VSD Final Presentation

Introduction and Overview

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15.05.2012

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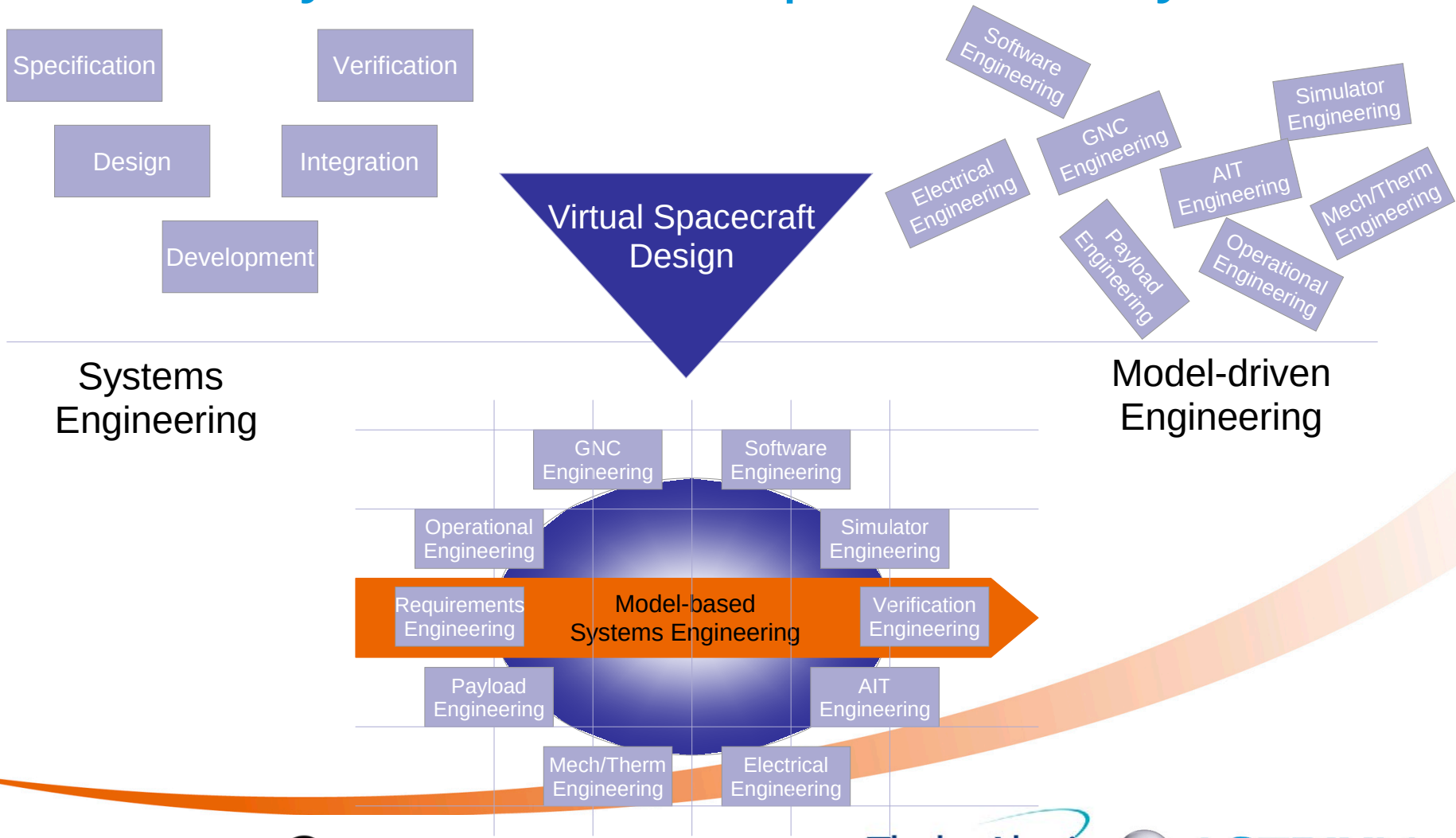
VSD should demonstrate the value & feasibility of MBSE for Space Industry



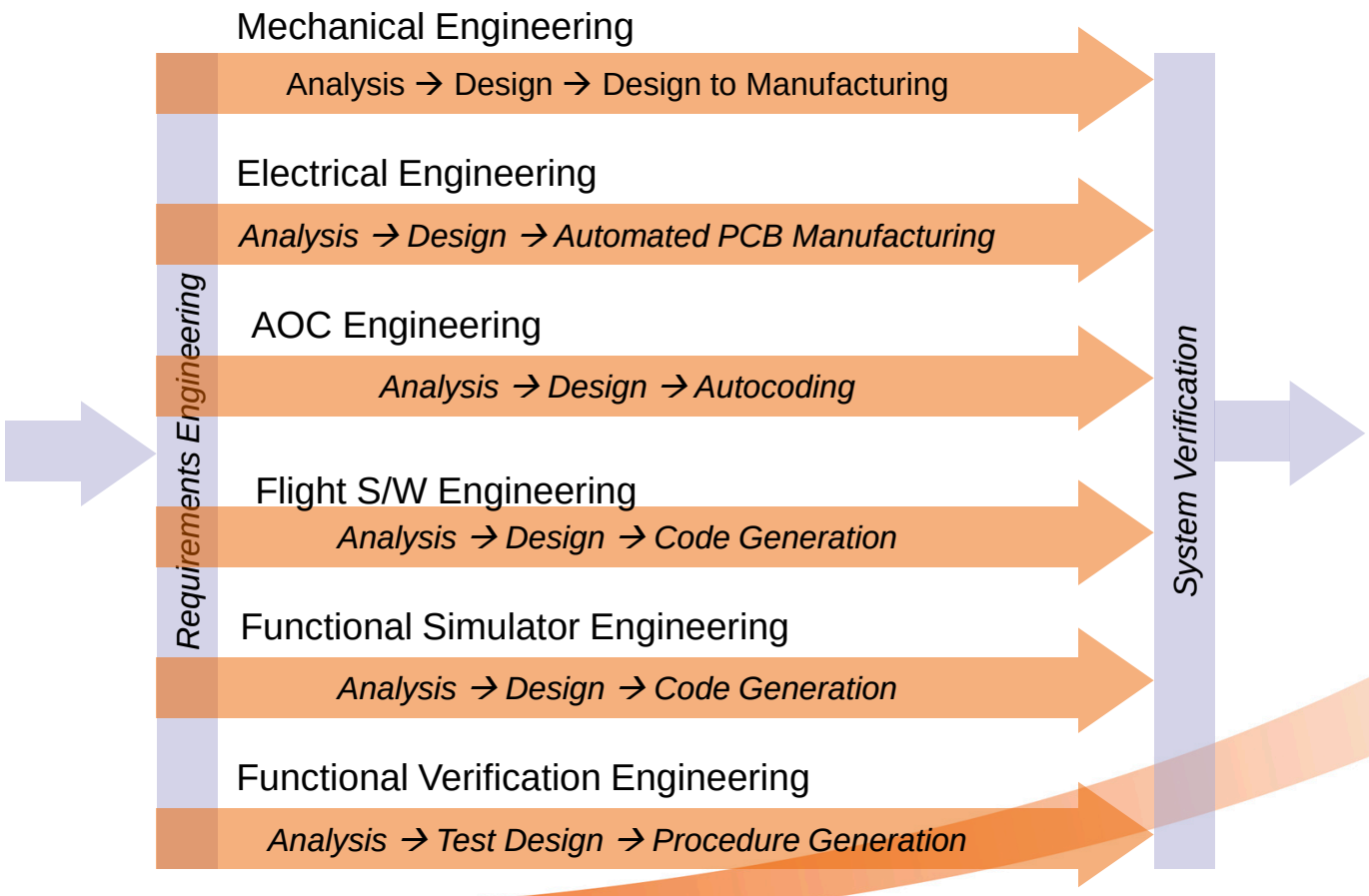
System Engineering has a key role to manage the complexity

- SE is an approach for complex system development integrate different views to “systems thinking”
  - Information flow along customer supplier chain
  - Data sharing of engineering disciplines
  - Interface between management and engineering
  - Along the life-cycle
- The System Engineering approach has been applied successfully since the beginning of space programs
- Standardization of SE best practices in ECSS allow a consistent application across programs

The context for Systems Engineering gets increasingly challenging

- General project complexity
  - Increasing technical complexity on programs
  - Additional programmatic constraints
  - Changing business models
  - Shrinking budgets
- Re-use strategies and product-orientation
- Agile process methods through life-cycle
- Rapidly emerging, high sophisticated tools to support model-based engineering on discipline level

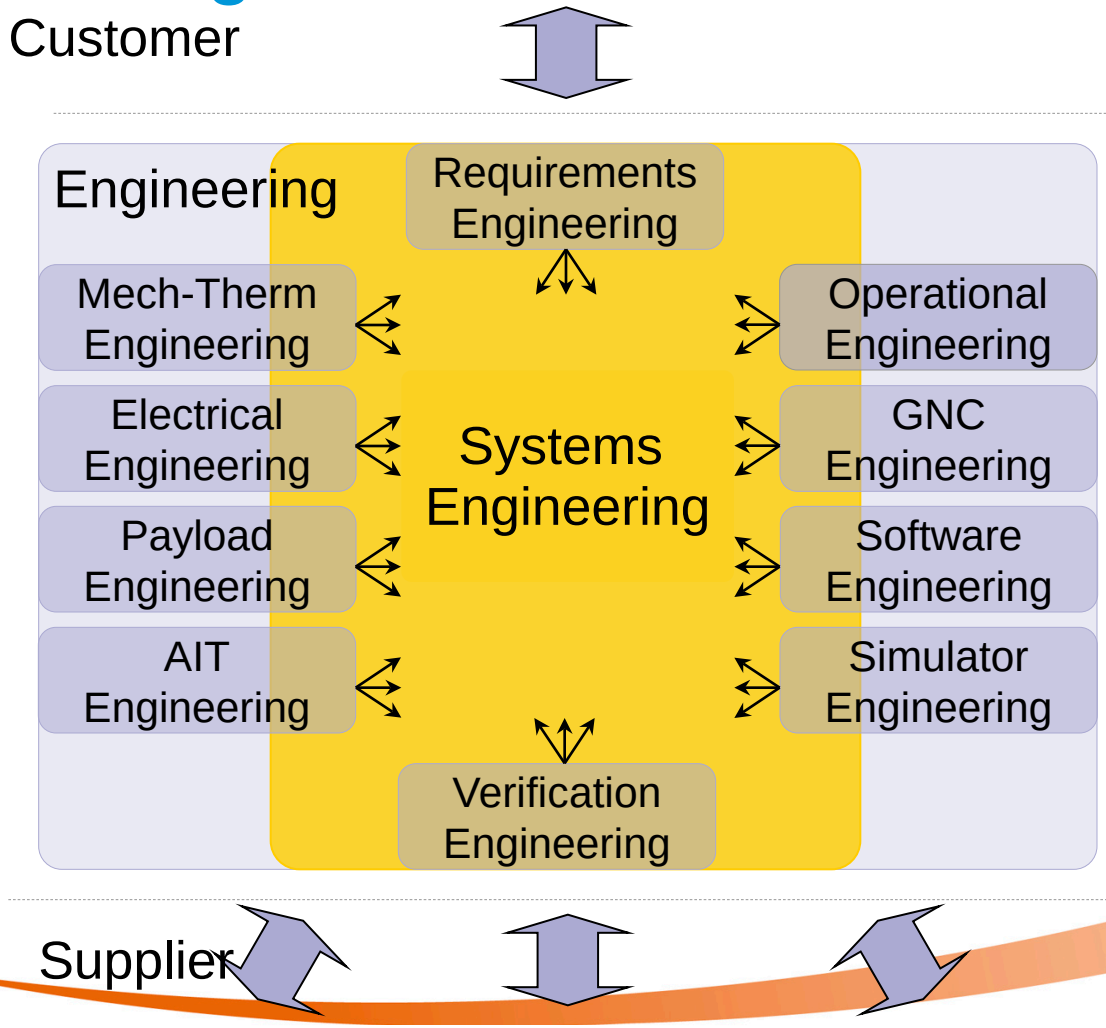
Model-driven / -based Engineering is a standard approach across all disciplines



Improving efficiency of SE process through application of models: MBSE

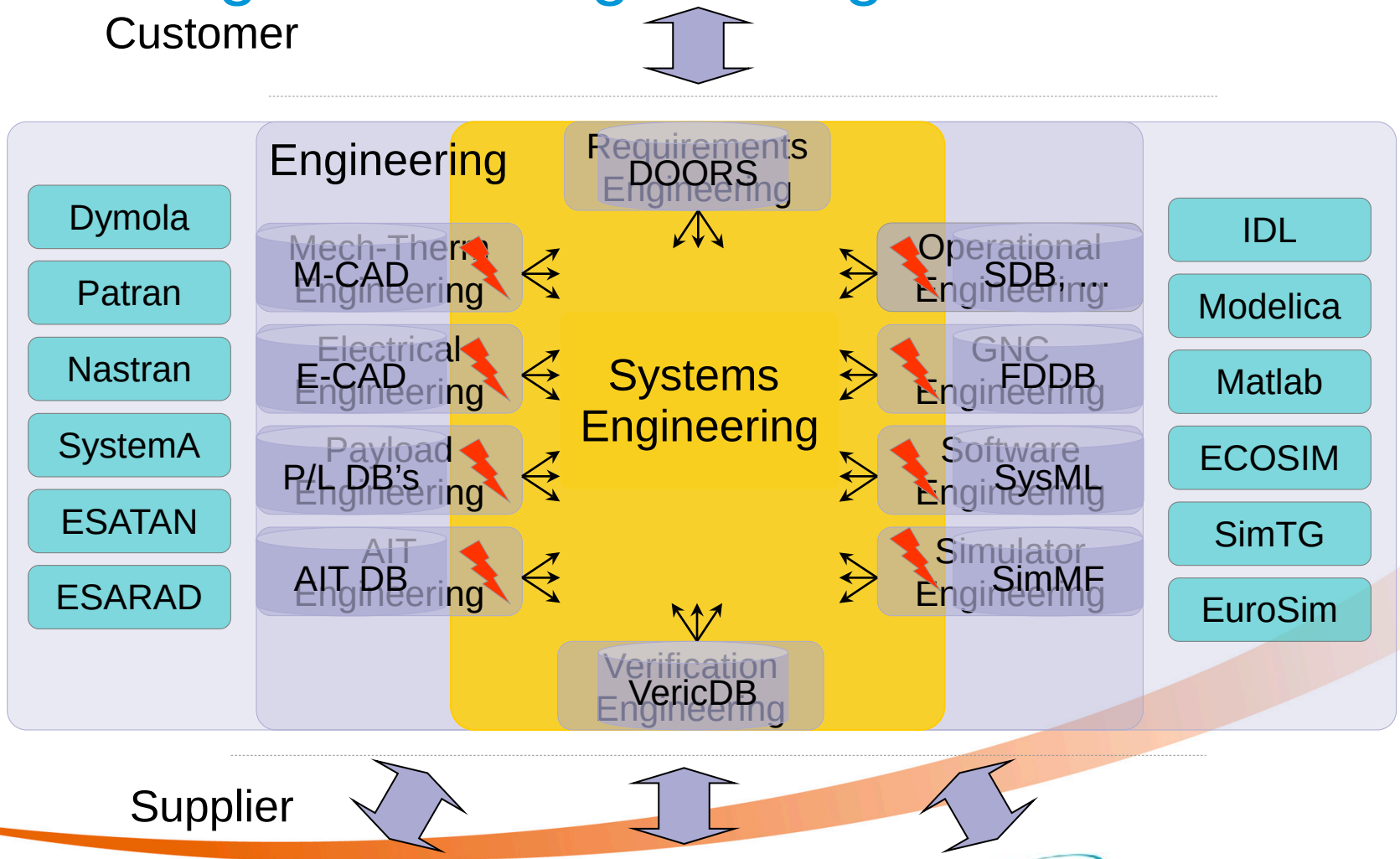
- Emerging modeling techniques need to be applied to improve integration and coordination role of SE
- Turning SE into MBSE is requires consideration of
  - Interfaces to various parties – coherently share of information
  - Heterogeneous tools and models on engineering disciplines
  - Multiple views forming the “system level”
  - Support agile process models (i.e. concurrent modification)
  - Established PLM solutions
  - Overall trends in tools, technology and standardization
- Virtual Spacecraft Design was to prototype MBSE for space programs to demonstrate benefits

