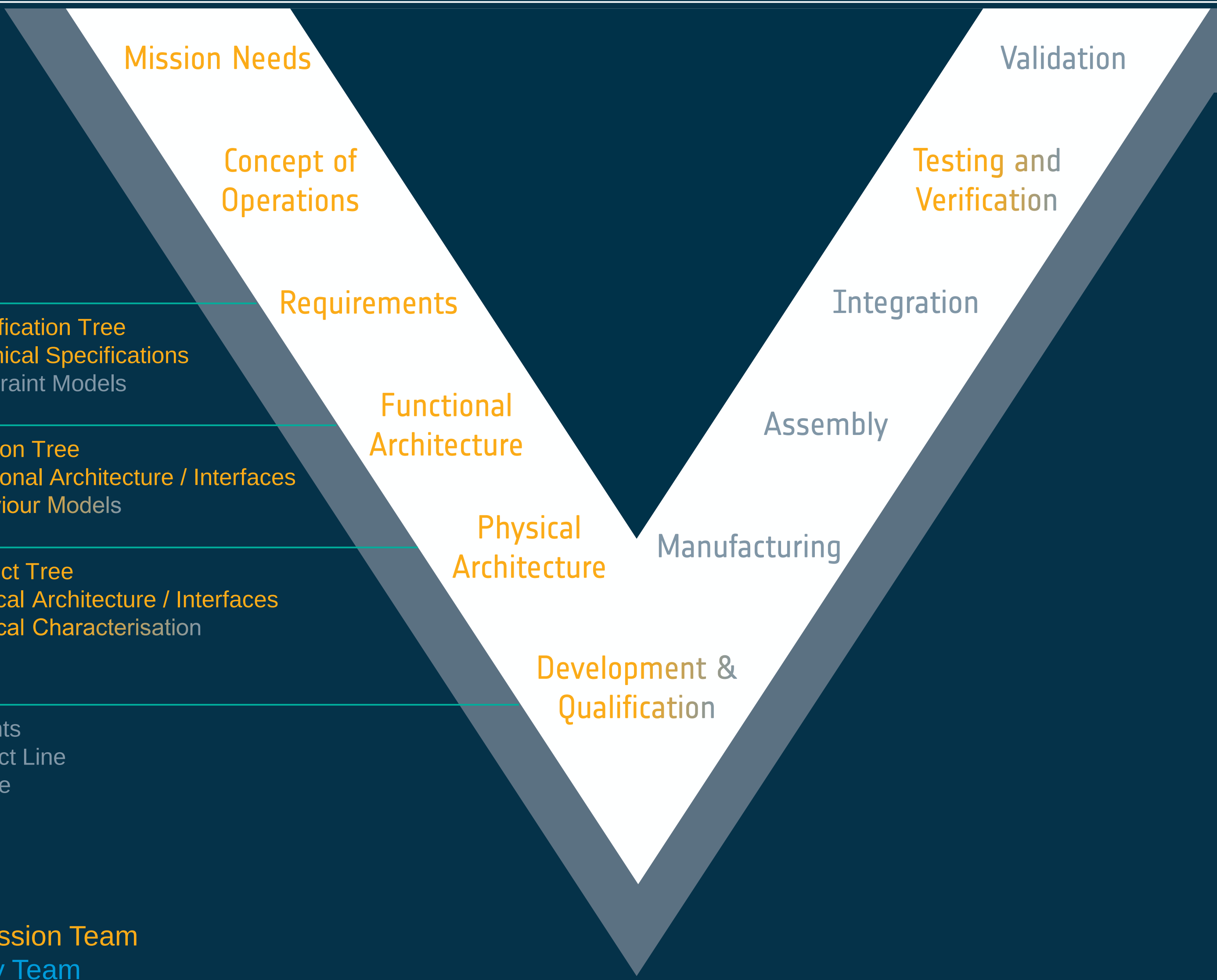
Chosen Solution	• Gradual development since **<u>2012</u>** → now forms basis of SCI MBSE Infrastructure • Cost (to maximise Science Consortia engagement) • Shared model server enables collaboration • Flexibility/customisation

Lessons Learned	• Modelling as Systems Thinking “lighthouse”
	• Define and document a clear modelling approach
	• Start early
	• Identify to what level is necessary to model
	• Facilitate sharing and usage – lower the entry barrier
	    • General problem of “intimidation” from tool
	    • **SysML too general/unintuitive for Systems Engineers → develop “ESA SysML Profile”**
	    • Need to deploy easy-to-use interfaces

