



Jet Propulsion Laboratory
California Institute of Technology

JPL Systems Environment

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Jet Propulsion Laboratory, California Institute of Technology

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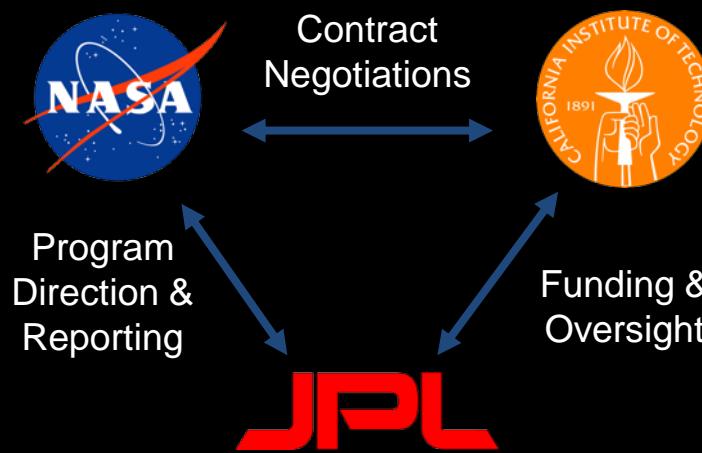
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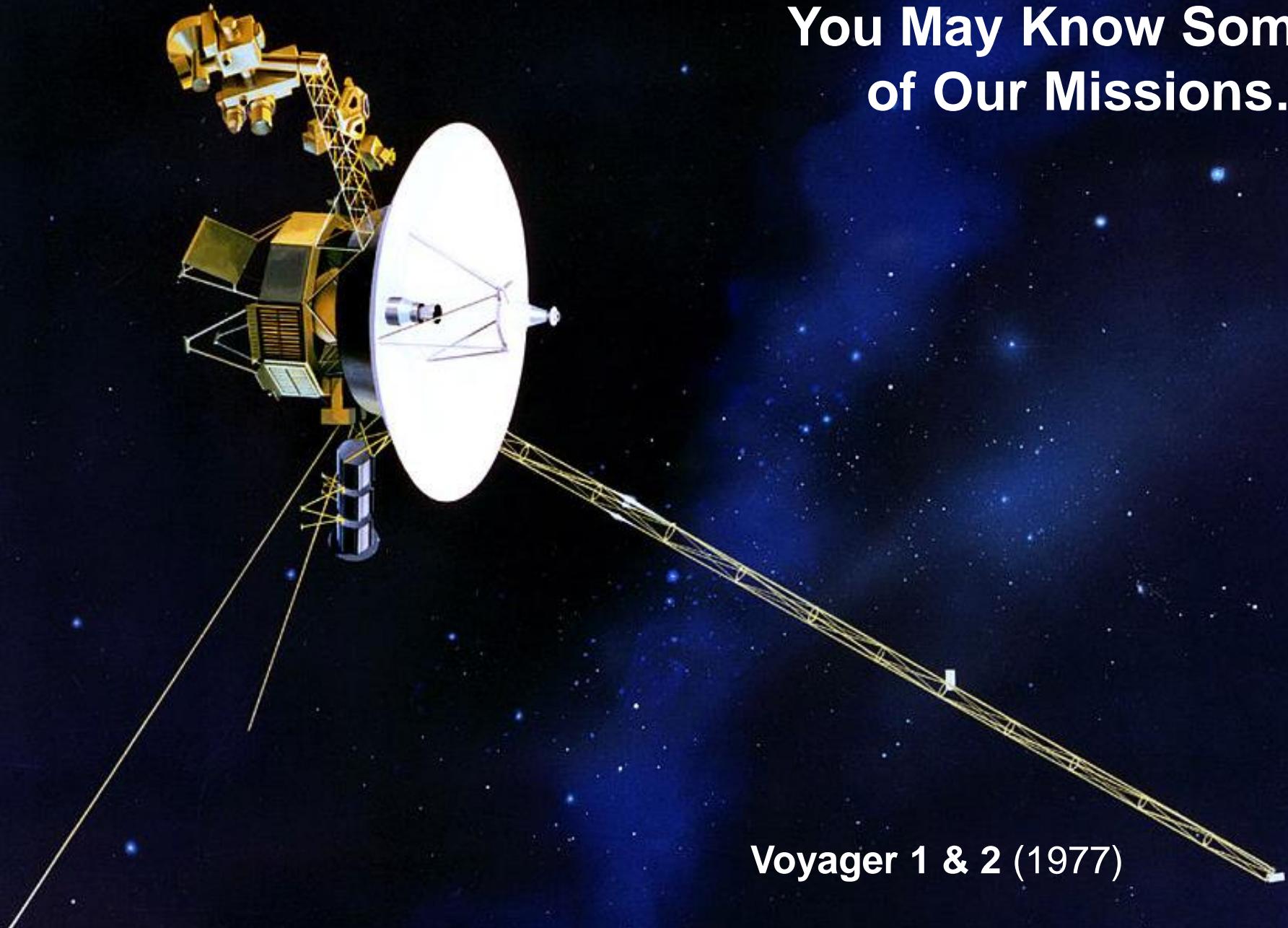
NASA Jet Propulsion Laboratory (JPL)