For the integrated “systems view” SE is to integrate data from different sources

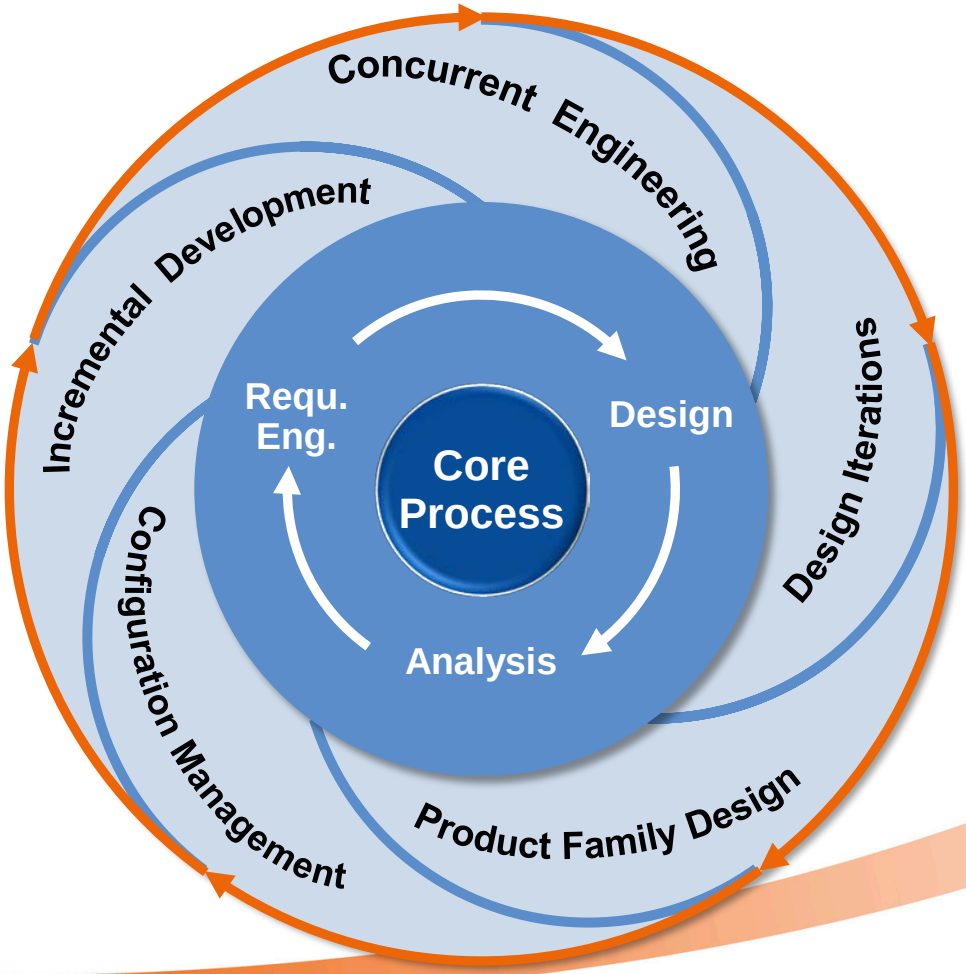


- Data exchange along customer supplier chain (“extended enterprise”)
- Data sharing among disciplines
- Data ensuring design coherence (“traces”)
- Key design driver, performance & trade

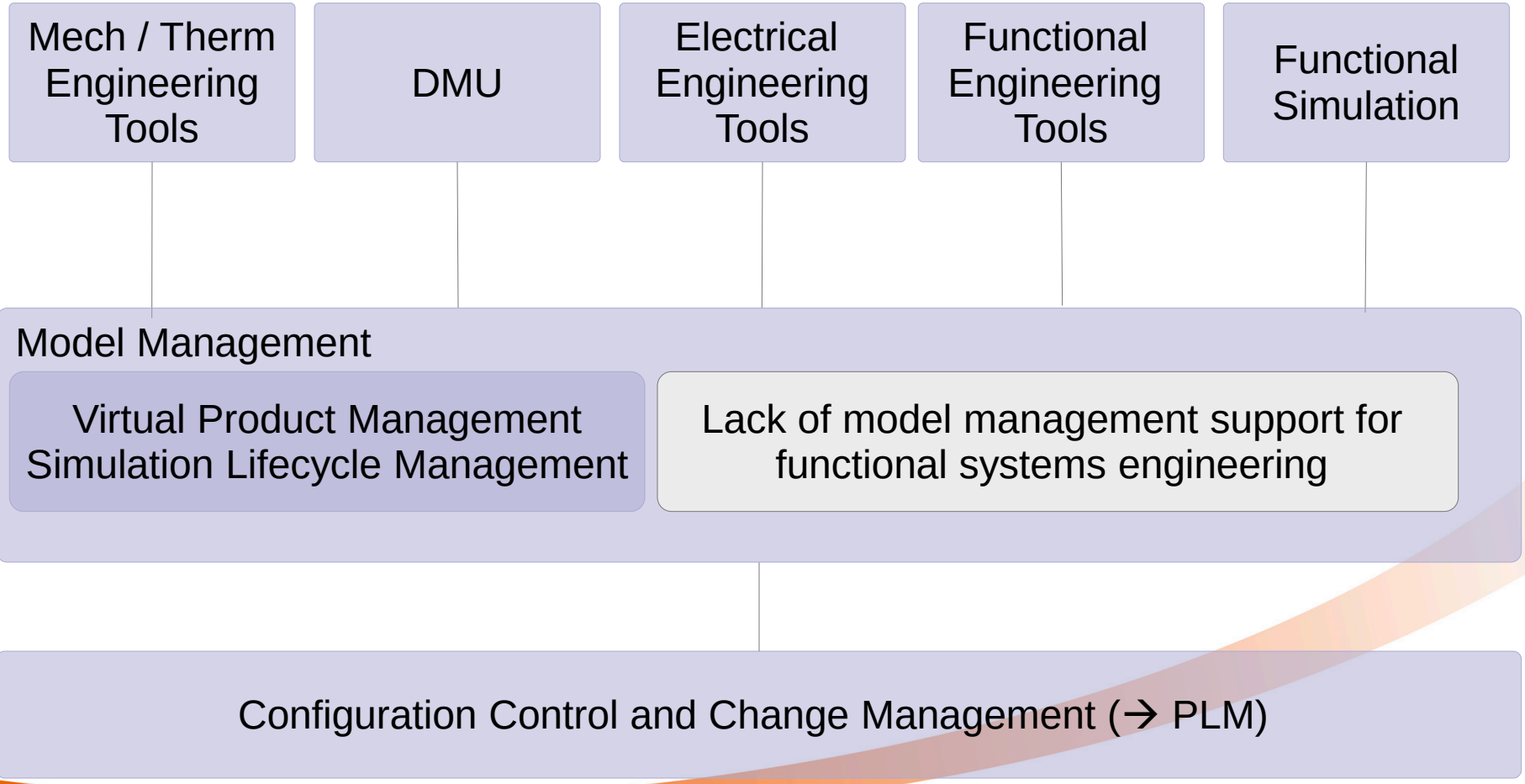
MBSE requires integration of heterogeneous engineering tools



Agile process methods are “turning the wheel” and need to be supported by MBSE

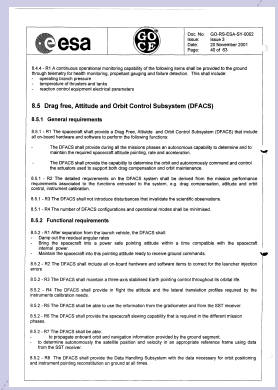


Established overall PDM context, lacking support of model management



Various disconnected manually defined “views” form the system model

Requirements



8.4.4 - R1 A continuous operational monitoring capability of the following items shall be provided to the ground through telemetry for health monitoring, propellant gauging and failure detection. This shall include
- thruster valve operation
- temperature of the valves and tanks
- reaction control equipment electrical parameters

8.5 Drag free, Attitude and Orbit Control Subsystem (DFACS)

8.5.1 General requirements

8.5.1 - R1 The spacecraft shall provide a Drag Free, Attitude and Orbit Control Subsystem (DFACS) that include all on-board hardware and software to perform the following functions:
- The DFACS shall provide during all the missions phases an autonomous capability to determine and to maintain the required spacecraft attitude pointing, rate and acceleration.
- The DFACS shall provide the capability to determine the orbit and autonomously command and control the actuators used to support both drag compensation and orbit maintenance.

8.5.1 - R2 The detailed requirements on the DFACS system shall be derived from the mission performance requirements associated to the functions entrusted to the system, e.g. drag compensation, attitude and orbit control, instrument calibration.

8.5.1 - R3 The DFACS shall not introduce disturbances that invalidate the scientific observations.

8.5.1 - R4 The number of DFACS configurations and operational modes shall be minimized.

8.5.2 Functional requirements

8.5.2 - R1 After separation from the launch vehicle, the DFACS shall:
- Damp out the residual angular rates
- Bring the spacecraft into a power safe pointing attitude within a time compatible with the spacecraft power budget
- Maintain the spacecraft into this pointing attitude ready to receive ground commands.

8.5.2 - R2 The DFACS shall include all on-board hardware and software items to correct for the launcher injection errors

8.5.2 - R3 The DFACS shall maintain a three-axis stabilised Earth pointing control throughout its orbital life

8.5.2 - R4 The DFACS shall provide in flight the attitude and the lateral translation profiles required by the instruments calibration needs.

8.5.2 - R5 The DFACS shall be able to use the information from the gradiometer and from the SST receiver

8.5.2 - R6 The DFACS shall provide the spacecraft slewing capability that is required in the different mission phases.

8.5.2 - R7 The DFACS shall be able:
- to propagate onboard orbit and navigation information provided by the ground segment,
- to determine autonomously the satellite position and velocity in an appropriate reference frame using data from the SST receiver.

8.5.2 - R8 The DFACS shall provide the Data Handling Subsystem with the data necessary for orbit positioning and instrument pointing reconstitution on ground at all times.

Operational Modes

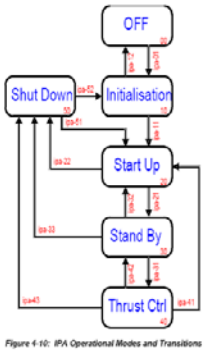
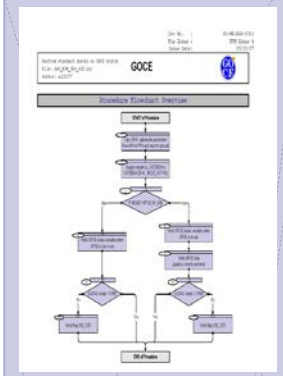
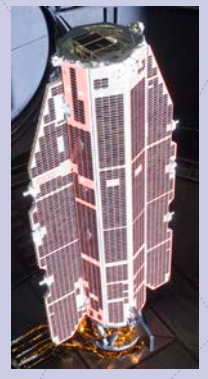


Figure 4-10: IPA Operational Modes and Transitions

Operational Proc



Configuration



Integration Procedure

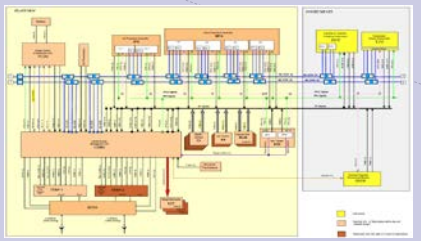
Verification Matrix

7.1.1 Platform SM Verification Matrix

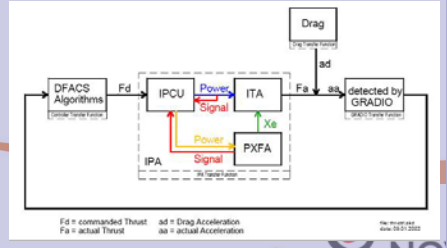
The following table summarises the key requirements and verification method versus the SM configuration:

Requirement Category	Equipment- Level	Platform- Level	Spacecraft- Level
Function	-	-	-
Performance	-	-	-
Leakage	-	-	-
Alignment	-	T	T
Thermo Elastic Stability	-	A	T
Interfaces	T, I	T, I	-
Physical Properties (mass, CoG)	T [1]	-	T
Quasi Static Load	-	-	T
Vibration	-	-	T
Acoustic	-	-	T
Separation Shock	-	-	T
Thermal Verification (TV/TB Test)	-	-	-
EMC- R & C	-	-	-
ESD	-	-	-
Magn. Moment	-	-	-
Radiation environment	-	-	-
Oxygen	-	-	-

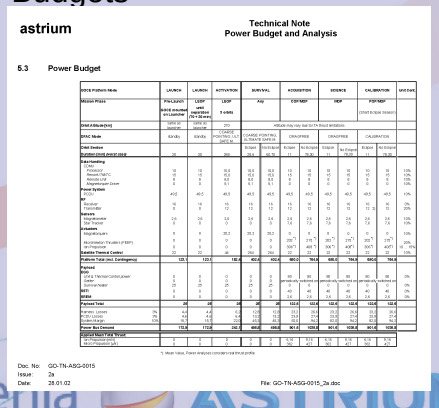
Electrical Interfaces



Functional Architecture



Budgets



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Technical Note
Power Budget and Analysis