MBSE in ESA Missions PLATO

Mission Context		
Directorate	SCI	
Programme	Cosmic Vision M3	
Project Phase	C	
Objective(s)	Detection and characterisation of terrestrial exoplanets around bright solar-type stars, with emphasis on planets orbiting in the habitable zone.	
Contractor(s)	OHB (Prime), TAS (FR, UK), RUAG Space	
Points of Contact	Jose Lorenzo Alvarez (jose.lorenzo.alvarez@esa.int)	*Mission and Payload Manager*
	Sami-Matias Niemi (sami.matias.niemi@esa.int)	*Mission System Performance Engineer*
	David Pena Hidalgo (david.pena.hidalgo@esa.int)	*TEC-SW Support*
	Jamie Whitehouse (jamie.whitehouse@esa.int)	*MBSE Support*

MBSE in ESA Missions PLATO



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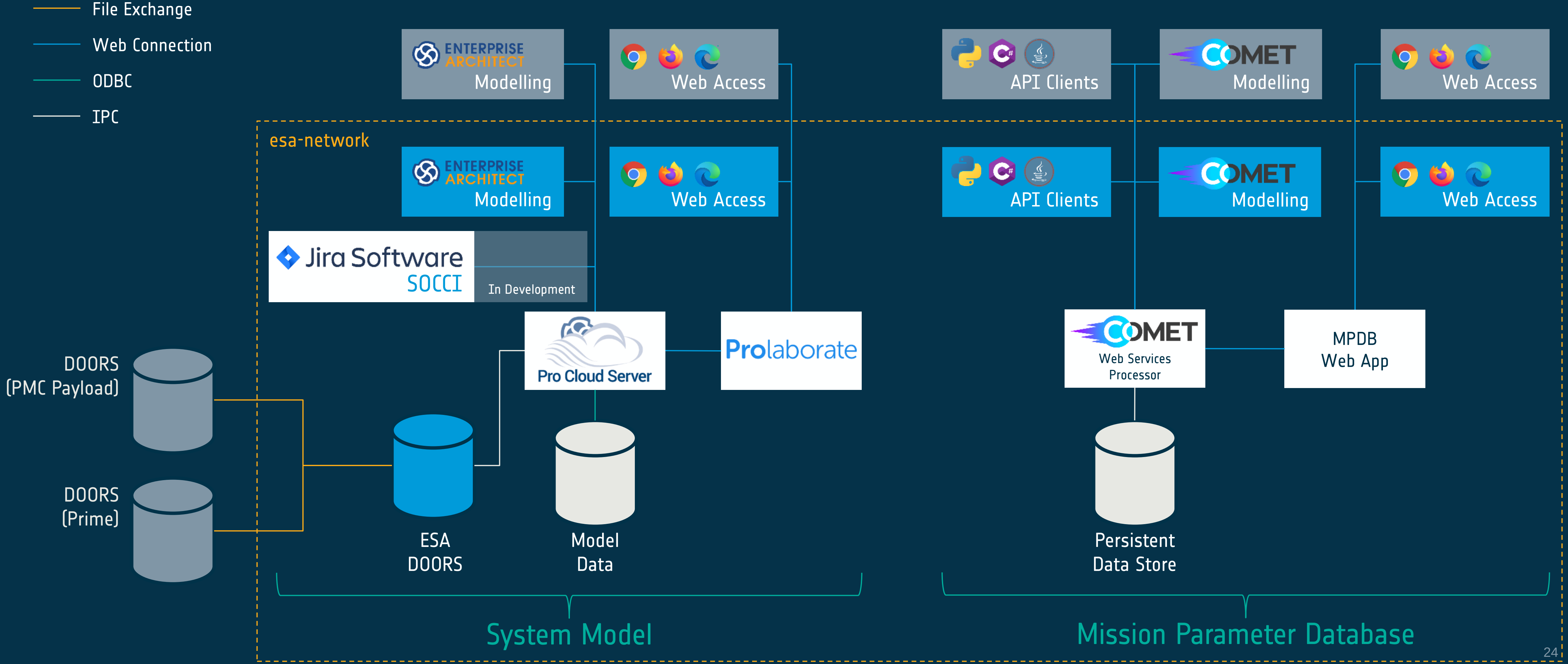
Primary Goals

- → Assess benefit and usage of MBSE in real missions in development and confirm scalability
- → Extension of previous Euclid efforts to include:
  - → Full functional modelling
  - → Interface modelling/management and ICD generation
  - → Interaction with industry
- → Management of instrument characterisation data across lifecycle (input to performance simulators)
- → **Integrate more stakeholders**
  - → **Tool-based requirement exchange (DOORS)**
  - → **SOCCI interface w/SCI-O**
  - → **Operational Ground Segment Data Exchange (GSTP w/ OPS)**