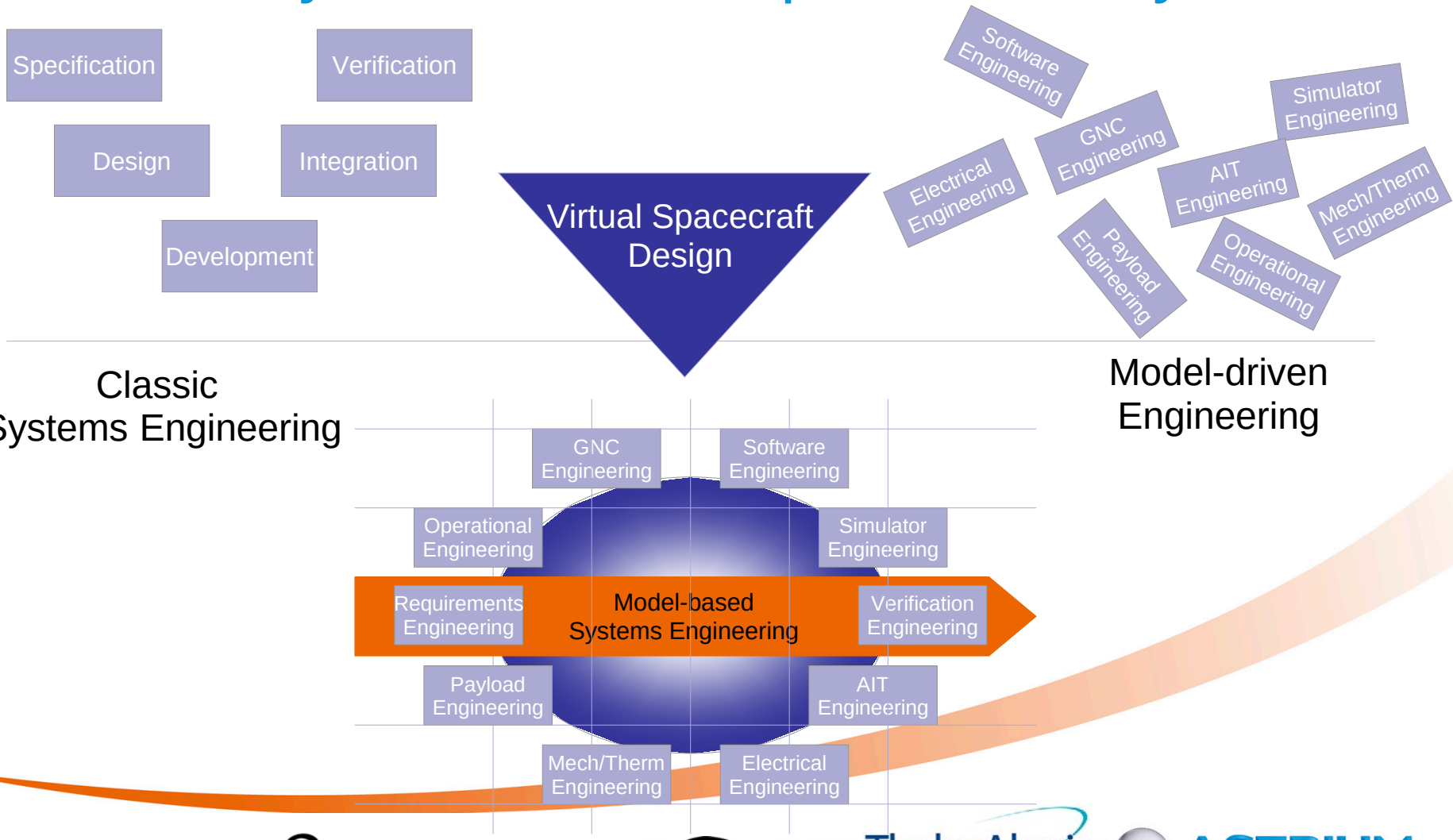
5.3 Power Budget

Manual process to ensure coherence between views

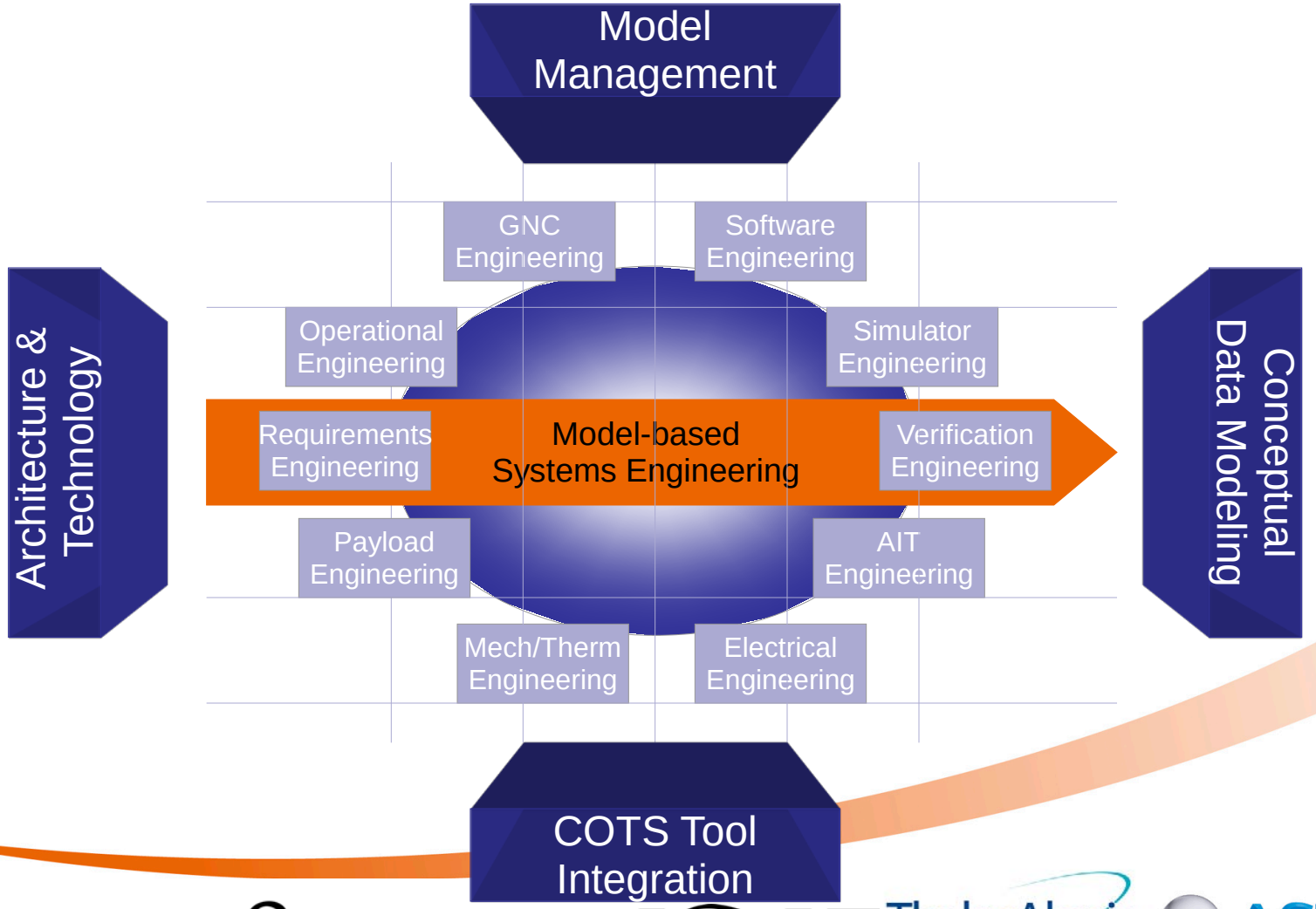
Consideration of current trends in tools, technologies and standardization

- ISO STEP 10303 (STEP) failed to deliver a generic, affordable solutions for SE
- General observation on COTS tools applied
  - High costs for licensing, maintenance and customization
  - Limited capabilities and support for integration
  - PDM tools provide integration solution – i.e. good support for document management
- Emerging SysML as graphical modeling language
- Emerging open source solutions for model management

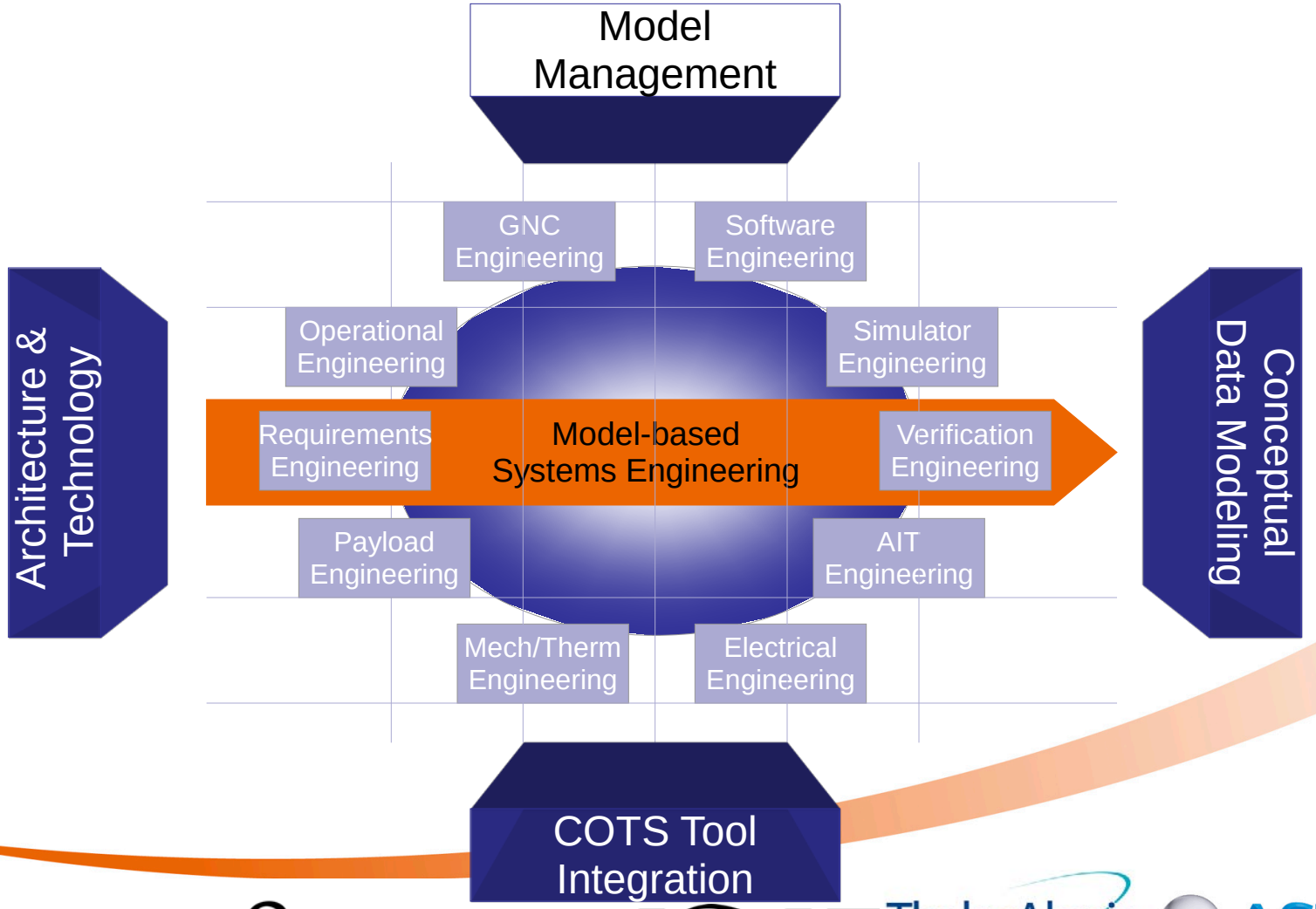
VSD should demonstrate the value & feasibility of MBSE for Space Industry



VSD developed a solid technological basis to enable MBSE



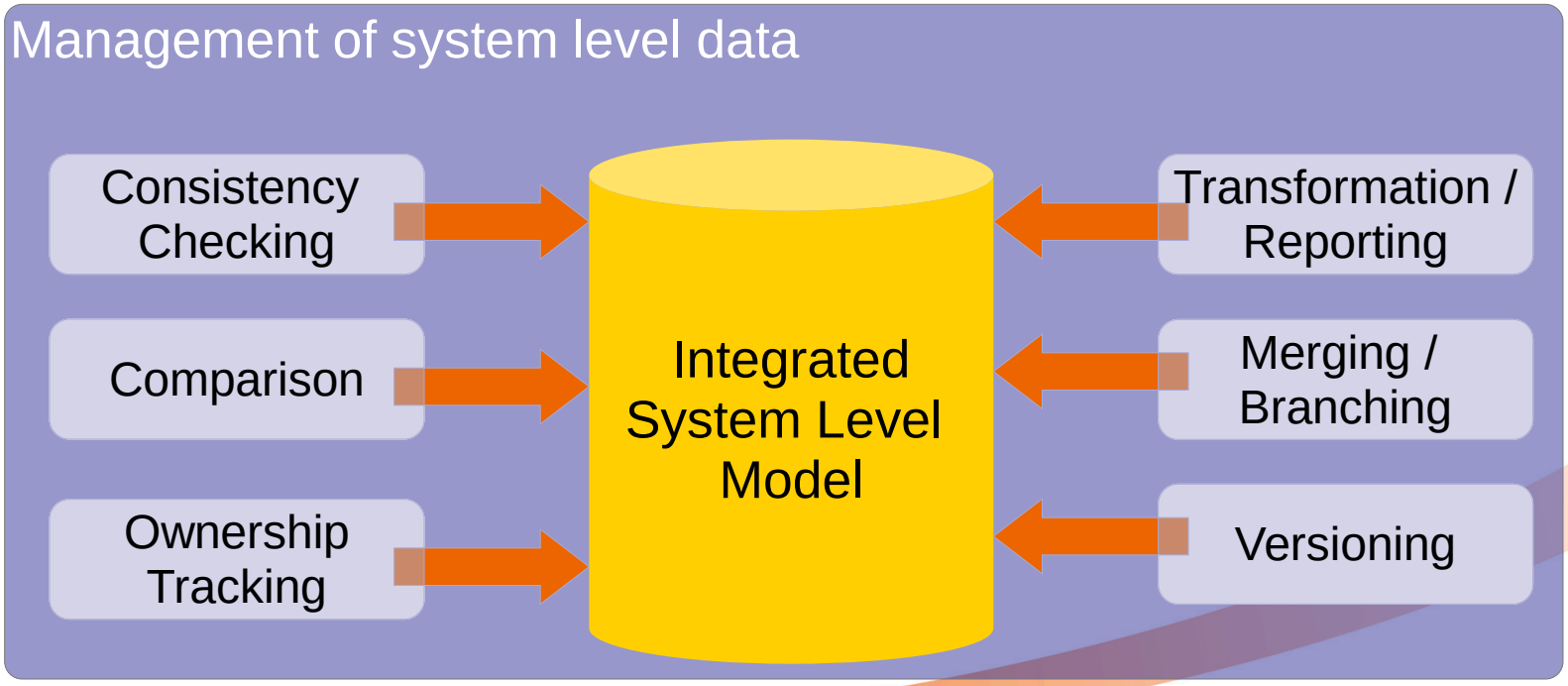
Functions performing the integration of models, ensuring the coherence



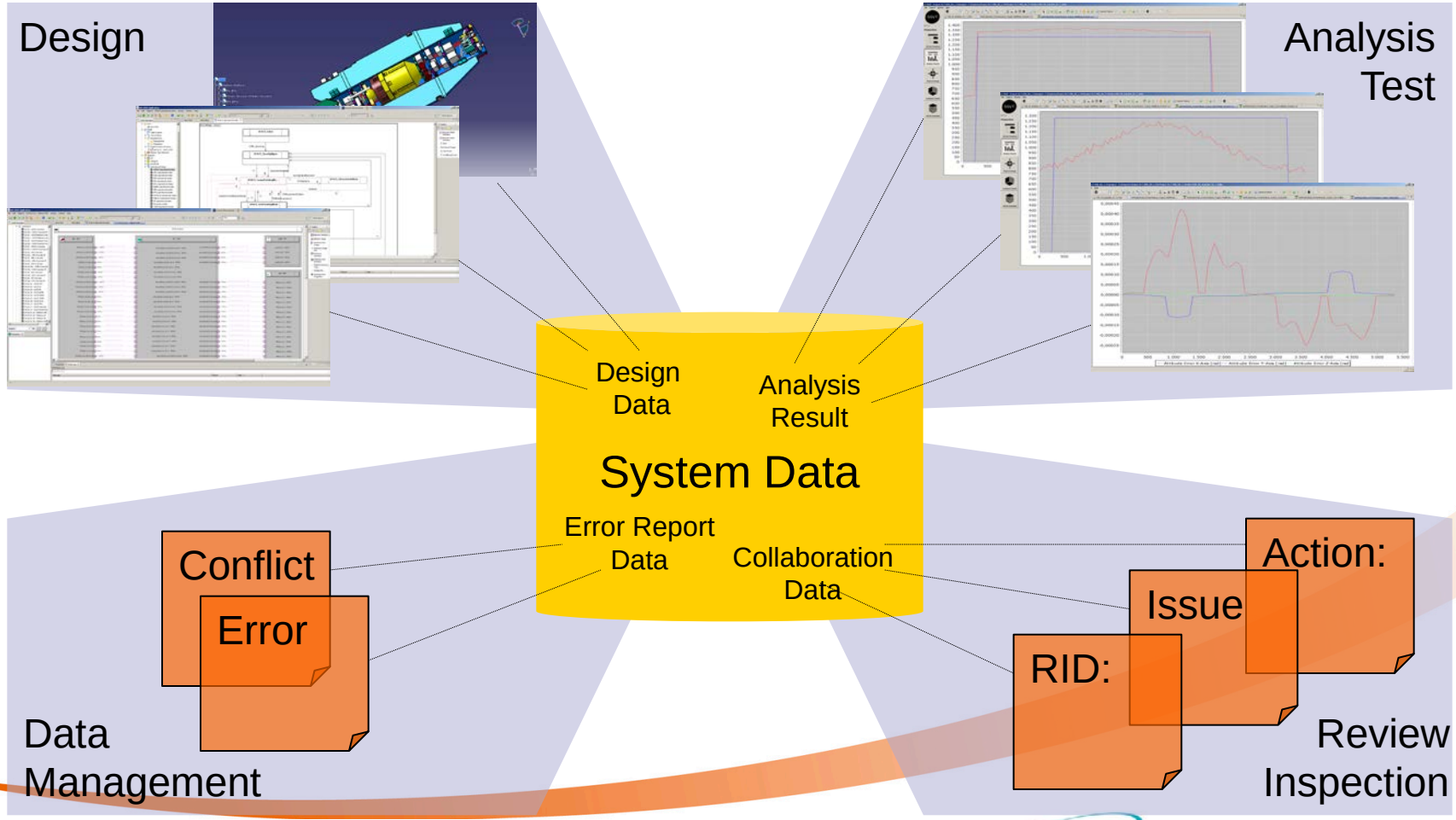
Functions enabling the model integration, in an agile process environment

- Dealing with models requires functions assuring that the models are managed in the correct way
  - Consistency, completeness, versioning, …
- Engineering tools have completely different approaches for model management
  - Difficult to manage “integrated system model” in a distributed fashion in current engineering tools
- Dedicated functions are required allowing the management of the integrated system model
  - i.e. “stitching”, consistency, dealing with frequent updates, …

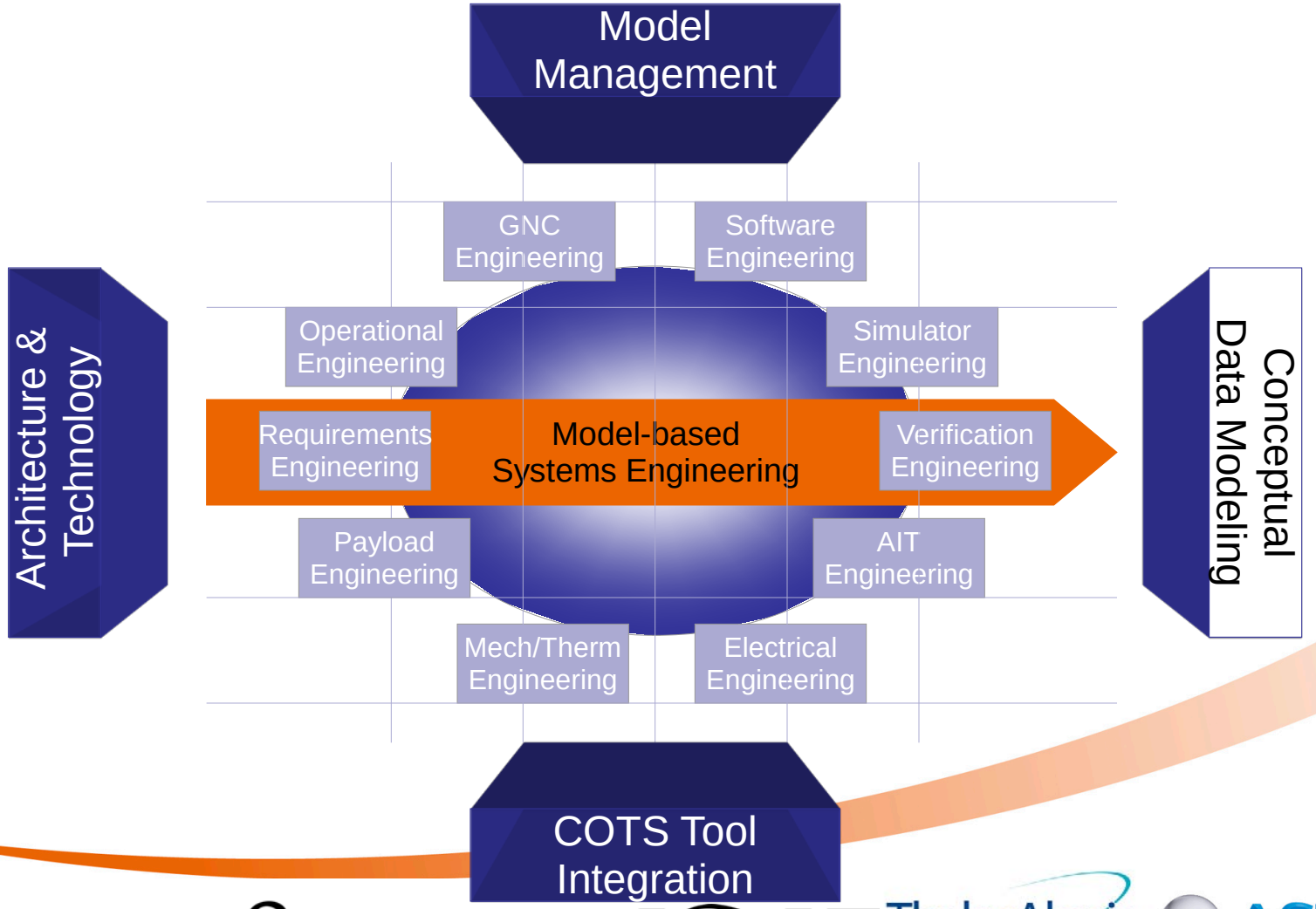
Shared system level data will be managed by functions of the shared repository



Model management as a comprehensive approach to integrate various processes



Conceptual data model, the basis for the integration of the system model integration



Comprehensive specification of data forming „system level model“ is required

- Backbone of MBSE is integrated “system level model”
- Internal data structure (→ data model) of different engineering tools is completely incompatible
  - “system level model” is formed of aspects from different tools
  - Very difficult to stitch different aspects to a coherent model
- The conceptual data model for space SE specifies the data structures required for the integrated “system level model”
  - Semantic (→ meaning of data) integration platform

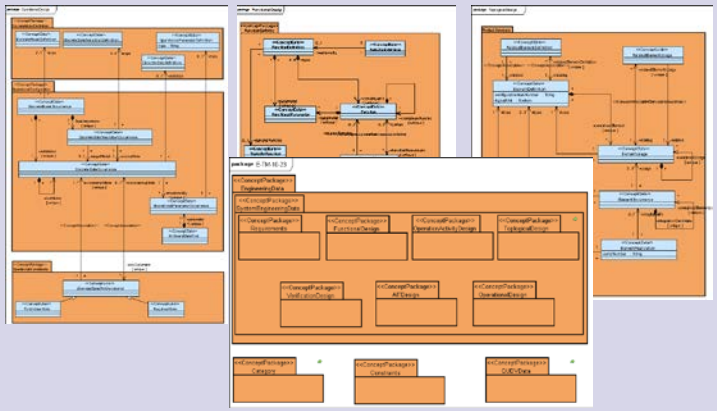
Key requirements driving the engineering for the conceptual data model

- Concepts captured in the data model shall be directly derived from actual process artefacts
- Conceptual data model shall be “exhaustive” – all items need to be covered
- Shall enable model-driven S/W engineering for the backend of the infrastucture
- Shall be robust against changes of the technologies used for the implementation

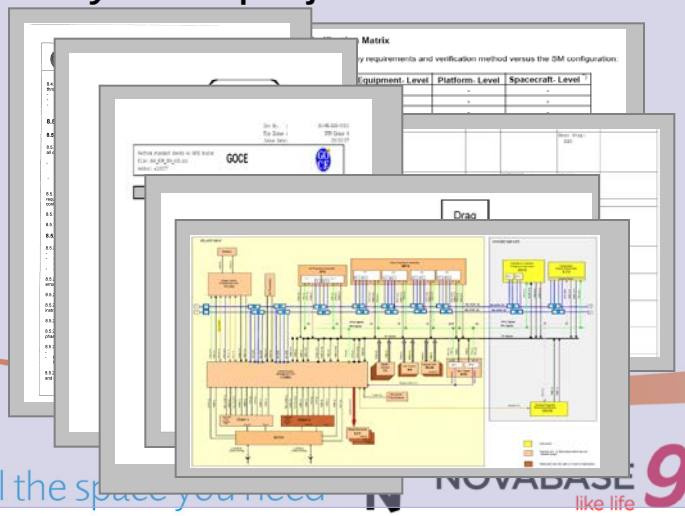
Data Model is derived from actual project models, views, spreadsheets, …

Standards

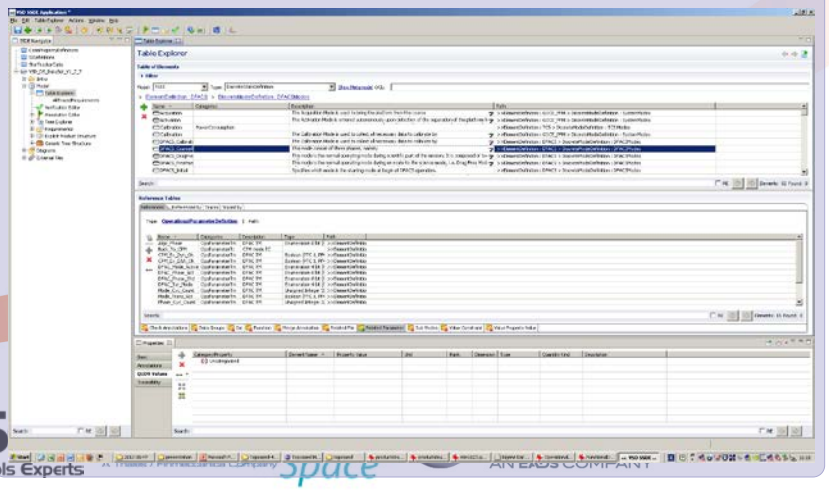
Definition of Data Model in UML



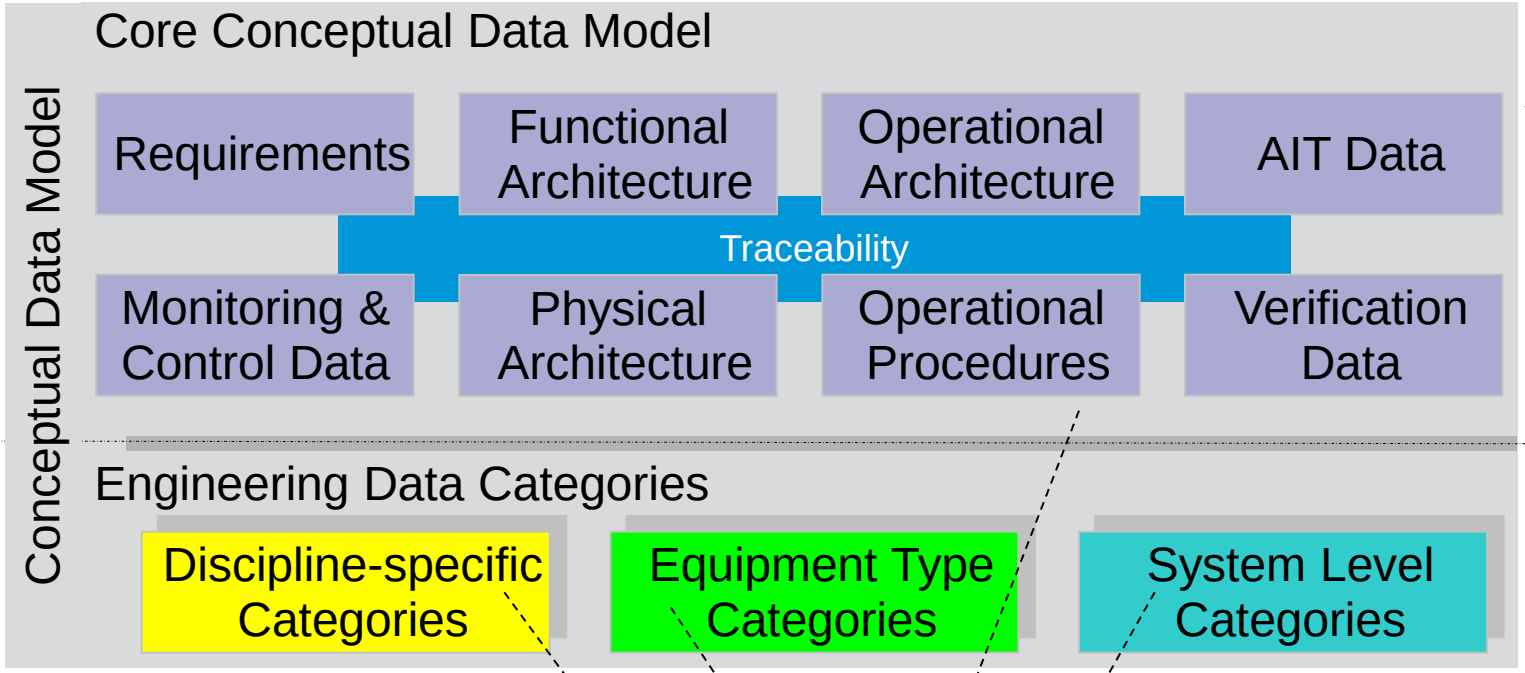
Analysis of project models



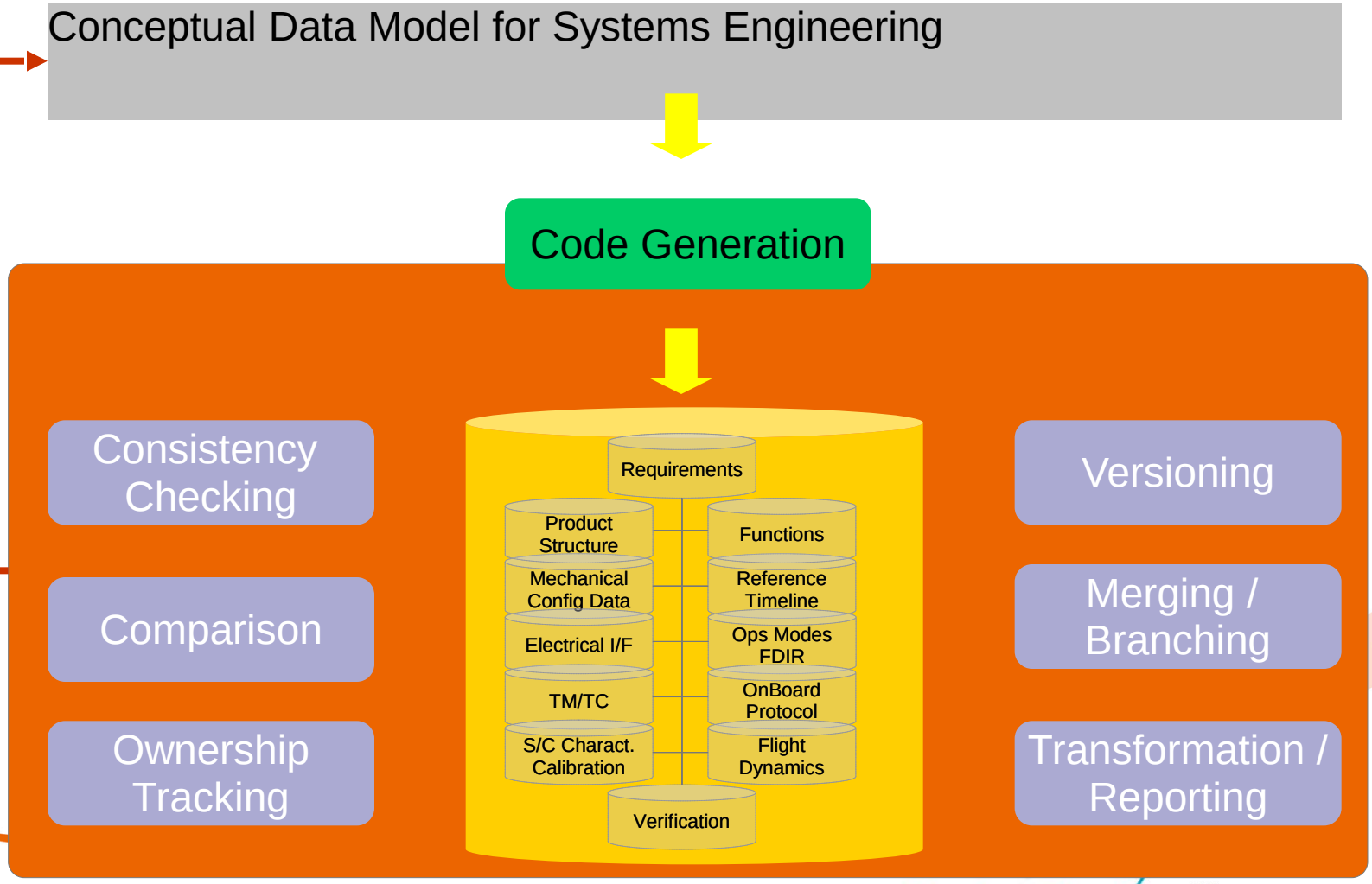
Data model validation



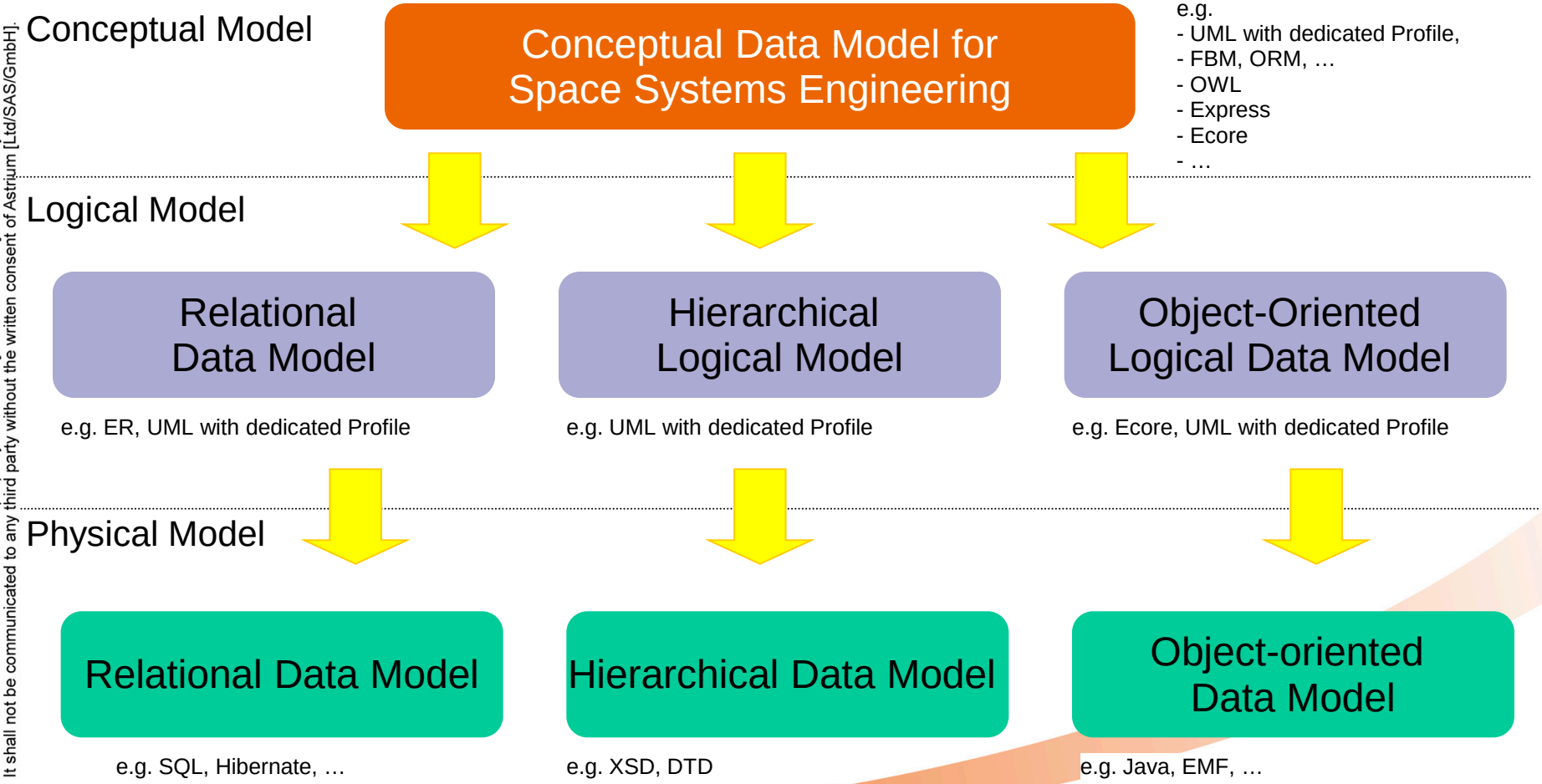
The conceptual data model is a comprehensive and exhaustive specification of system level data