ESA Mission Team
Industry Team
No MBSE implementation currently foreseen

MBSE in ESA Missions PLATO

MBSE Architecture



MBSE in ESA Missions PLATO

Takeaways

Chosen Solution

- Reuse of heritage infrastructure
- Addition of general user “web viewers” (Prolaborate / TM-10-25 Web App)
- Move to more structured tool for mission parameter data (COMET)

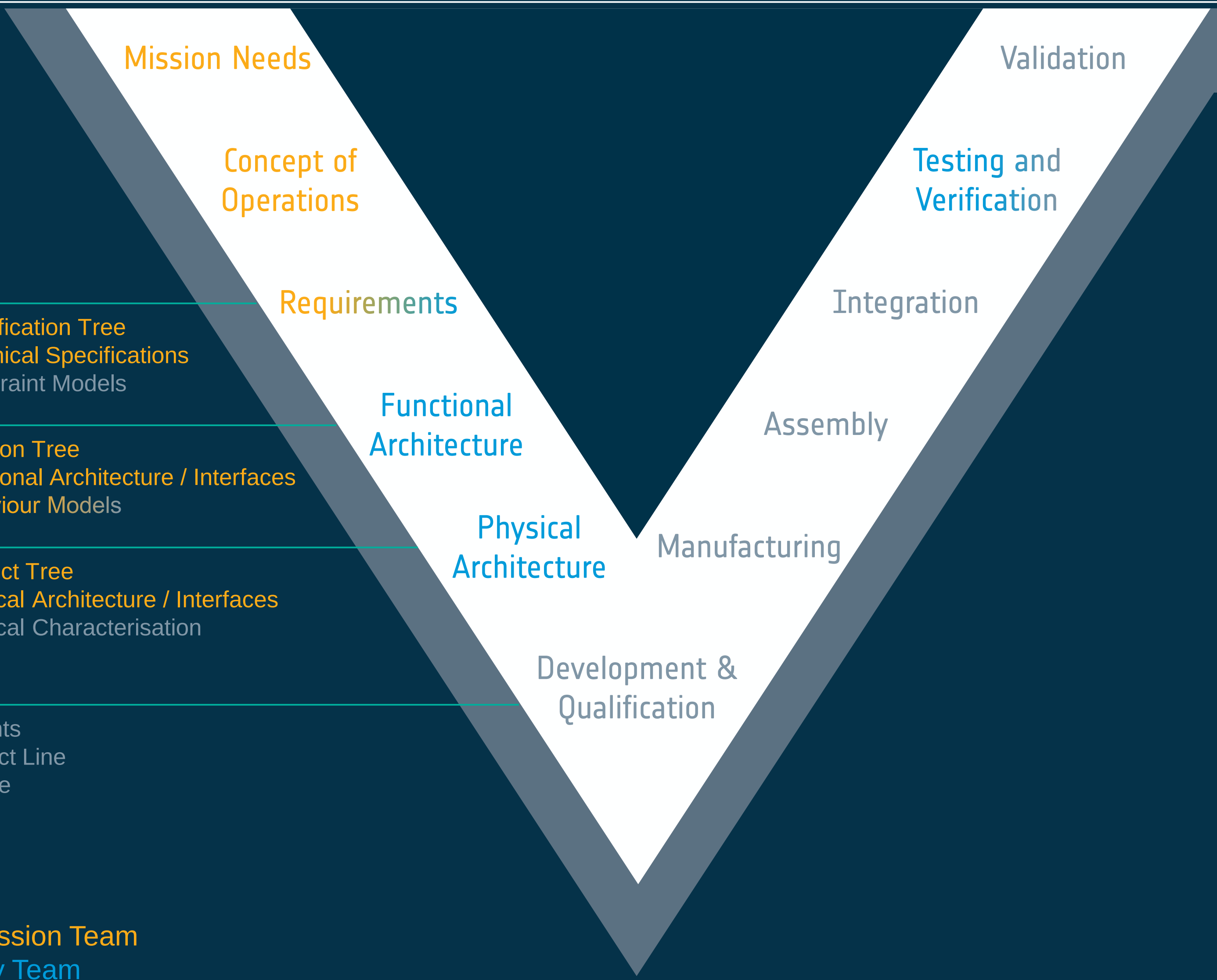
Lessons Learned

- Early training of System Engineers into MBSE approach
- Efficient control and impact assessment of changes
- Align modelling with SE processes
- **Efficient collaboration infrastructure for concurrent access by different stakeholders**
- **Emphasis on usability and interaction for external users**
- Need to formalize or standardize interface for exchange of information

MBSE in ESA Missions MSR-ERO

Mission Context		
Directorate	HRE	
Programme	Mars Sample Return	
Project Phase	B2	
Objective(s)	The Earth Return Orbiter (ERO) is a component mission of the Mars Sample Return (MSR) campaign. Following launch of Martian soil samples into orbit, ERO will capture and seal the samples in a biocontainment system. The spacecraft will then return to Earth, where it will release the entry capsule for the samples.	
Contractor(s)	ADS (Prime)	
Points of Contact	Jakob Huesing (jakob.huesing@esa.int)	*ERO CCRS Payload Engineer / MBSE Coordinator*
MBSE2021 Presentations	MBSE on MSR ERO: a use case (Jean-Baptiste Bernaudin, ADS)	Wed 29/09/2021 @ 11:45CET
	Incorporating Model Based Reviews into the life cycle of the Earth Return Orbiter (Lorenz Affentranger, ESA/ESTEC)	Wed 29/09/2021 @ 12:05CET

MBSE in ESA Missions MSR-ERO



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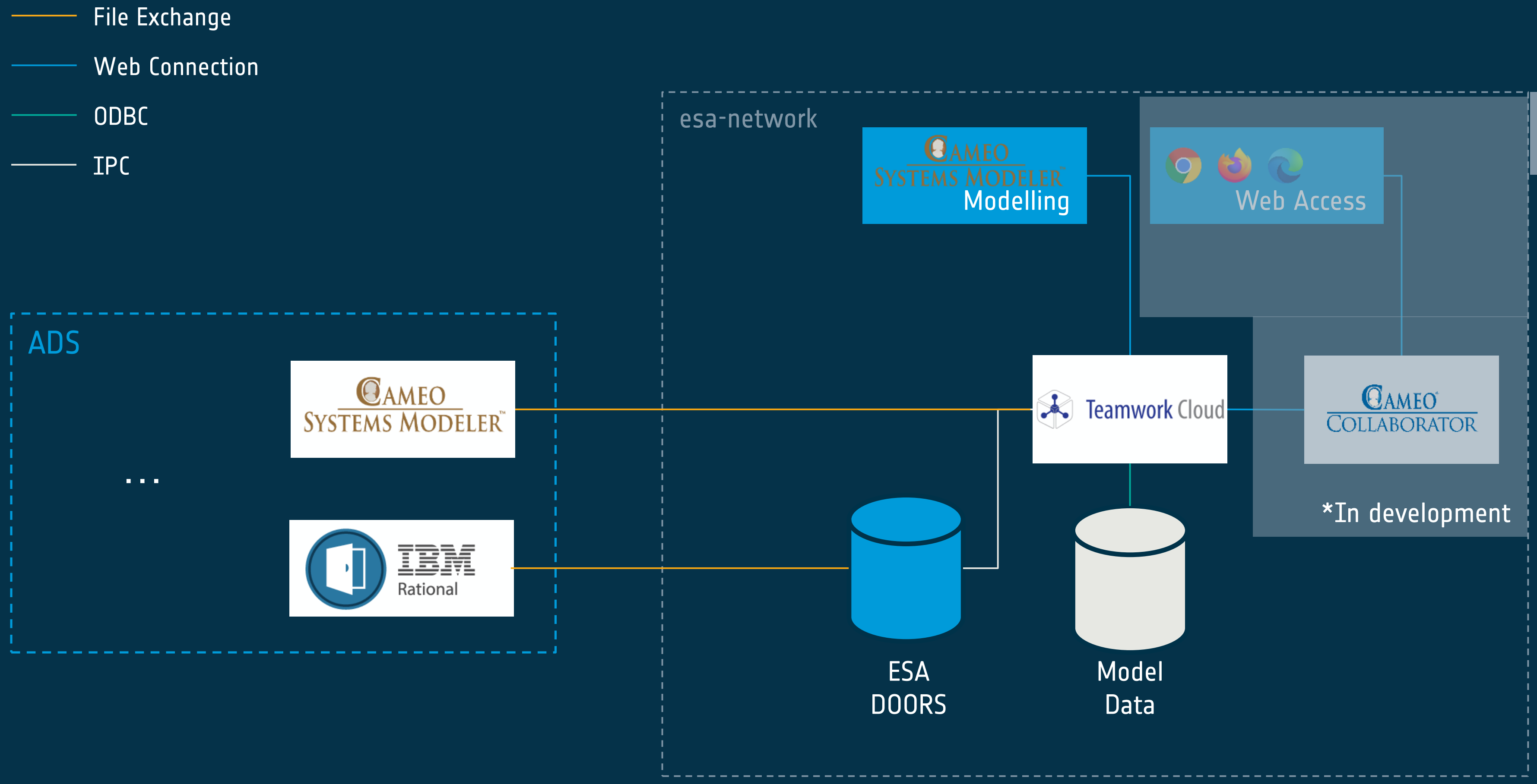
Primary Goals