Model driven S/W engineering is key to manage development costs

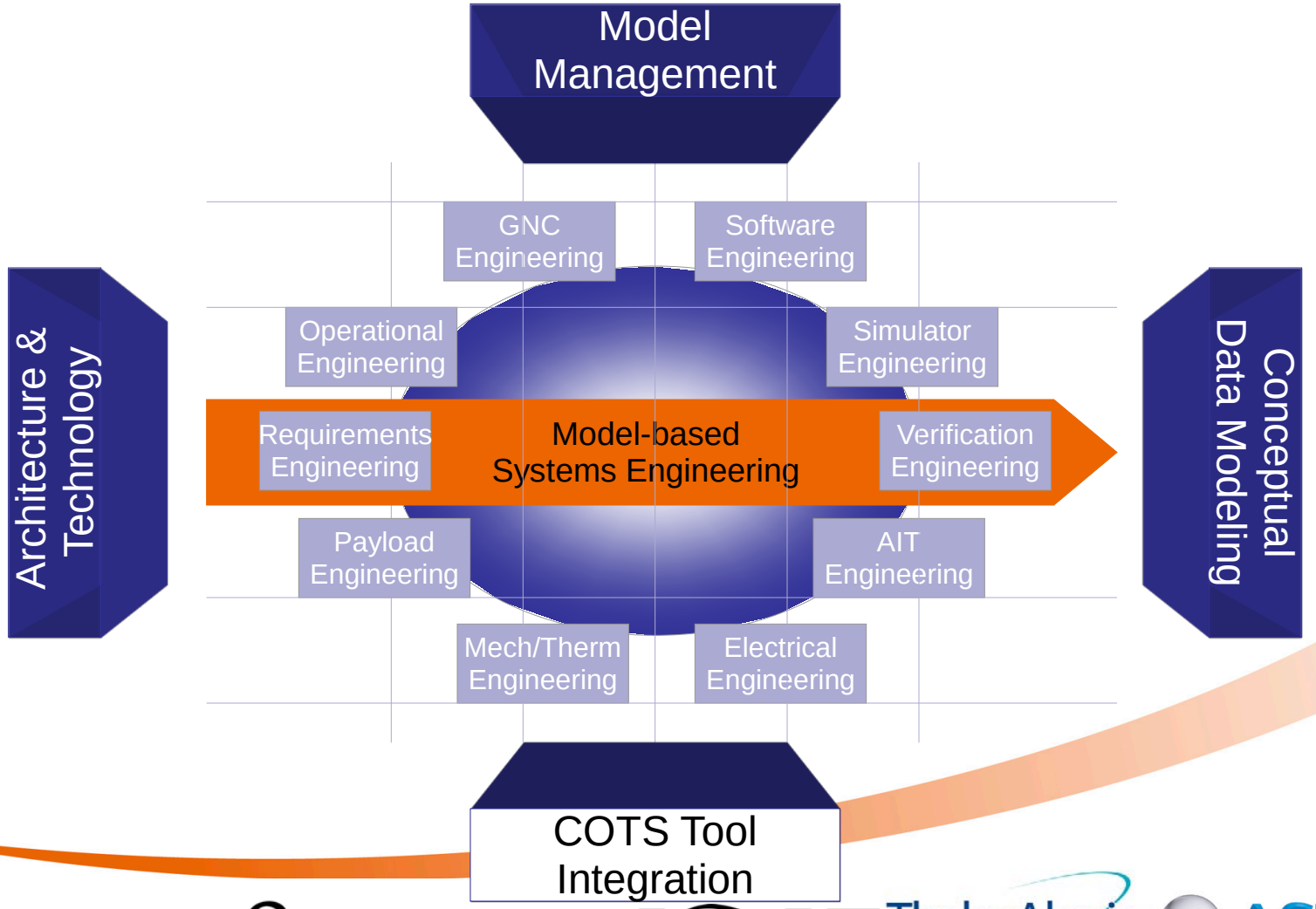


Technology independence of conceptual data model for long term maintenance



Adapted from Serge Valera ESA
The "Knowledge Sharing Challenge"
for Partners in European Space Projects
The Open Group Conference Amsterdam 2010

Allowing the integration discipline processes and tools – “as they are”



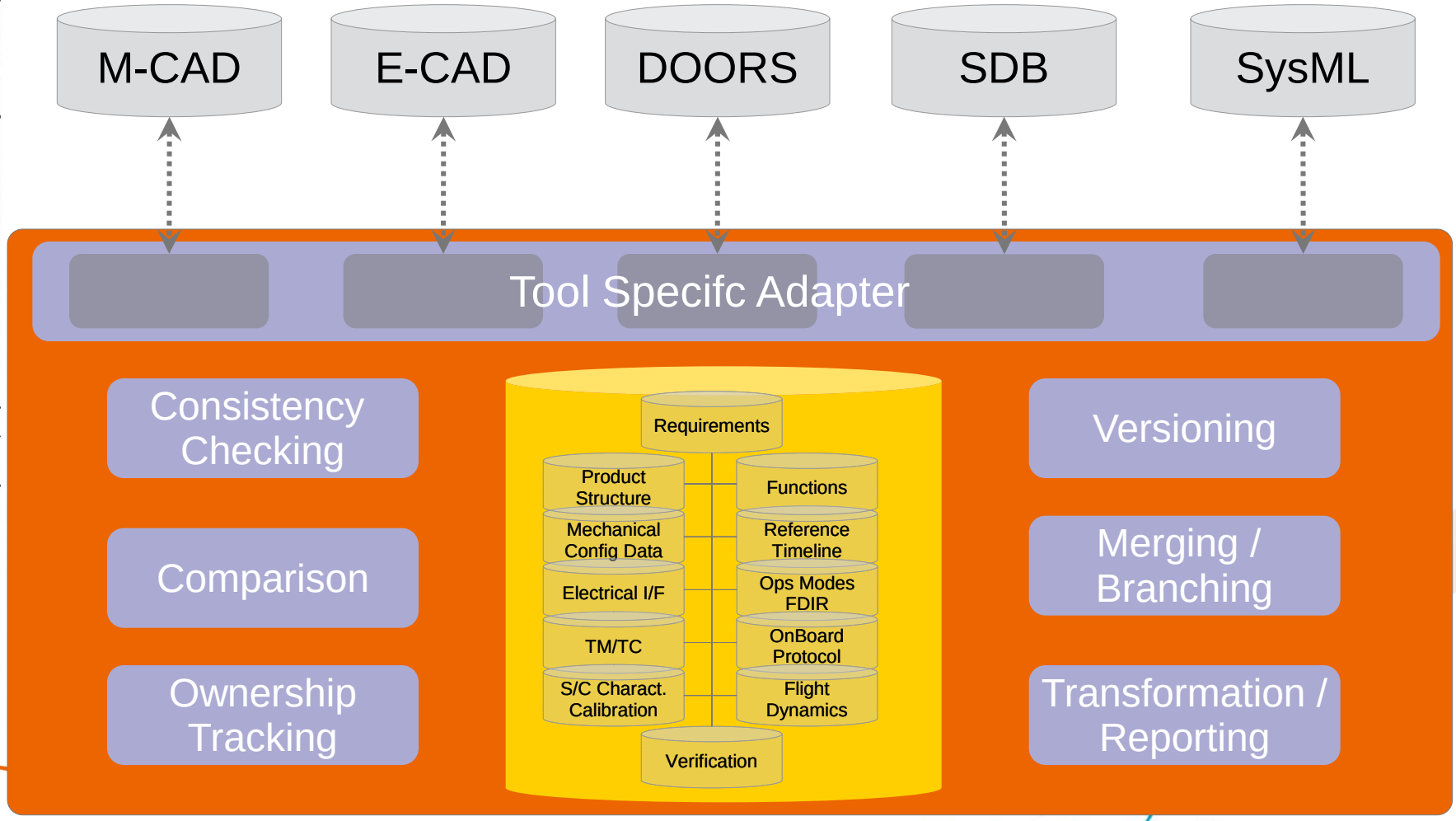
“Hybrid” for the tool integration in VSD

- Integration of “system level model” requires integration of the different engineering tools
  - Engineering tools to be integrated are not compatible
- Established domain discipline processes and tools shouldn’t be bothered by “system level model”
- Pragmatic approach for tool integration
  - Relevant subset of data is retrieved on “data level”
  - Domain models (“as whole model”) is kept under configuration control with “system level model”

VSD tool integration complements discipline processes with “system model”

- Central repository acts as “buffer” for shared engineering data on system level
- Data ownership remains with the disciplines – and is fully tracked on system level
- Different organization of data will be managed through data mapping
- Retrieval of information may comprise the following
  - Engineering data and properties
  - Engineering views
  - Submodels in a tool independent format (→ VRML)
  - Tool native data as file for configuration control

Information hub to minimize number of interfaces between different tools

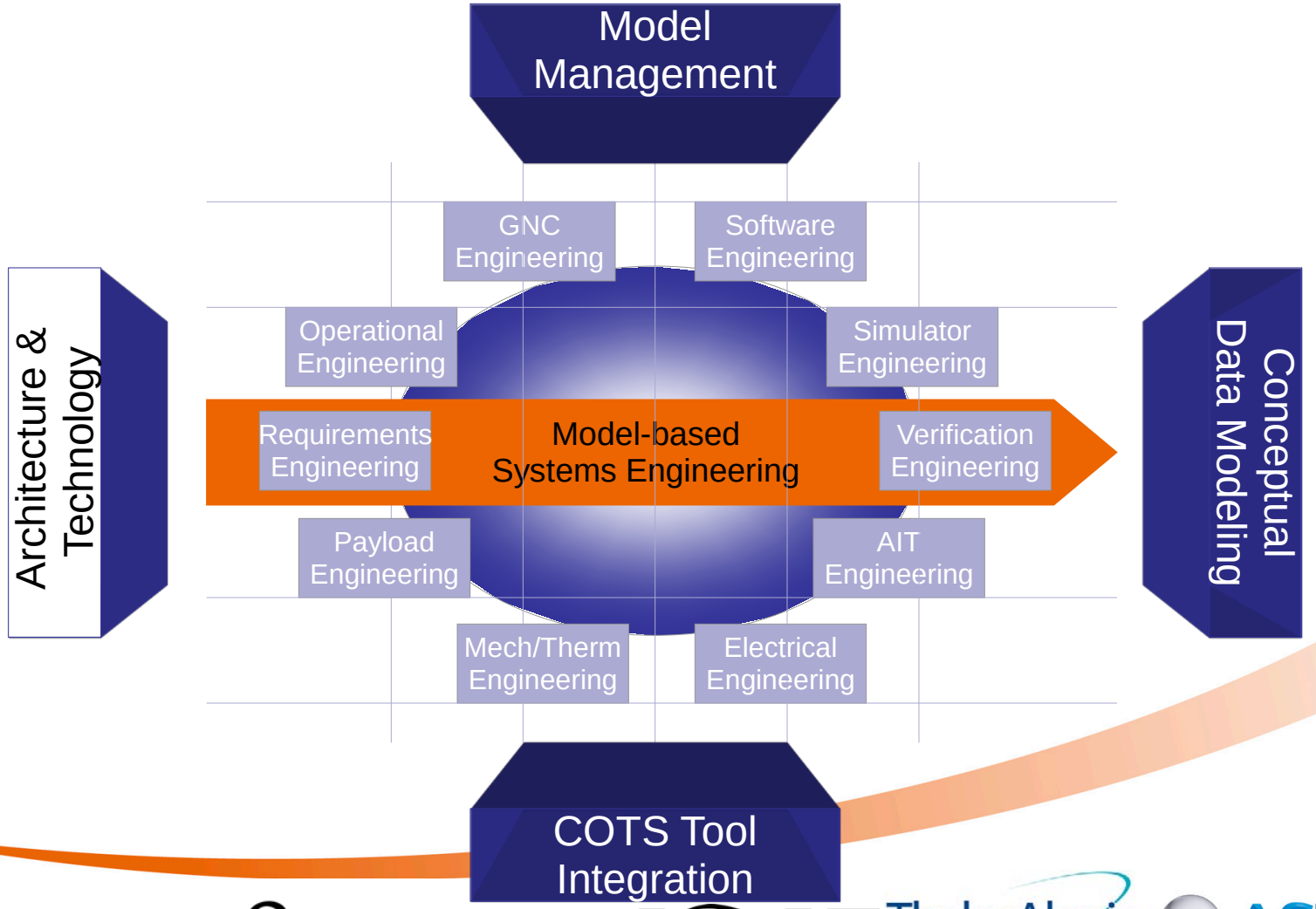


CASE Study on Tool Integration: Catia

- Catia is used to define many critical system properties, also required by functional engineering
- Engineering properties are extracted and re-hosted to the VSD data model
- Sub models on part level are extracted from Catia in VRML format
- Use and application of catia data in different applications without dependency to Catia

videos\CATIA_Import.mp4

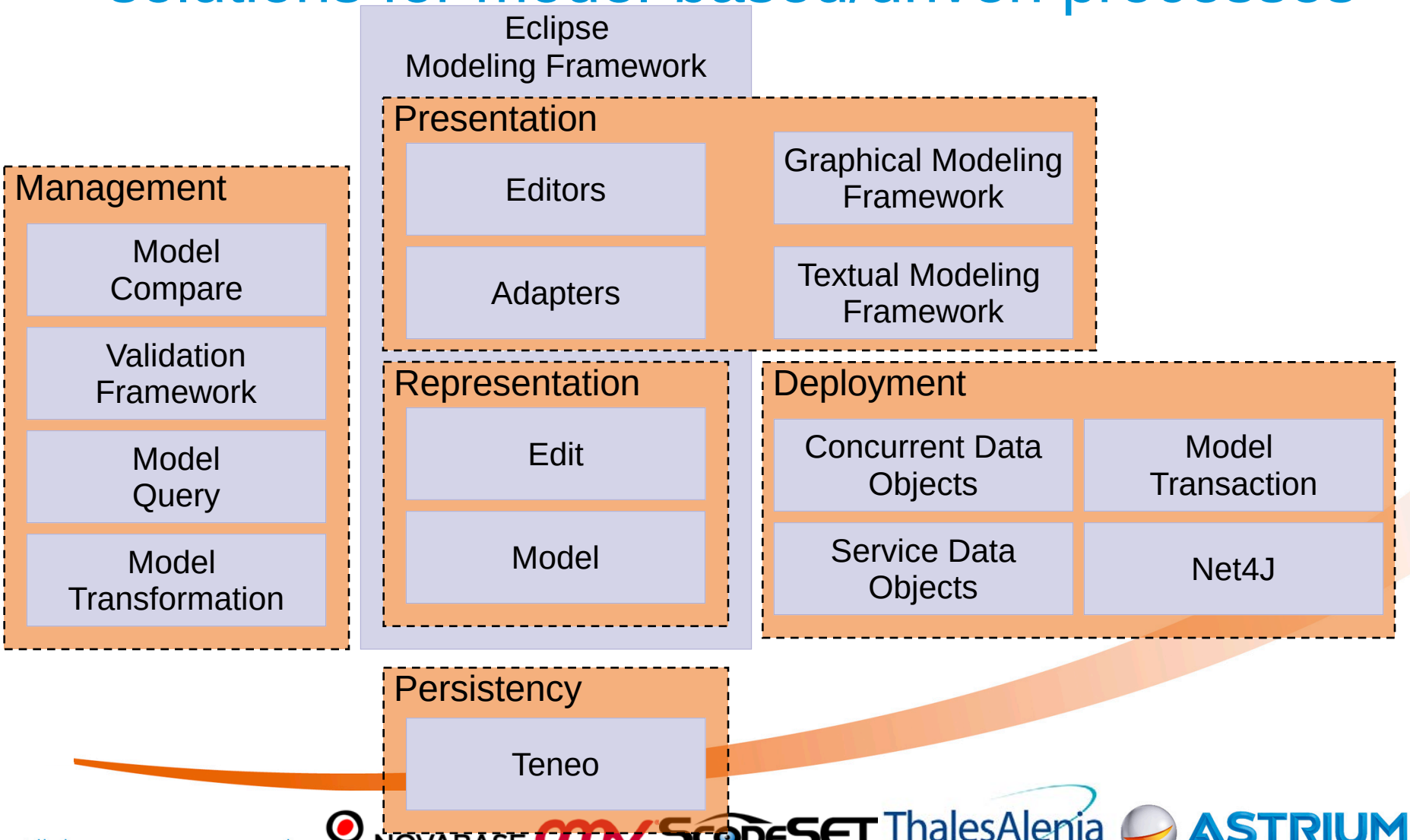
Demonstrating MBSE based on robust architecture and solid technologies



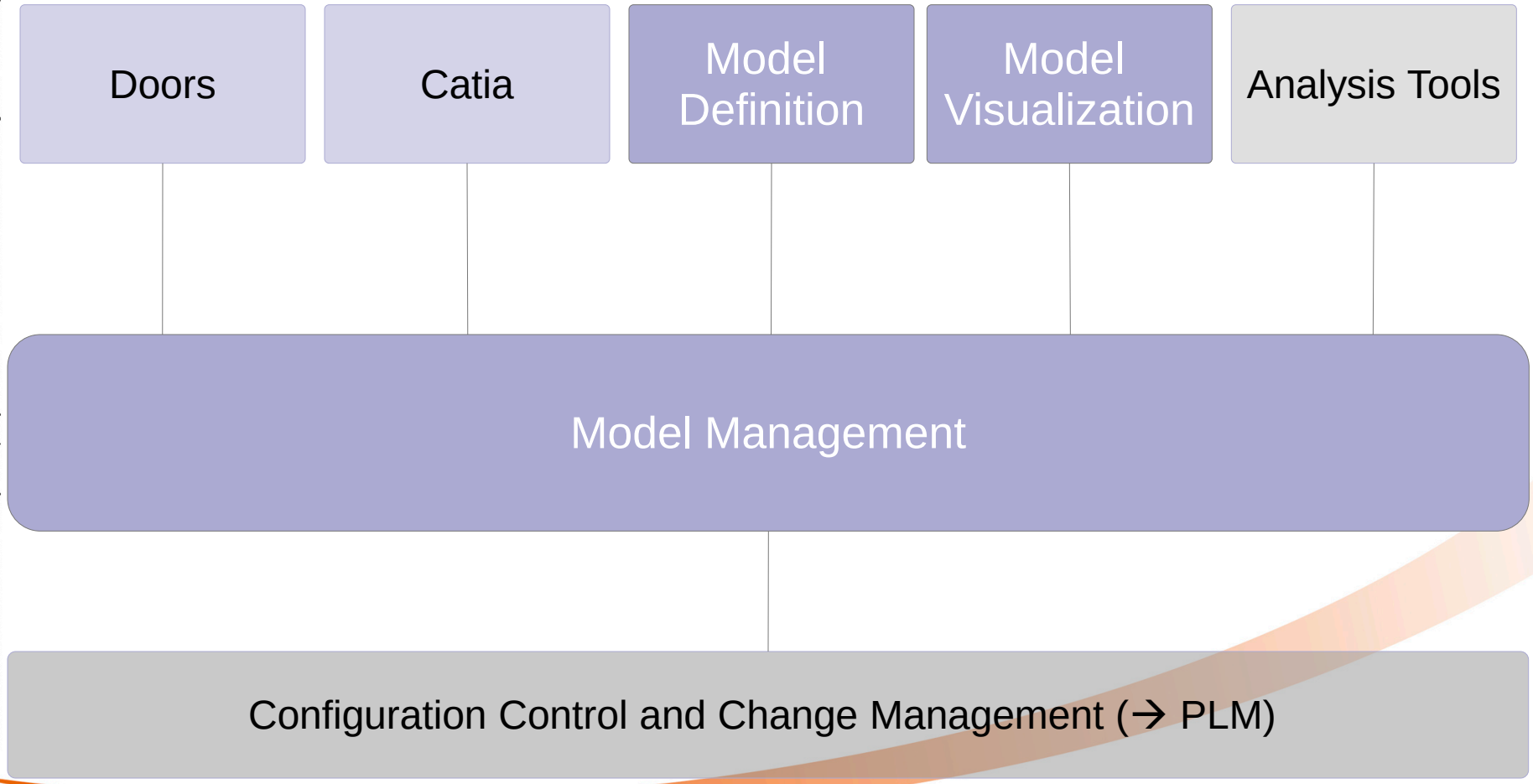
Technology selection – critical choice for cost efficiency and openness of solution

- For “system level model” representation appropriate technologies were to be selected
- Drivers for the selection of the implementation technologies were
  - Cost efficiency
  - “Plug and play” between different COTS tool vendors
  - Functionality provided
  - Application of the conceptual data model
- Eclipse Modeling Framework offers a rich, fast growing platform for advanced modeling solutions

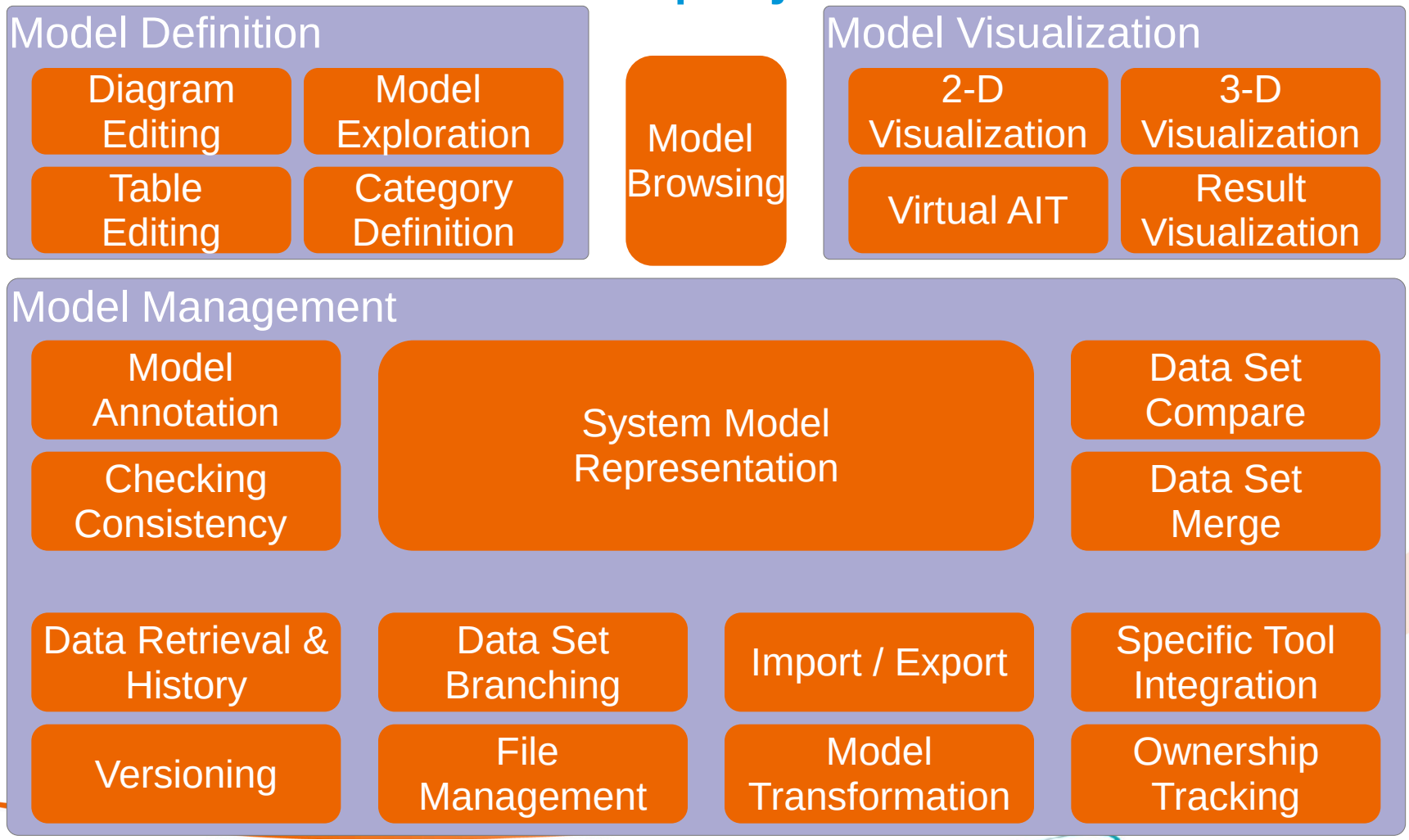
Eclipse offers a rich framework to build solutions for model-based/driven processes



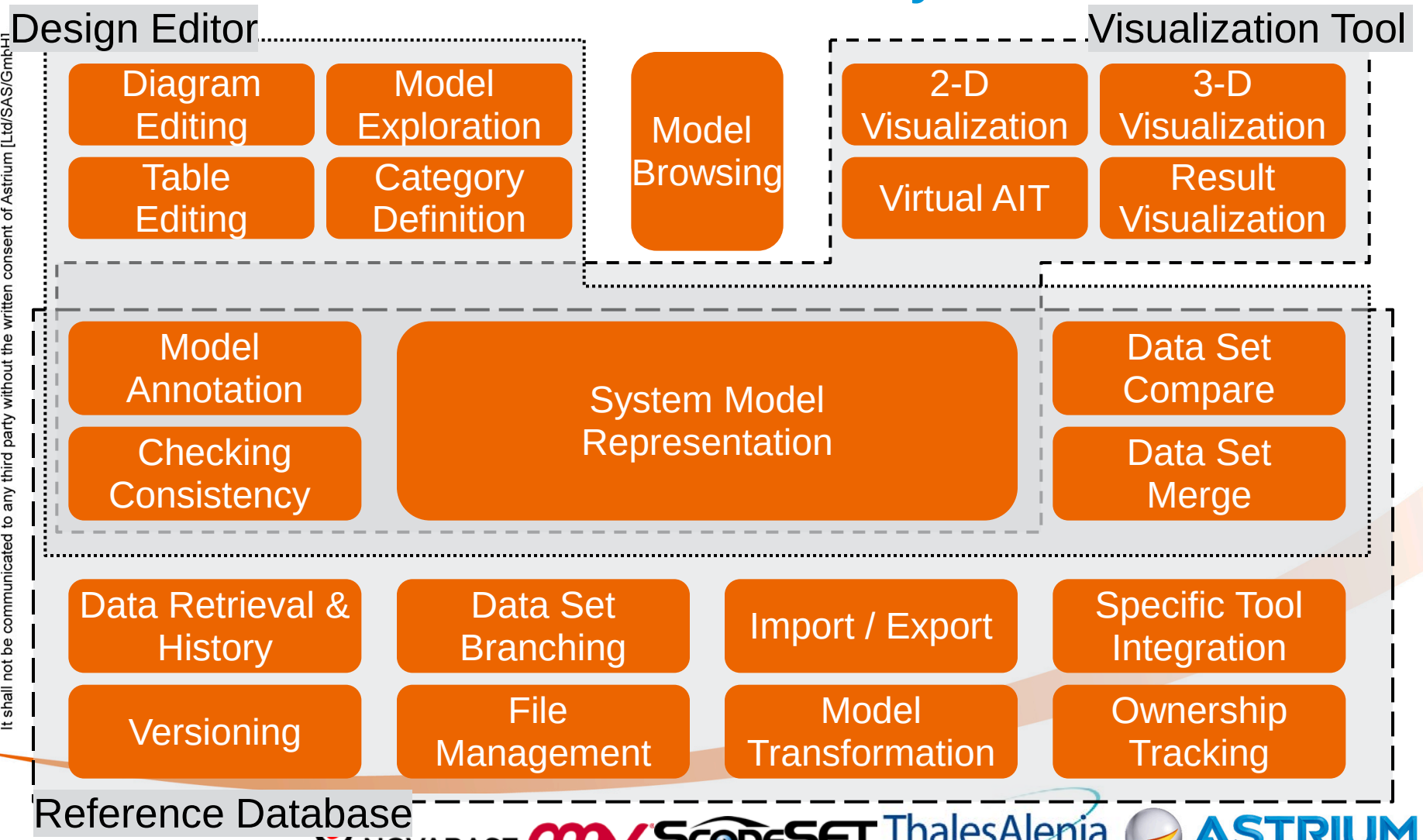
Key focus for the development, was lack of integrated model management and data sharing



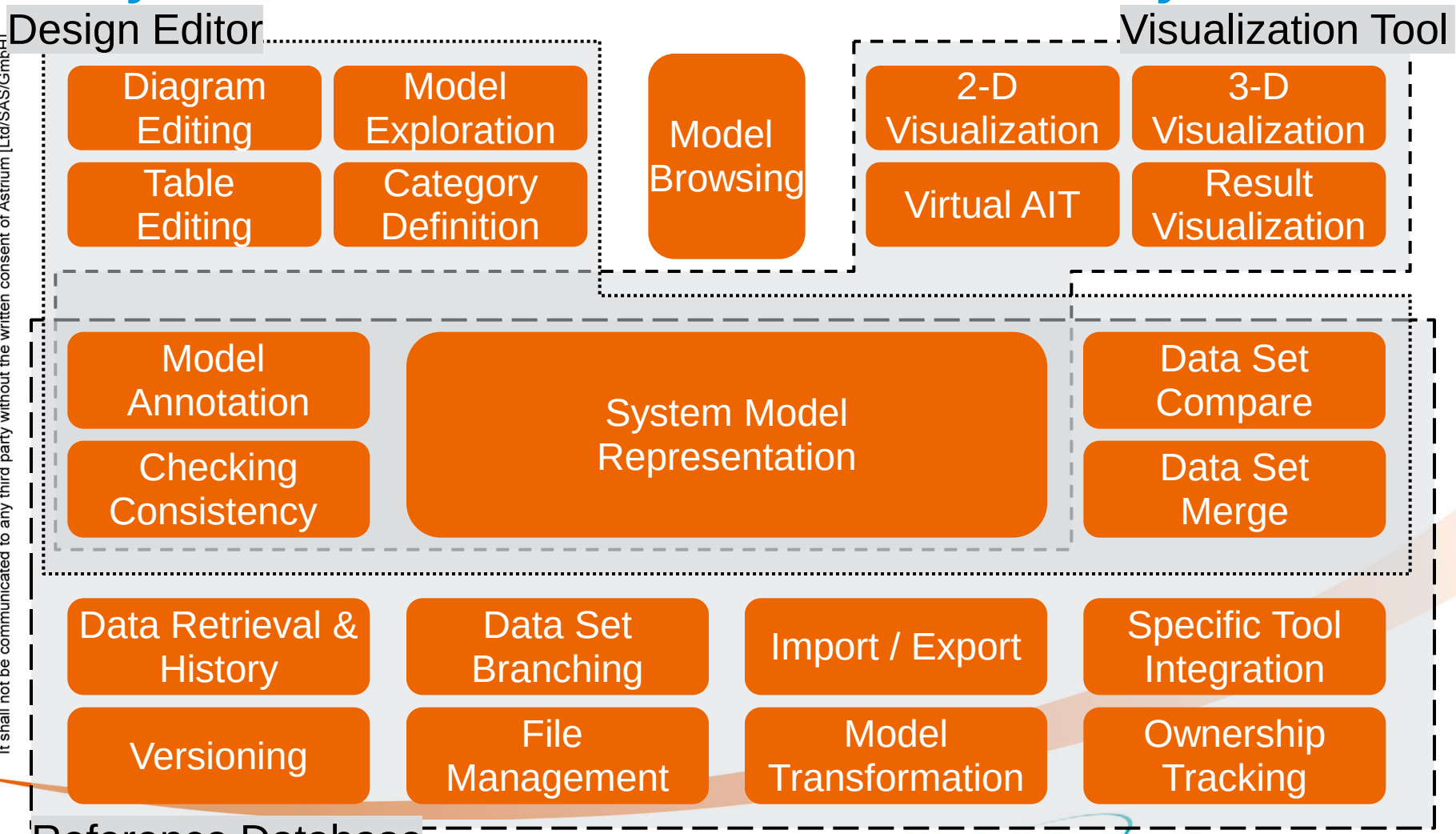
Overall decomposition of the functionality realized in the VSD project