- → Tight development schedule → Logical flow of requirements and traceability from an early phase on, improve impact and change analysis
- → Complex interfaces at campaign, mission and system levels → Single source of truth which can improve consistency and communication
- → **Require Industry to develop integrated System Model (so-called "Digital Integrated System Model")**
  - → Requirements Model
  - → Functional, Operational and Physical Architectures
  - → Explore integration of Interface and Verification data
  - → Full traceability from requirements to functional and physical architectures

ESA Mission Team
Industry Team
No MBSE implementation currently foreseen

MBSE in ESA Missions MSR-ERO

MBSE Architecture



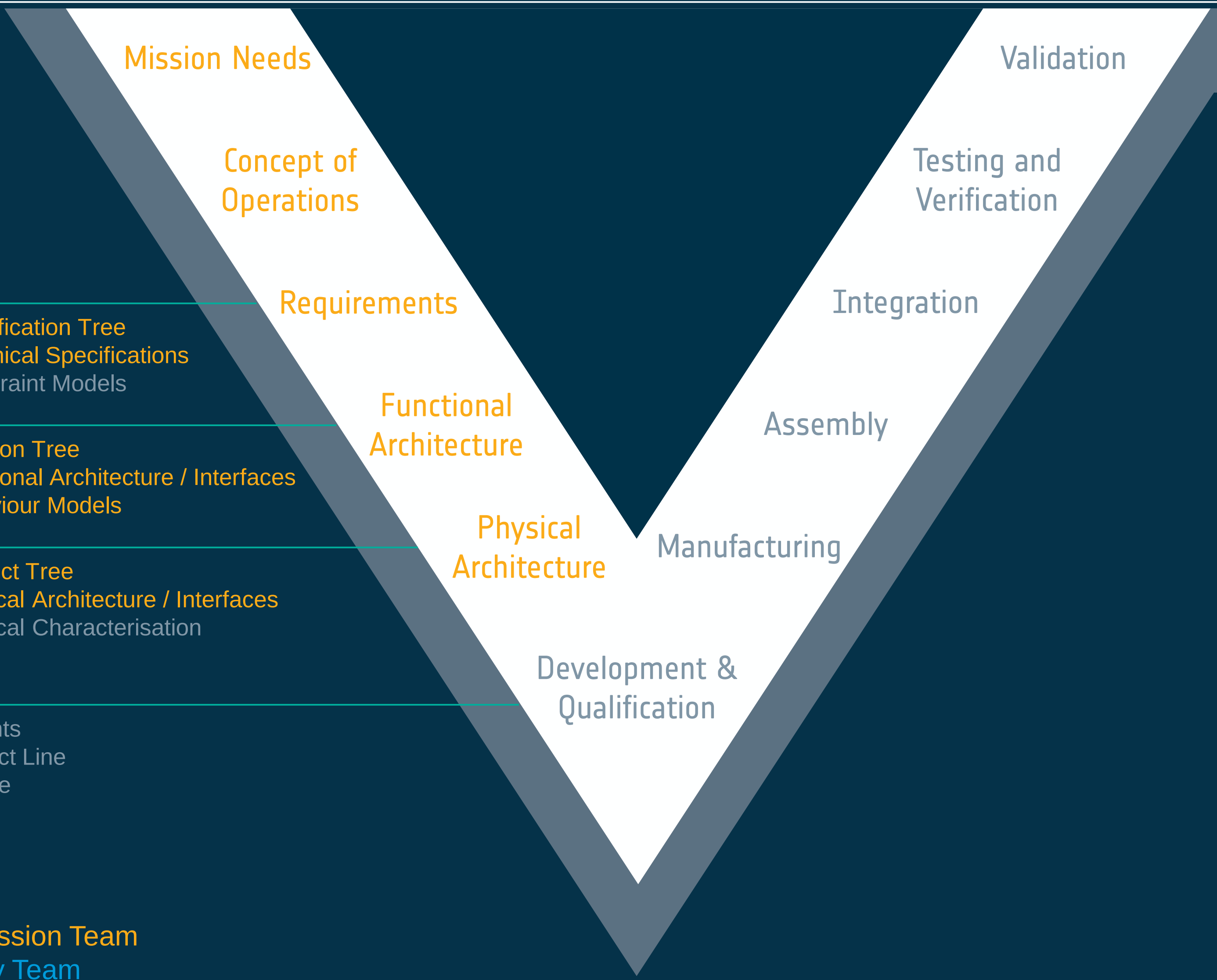
Chosen Solution

- NASA Campaign model (SysML/Cameo System Modeler) interface anticipated but dropped
- Simplify interaction with Industry by aligning systems and profiles (ADS MOFLT/SECAM)

MBSE in ESA Missions Galileo 2nd Generation (G2G)

Mission Context		
Directorate	NAV	
Project Phase	B2	
Launch Date	2024	
Objective(s)	Galileo is Europe's civil global satellite navigation constellation, currently the world's most precise satnav system, offering metre-scale accuracy to more than 2 billion users around the globe. With improved accuracy, the new generation should be able to offer decimetre-scale precision positioning to all.	
Contractor(s)	ADS / TAS	
Points of Contact	Catherine Morlet (catherine.morlet@esa.int)	*Galileo System Evolution Architecture Engineer*
	Alberto Gonzalez Fernandez (alberto.gonzalez.fernandez@esa.int)	*MBSE Support*

MBSE in ESA Missions — Galileo 2nd Generation (G2G)



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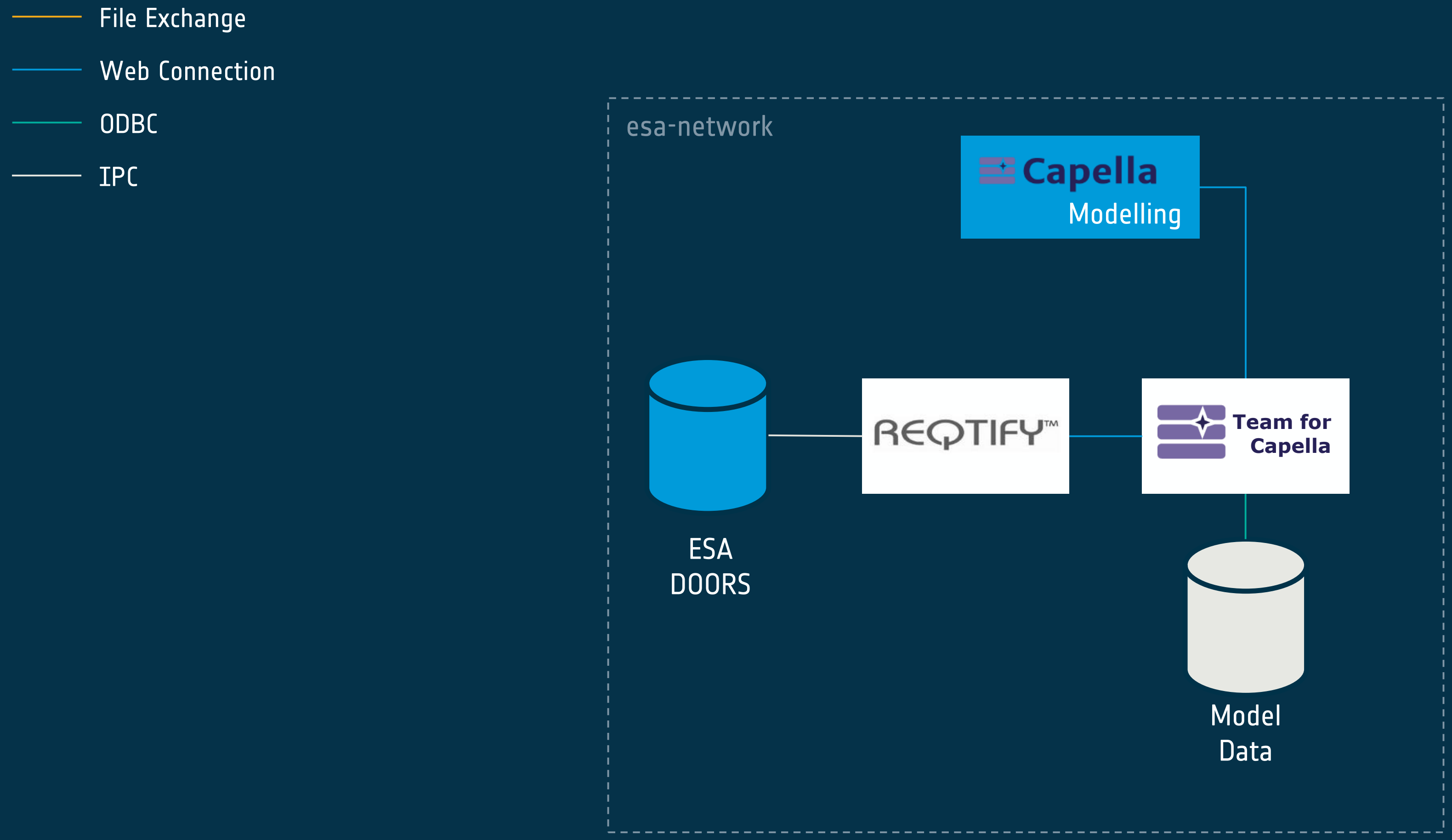
Primary Goals