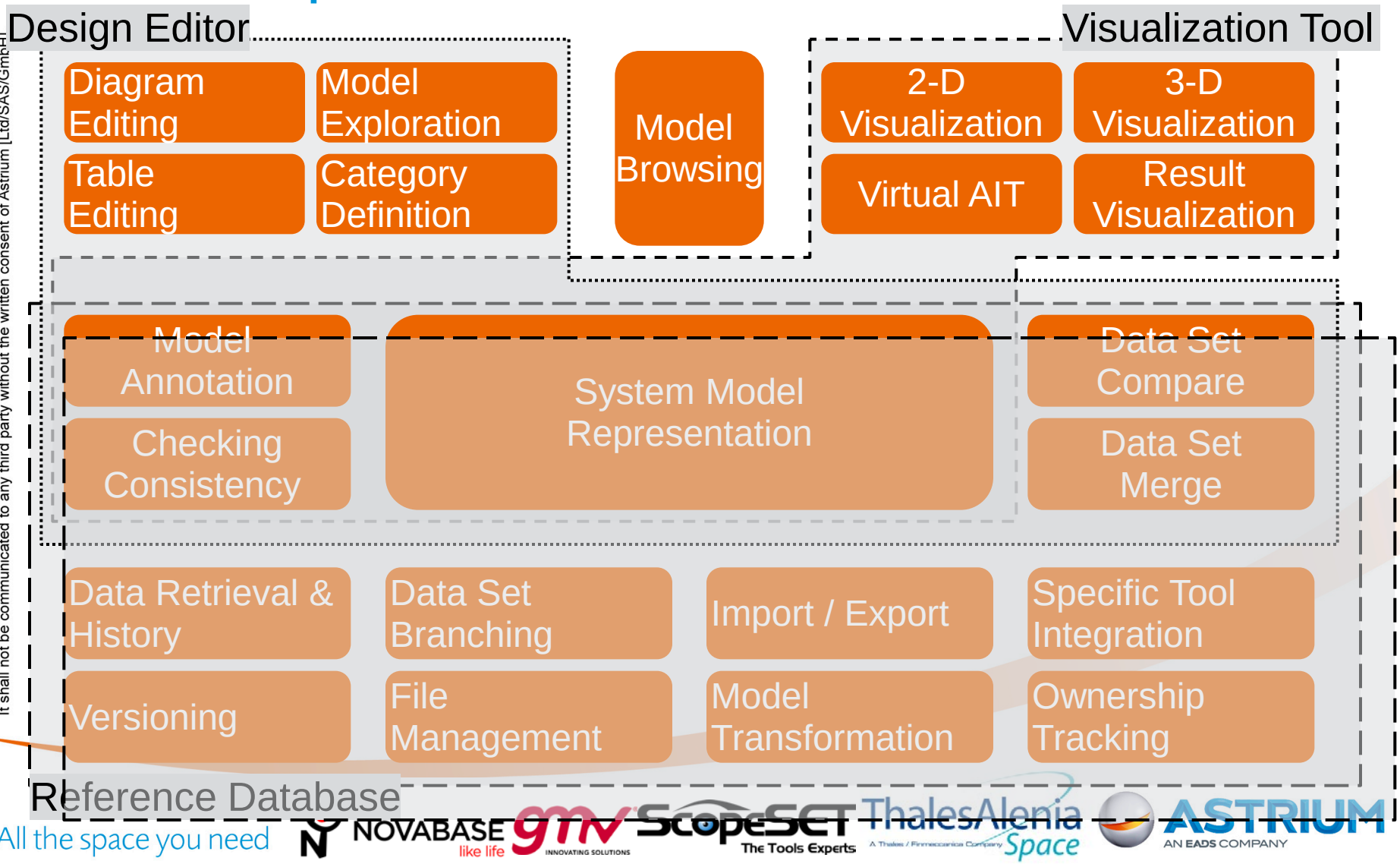
Space System Reference Database as the shared information hub on system level



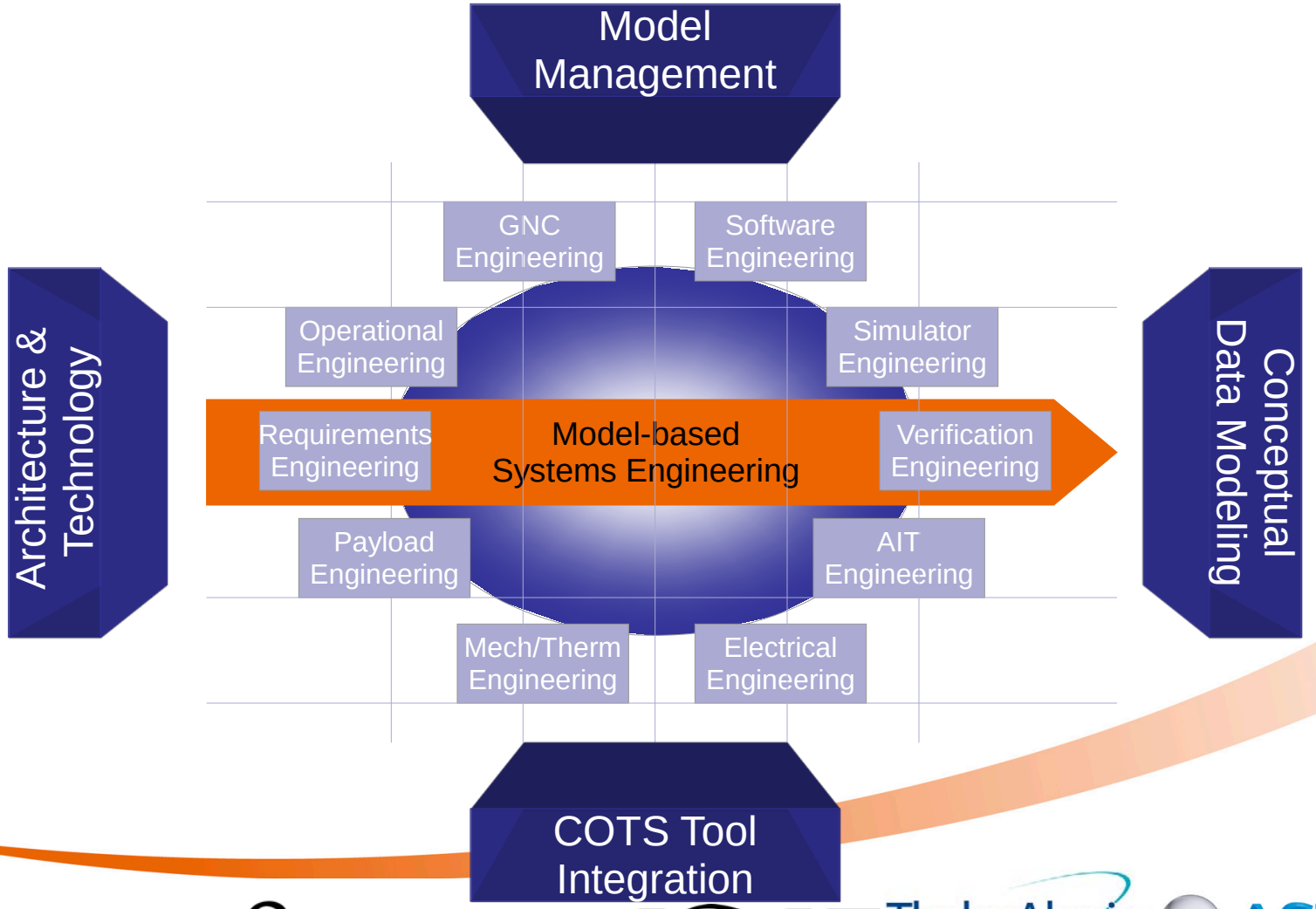
Space System Design Editor to define system level data, in a coherent way



Space System Visualization Stool to allow no discipline visualization and review



Wrap-up: VSD developed a solid technological basis to enable MBSE



VSD demonstrates five key values for the stakeholders applying MBSE

Efficient systems engineering processes based on an underlying "integrated systems model"

Effective multi-disciplinary engineering	Open modular framework	Progress tracking	Full tracing of the design coherence	Early and continuous V&V
				

VSD Demonstrator

All the space you need

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The backbone for efficient and effective multi-disciplinary data sharing

- Conceptual data model specifies commonly shared reference for model integration
- Increased consistency through commonly shared data – managed in an integrative way
- Visualization crossing tools imposed boundaries
- Full support of concurrent engineering processes
- Integrated support collaborative processes
- Enabling multi-disciplinary re-use of data

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Conceptual data model specifies commonly shared reference for model integration

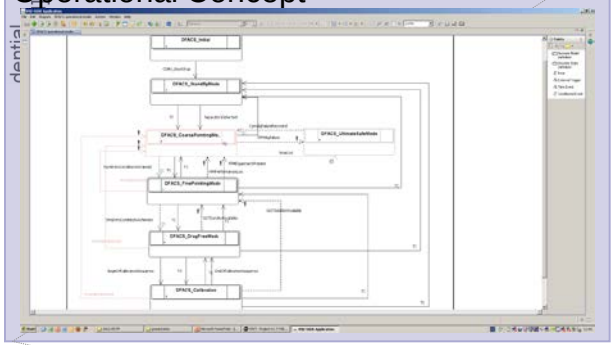
- SE needs are driving the content and structure of conceptual data model for space SE
- Conceptual data model defines exhaustively system level managed / needed data
  - All relevant relevant aspects of disciplines can be captured
  - System level artefacts can be generated from data
- Conceptual data model is a key asset for SE and has various use cases
  - tool development, standardization, (MB)SE - methodology, training, …

Increased consistency through commonly shared – integrative managed - data

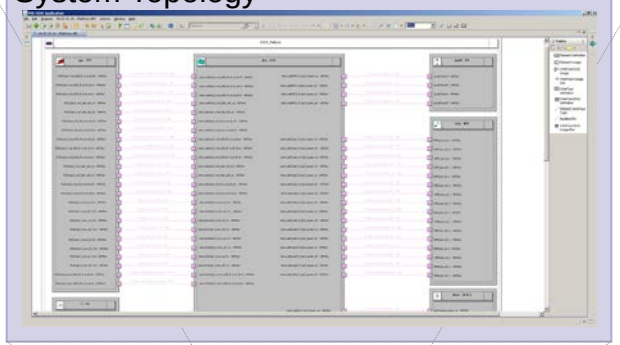
- Discipline data can be seamless integrated on system level across tool boundaries
  - Required discipline data will be retrieved from tools directly
  - Established discipline tools can be used as they are
- All system relevant data can be modeled, views defined - close to the existing notation
- Increased consistency through dedicated checks on consistency and completeness
- Data ownership can be fully tracked