- → Requirements traceability with existing DOORS modules and system model
- → Functional analysis of system, including identifying critical scenarios
- → Justification of system design through model artefacts
- → **Management of classified and unclassified information in a system model environment**

ESA Mission Team
Industry Team
No MBSE implementation currently foreseen

MBSE in ESA Missions Galileo 2nd Generation (G2G)

MBSE Architecture



Chosen Solution

- TAS provides technical support → use of applications and methodologies used in TAS projects
- End-to-end requirements traceability from Reqtify tool
- Model server (Team for Capella) allows for collaborative work with model

MBSE in ESA Missions   Galileo 2nd Generation (G2G)

Takeaways

Lessons Learned	• Methodology alone is not sufficient: must enforce consistent and correct modelling processes • Understand what information to model and why: easy to overextend modelling
Open Points	• **Maintaining coherent information across classified and unclassified models (iteration between black ←→ white box models)**

MBSE in ESA Missions Conclusions

Increasing interest and adoption in missions

Collaboration across ESA and Industry

Interoperability and exchange remains a key issue

Heterogeneous approach across ESA mission teams

MBSE in ESA Activities Completed Activities*

*Highlights, not exhaustive

Activity Name	Point of Contact	Contractor(s)	Objective
MBSE_Implement	Maxime Perrotin	- Creotech Instruments - N7 Space	Learn how to put model-based systems/software co-engineering into practice to achieve more effective development of smallsat. Example application: HyperSat – Polish national small satellite. In particular focusing one use case: preparation of thermal control subsystem and thermal balance test.

Common Information Platform (CIP) / Model-based Requirements Verification Lifecycle (MARVL)	Quirien Wijnands	- RHEA Group
		- ADS
		- ScopeSet
		- 3DSE
			• A platform that facilitates model-based information exchange through the project life-cycles between:
			  • interdisciplinary / multifunctional information exchange
			  • multiple stakeholders (e.g. ESA, Airbus)
			• A platform that supports traceability through the project lifecycle
			• Support technical oversight and formal review process

Paperless Ground Segment Engineering (PLGSE)	Marcus Wallum	Telespazio Vega DE	• Activity to develop a Ground Segment Systems Engineering Framework (GSEF) for the Operational Ground Segment. • Focus on the development of a model centric implementation of the ECSS-E-ST-70C processes. • Strong emphasis on user interface, to separate the user from the underlying Data Model. • Euclid mission considered as a use case.

MBSE in ESA Activities Ongoing & Planned Activities*

*Highlights, not exhaustive

Activity Name	Point of Contact	Contractor(s)	Objective
System Architecture for a System Factory (SASyF)	Andreas Jung	- GMV - ADS - OHB - TAS	The specification and architecture of a Model-Based System Engineering infrastructure for Space System Engineering, the so-called “system factory”, covering all phases of a space system development, by applying the Arcadia method.
SAVOIR Electronic Data Sheets (EDS)	David Perillo	- CGI - ADS - OHB - TAS	• Replace paper ICDs with machine-readable mechanism to describe interfaces of electronic units on-board spacecraft (Sensors, actuators, instruments, other units) • Automatic generation of artefacts (documents, code, etc.) from interface descriptions
Overall Semantic Modelling for Systems Engineering (OSMOSE)	Serge Valera	- GMV (Governance) - GorillaIT (Ontology) - ESA - ADS - OHB - TAS	• Converge towards a Single European Ontology (and define what it is) for Space Projects • Enable exchange of data from any two modelling languages via a translation layer governed by the Single European Ontology for Space Projects • Iterative development of overarching Space System Ontology, starting from a “skeleton” ontology drawn from existing work in e.g. ECSS-E-TM-10-25/23, ESA SysML Profile

MBSE in ESA Activities   Ongoing & Planned Activities*

*Highlights, not exhaustive

Activity Name	Point of Contact	Contractor(s)	Objective
TASTE	Maxime Perrotin	Large number of companies over 15 years (>20000 commits across 18 repositories)	Open-source tool-chain for model-based embedded software development. • A tool-chain targeting heterogeneous, embedded systems, using a model-centric development approach • A laboratory platform for experimenting new software-related technologies, based on free, open-source solutions • A process supporting the creation of systems using formal models and automatic code generation
Advanced Digital Ground Segment Engineering (ADGE)	Marcus Wallum	- CGI - Solenix - Space Cube	To build a mature, modern, fully web-based platform that enables a model-based approach for ground segment engineering, to be used by mission and subsystem engineers to design, develop, validate and support operations of multi-mission and mission-specific ground segments.
Generative Concurrent Design	Marcel Verhoef	- RHEA Group - OHB Systems - Siemens	Solution for generative engineering that supports multi-user concurrent decision making. By creating and analysing multiple architecture variants, the design space for early concurrent trade-off studies can be significantly increased, leading to potentially better solutions. This solution will bridge between COMET capabilities (concurrent design, E-TM-10-25 standard) and Siemens Dx (generative engineering, integration with multidisciplinary behavioural simulation)

MBSE in ESA Activities Ongoing & Planned Activities*

*Highlights, not exhaustive

Activity Name	Point of Contact	Contractor(s)	Objective
Digital Engineering Hub Pathfinder	Marcel Verhoef	- RHEA Group - OHB Systems - Astos Solutions - Open Engineering	• To ensure seamless and timely sharing of engineering information between all disciplines in space system development teams, focusing on early lifecycle phases 0, A and B. • To foster an interoperable and future-proof, (community-) open-source, evolvable ecosystem in which evermore capable data-exchange solutions become available to run European space projects effectively. • To ensure that – in the future – the data exchange capabilities will scale from the early lifecycle phases to the complete space system lifecycle.
Model-Based Engineering Hub	Marcel Verhoef	Contract 1: - ADS Friedrichshafen - ADS Bremen - SpaceCube - ScopeSET Contract 2: - RHEA Group - TAS France - OHB Systems - DE Konsult	• Enable (semantically correct) exchange of data between all stakeholders • Single European Ontology for Space Projects will be the basis for data exchange between tools • Global version and configuration control • Design of data storage/exchange TBD (Federated, centralised, etc.)

MBSE in ESA Activities   Other Activities/Programmes

ARTES Sunrise Programme

- Early phase studies for TIA programme
- Funding allocated to aid SMEs exploring MBSE for in-orbit servicing and deorbiting missions
- MBSE2021 Presentation: MBSE in an SME Context (Rhiannon Jenkins) (Wed 29/09/2021 @ 11:05CET)

OSIP (Over 20 Activities – 5 appearing in MBSE2021)

- Digital Twin for (AOCS) hardware unit modelling: Definition of TRL scale
- Application of MBSE to reverse-engineer OPS-SAT and improve OPS-SAT2
- Extending Ground Segment and Operations digital integration in early phase 0/A studies
- Science AOCS/GNC with SysML
- Harmonising MBSE standards into ECSS
- A Distributed Ledger approach to MBSE
- System Engineering Models meet Knowledge Graphs
- Model Based Avionics
- Paperless space system development: the long-awaited MBSE showcase
- Enabling model-based testing and automated test case generation for ground segment data systems
- Bridging the gap between ground segment system and software models and supporting IT infrastructure
- MYCID: Systematic search of optimal space system missions design using set-based concurrent engineering based on models
- End-to-End Space Systems Engineering Portal
- Integration of the COMPASS and TASTE toolsets (bridging the gap between architectural level design and system implementation and deployment in MBSE)
- TeePee4Space - Perform structural analyses on an heterogeneous and distributed set of models: showing the benefits of digital continuity at an extended enterprise level to systems engineers
- Enabling continuity: from design to operations
- Space to Ground Interface Control Model
- Artificial intelligence (AI) and natural language processing (NLP) to support space engineering activities
- EasyMod or how to facilitate the acceptability of the MBSE to systems engineers.
- Early in the loop MBSE assessment of electronic availably for Nano/Micro satellite mission
- FAMOUS improvement: transfer of academic knowledge to semantic interoperability
- MBSE towards Semantic Data Lakes and Machine Learning support for the engineering process
- Validating SEDS as a bridge between hardware and software models

Thank you for your attention,

and enjoy the MBSE2021 Conference!