Conceptual data model enables common representation and visualization of data

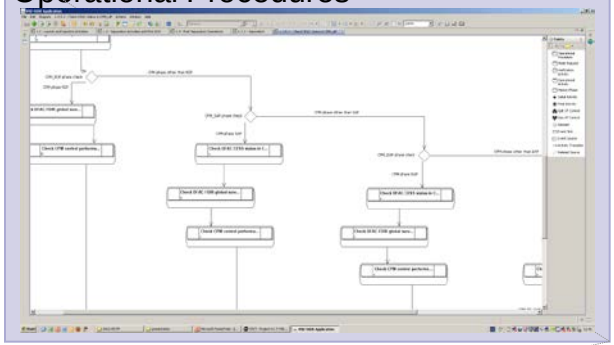
Operational Concept



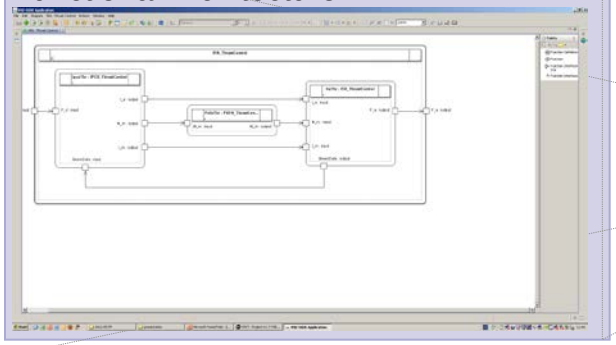
System Topology

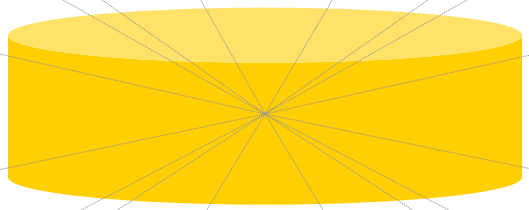


Operational Procedures

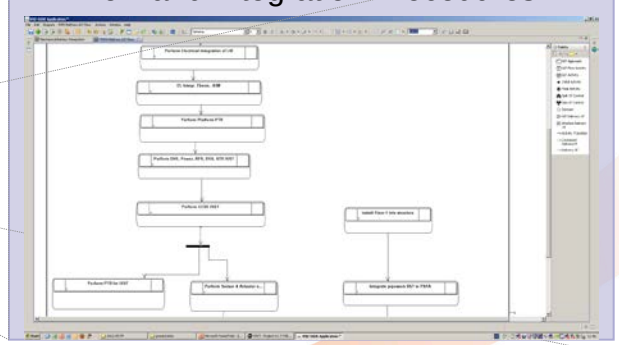


Functional Architecture

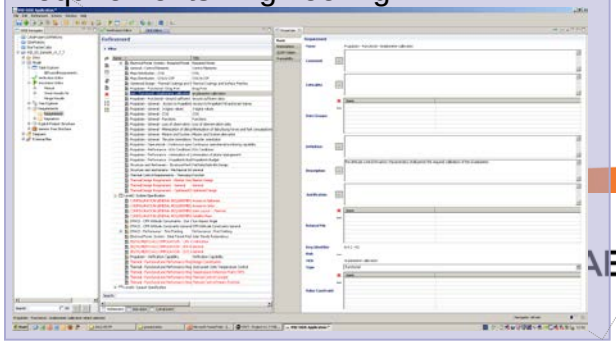




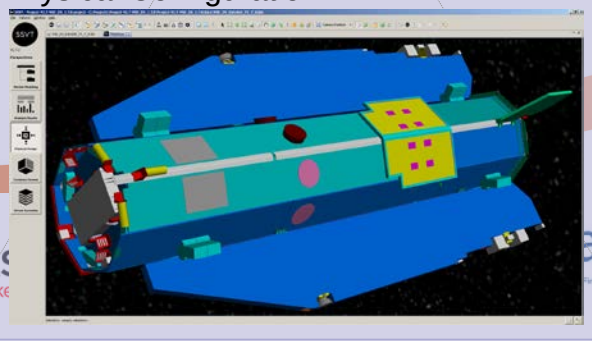
AIT Flow and Integration Procedures



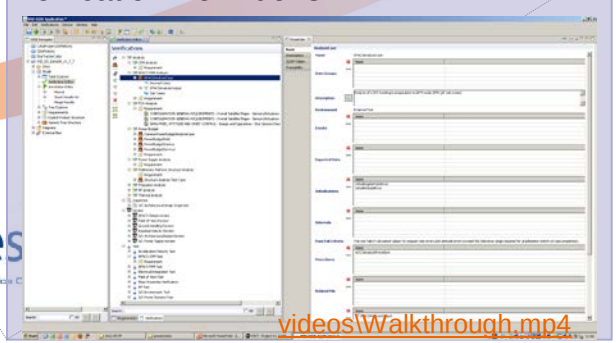
Requirements Engineering



Physical Configuration



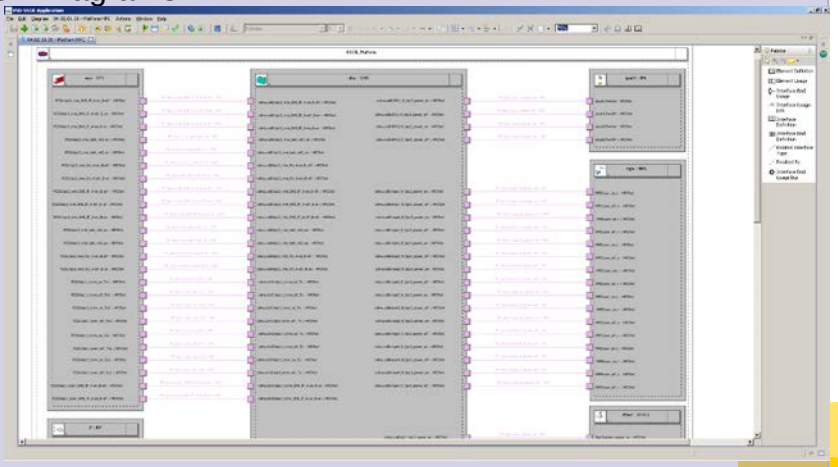
Verfication Definitions



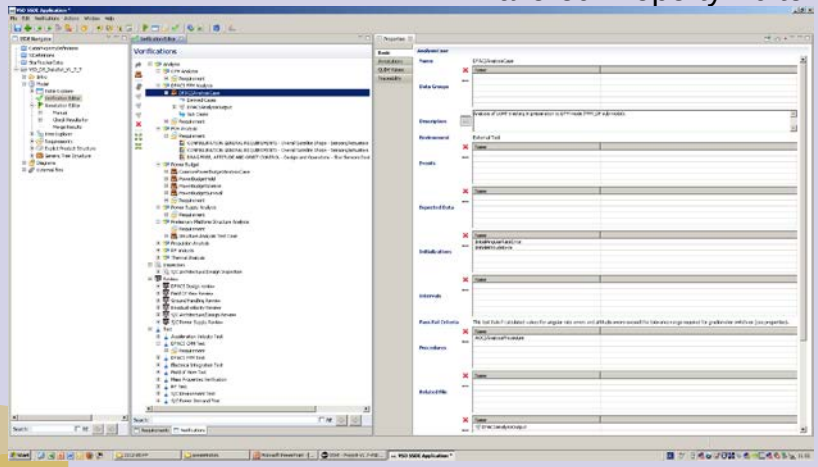
videos\Walkthrough.mp4

Editor allows definition of “system model” with powerful and flexible views

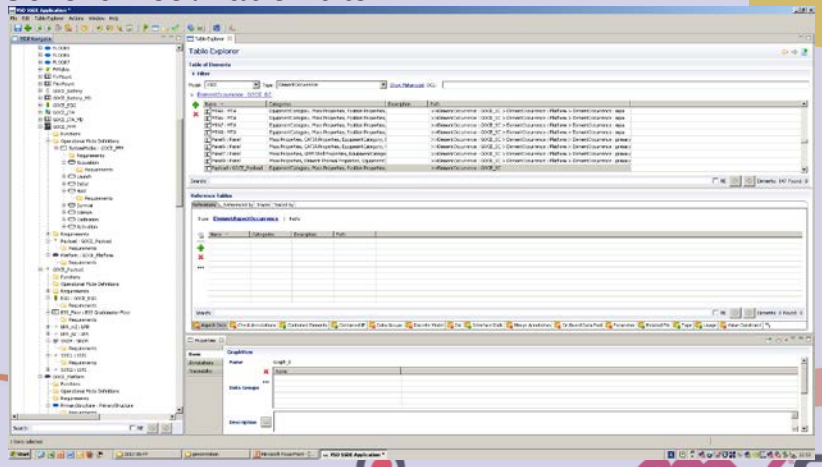
SE Diagrams



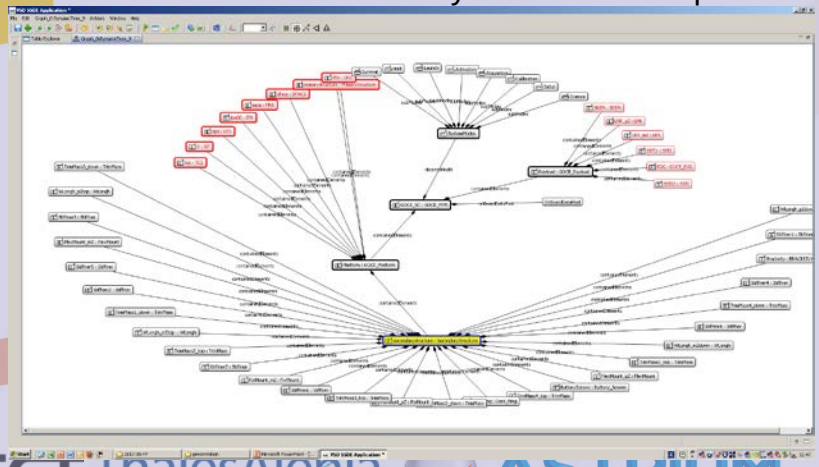
Tailored Property Editors



Generic Tree / Table Editor



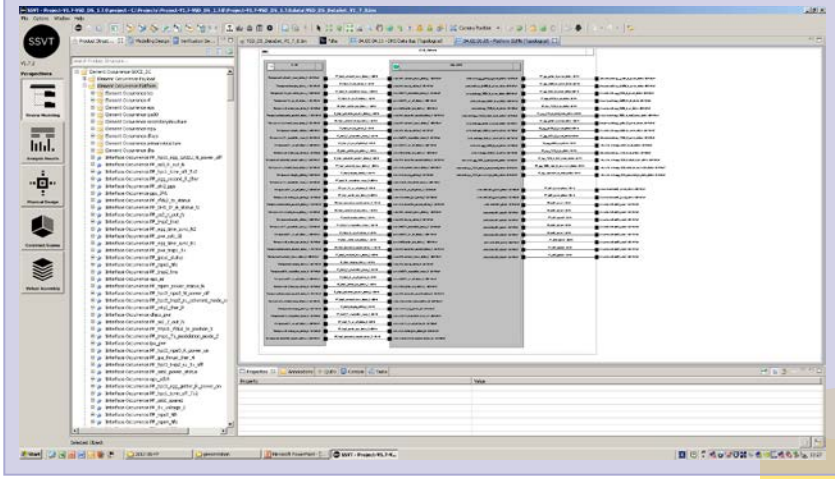
Dynamic Model Exploration



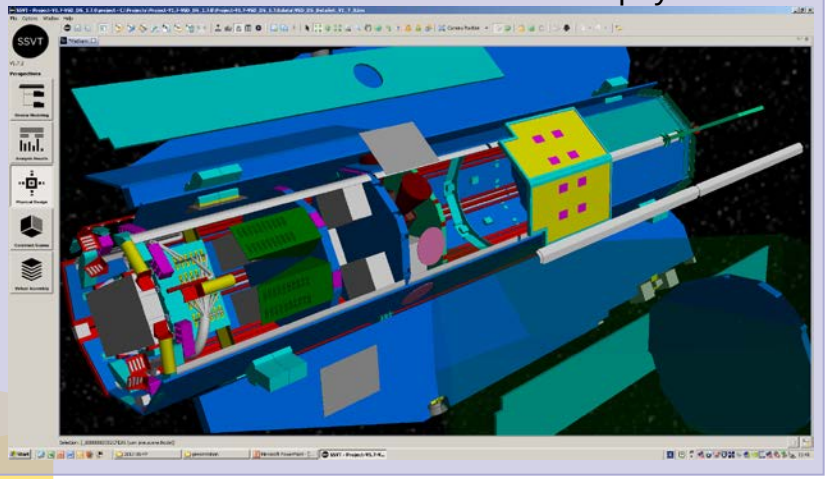
videos\ModeConstraints.mp4

Integrated visualization allows integrated review of complete engineering activities

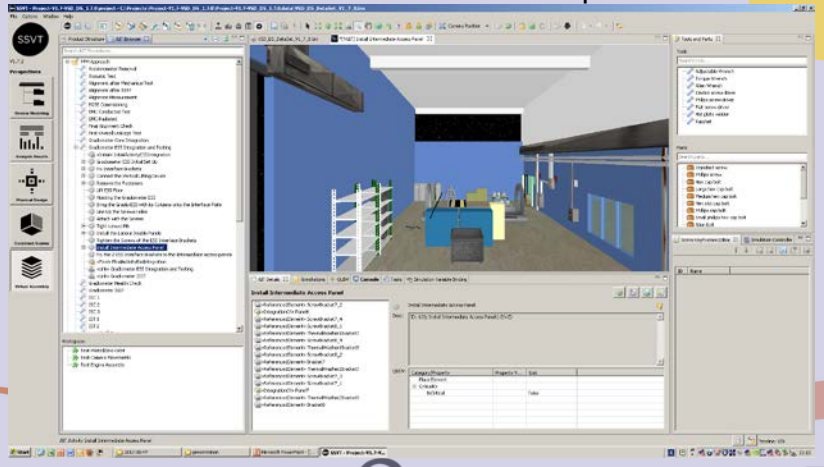
Visualization of all “functional” views and data



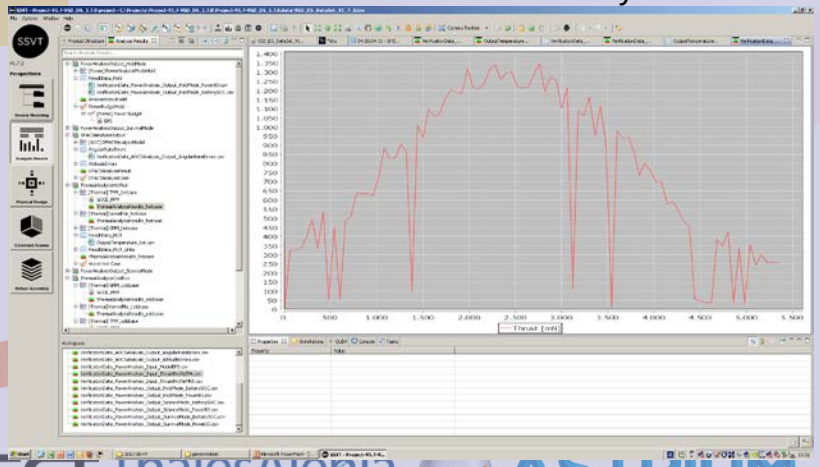
Visualization of all “physical” data



Definition and execution of animated AIT procedures



Visualization of analysis result data



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videos\Review.mp4

VSD fully supports Concurrent Engineering

- Concurrent engineering requires the management of conflicting updates to the data
- Following strategies are possible
  - Locking of data
  - Continuous distribution of data
  - Post-activity resolution and merge
- Powerful model management functions allow efficient distribution and merge of data
  - Repository is organized along the process needs
  - Data for editing is locally cached
  - A conflict detection (compare) and resolution (merge) is performed after the tasks have been executed

videos\CATIA_Update.mp4

VSD integrates collaboration data with engineering data

- Collaboration engineering refers to the geographically distribution of teams
- Typically support is focusing on audio/video capability
- VSD adds new concepts for collaborative processes
  - Central repository can be hierarchically arranged (per subcontract, site, …)
  - Model annotation concepts allows efficient collaboration and communication directly associated to the system model
  - Enhancement of forum like discussions possible

VSD demonstrates five key values for the stakeholders applying MBSE

Efficient systems engineering processes based on an underlying "integrated systems model"

Effective multi-disciplinary engineering	Open modular framework	Progress tracking	Full tracing of the design coherence	Early and continuous V&V
				

VSD Demonstrator

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VSD provides open and modular framework for MBSE

- VSD is based on Eclipse Modeling Framework is designed to develop tailored solutions
  - Open source, no license costs
  - Supports highly efficient development process
  - Huge user community and contributor community
  - Many functions, more to come…
- VSD provides open framework allowing to integrate COTS tool as they are
- Deployment according process needs
- Meeting the MS access challenge !

VSD demonstrates five key values for the stakeholders applying MBSE

Efficient systems engineering processes based on an underlying "integrated systems model"

Effective multi-disciplinary engineering	Open modular framework	Progress tracking	Full tracing of the design coherence	Early and continuous V&V
				

VSD Demonstrator

All the space you need

VSD supports the management of engineering processes & progress

- Controlling and tracking the engineering processes and progress is a key success factor
- Based on scattered repositories, and document orientation tracking is difficult
- VSD offers more functionality for process management
  - Consistency checks for all relevant data
  - Detection of broken ends
  - Impact analysis
  - Efficient change tracking on delivery, iteration or concurrent activities
  - Tracking of annotations such as comments, issues, problems, actions, discrepancies

VSD demonstrates five key values for the stakeholders applying MBSE

Efficient systems engineering processes based on an underlying "integrated systems model"

Effective multi-disciplinary engineering	Open modular framework	Progress tracking	Full tracing of the design coherence	Early and continuous V&V
				

VSD Demonstrator

All the space you need

Requirements can be entirely traced into design and verification

- All required traceability links – to ensure coherence – are defined in the conceptual data model
  - Requirements in to design, further to lower level requirements
  - Resign to design, design to verification
- Traces play an important role in ensuring consistency, impact analysis, design justification, and model re-use
- VSD repository and editors fully support the definition and navigation along traceability
- Data managed in COTS tools can be also integrated in the tracing schema

videos\Tracing.mp4

VSD demonstrates five key values for the stakeholders applying MBSE

Efficient systems engineering processes based on an underlying "integrated systems model"

Effective multi-disciplinary engineering	Open modular framework	Progress tracking	Full tracing of the design coherence	Early and continuous V&V
				

VSD Demonstrator

All the space you need

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VSD enables early and continuous verification and validation

- System level design forms essential set of data to be shared between disciplines for analysis
- On system level “models” can be provided complementing domain specific analysis models
  - Functional system simulation
  - System visualization (DMU-like) for review
  - Validation and visualization of AIT procedures
- Open modular framework can be leveraged to provide input data for analysis
  - Automated tie-in into Excel for budget analysis
  - Export of data in required format for domain analysis tools
  - Further enhancement for automated model preparation possible (e.g. Modelica)
- Management of status and progress of verification

videos\PowerAnalysis.mp4

VSD will provide benefits for space community based on demonstrated values

Key Values of MBSE	To achieve benefits further steps are required	Benefits to space community
Based of VSD technologies key values of MBSE can been demonstrated ▪ VSD is "backbone" for efficient Multi-disciplinary engineering ▪ VSD provides a open & modular framework for MBSE ▪ With VSD we can manage engineering progress ▪ VSD allows a new dimension of traceability ▪ VSD enables early system verification/validation	▪ Perform operational validation in pilot application ▪ Integrate VSD functions into operational environments ▪ Further research and development	▪ Higher efficiency through ▪ Better quality ▪ Risk reduction ▪ Optimising design ▪ Cost as result ▪ Reduced dependency from tool supplier ▪ Higher Flexibilit ▪ Better cost/performance ratio

Perform operational validation in pilot application

- Goce was used as sample mission to
  - Derive conceptual data model (complemented by other missions)
  - Scenario data to validate model and tool
- Re-modeling of a mission has its limits in terms of validation
- Perform operational validation based on the VSD demonstrator – in parallel to a classic project

For benefiting of MBSE in programs further activities are required

- On company level VSD functions need to be integrated in operational environments
  - Can be performed incrementally

  → Shared repository is a critical element – operational implementation already started

- ESA to support for the implementation shared infrastructure elements, e.g. for the “extended enterprise”

- Standardization in frame of ECSS
  - Data modeling language, methodology and update process
  - Update of ECSS-E-TM-10-23

VSD demonstrator can be used as technology validation platform

- Further functions are possible based on an "integrated system model" comprising
  - Further integration of domain specific models and tools
  - Support of further use cases
  - Challenge diagrams as main editing and communication mean
  - Perform logical checks on system model (→ reasoning)
- VSD offers a rich technology basis for prototyping, integrating and validation of new functions

→ Improved coordination of academia, TRP and industrial research

Summary

- The VSD project was to demonstrate the feasibility and value of MBSE for European space programs
- VSD developed demonstrator – on a solid technology bases - using an hybrid approach, building on top of COTS tools, integrated by open source technologies
- VSD demonstrates key values to SE in applying model based techniques
- A roll-out of MBSE requires preparation, for which close collaboration between ECSS, ESA and industry is needed