- Located in Pasadena, CA
- NASA-owned “*Federally-Funded Research and Development Center*”
- University-operated
- ~6,000 employees

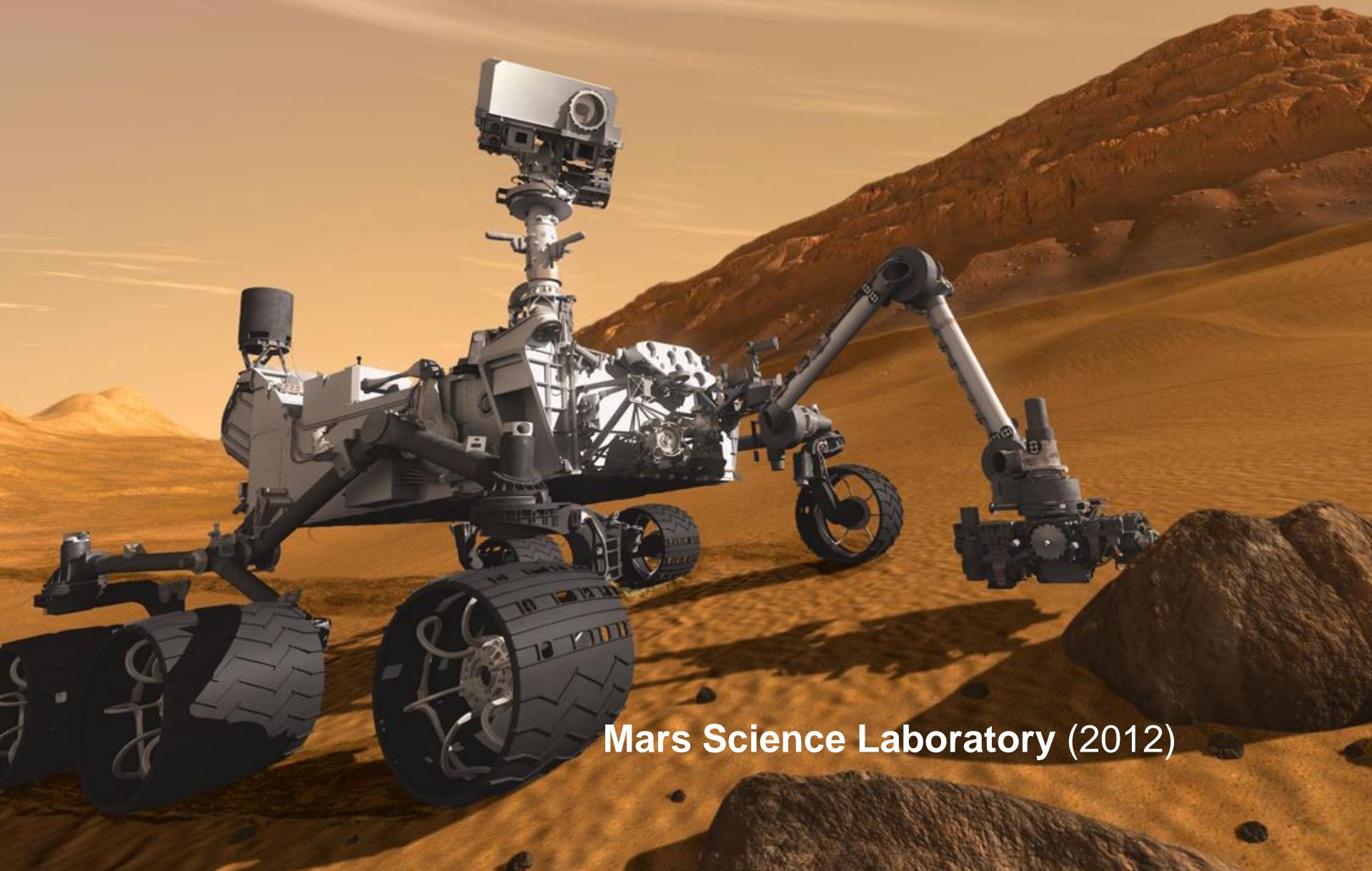


You May Know Some
of Our Missions...



Voyager 1 & 2 (1977)

JPL's Mission is Robotic Exploration



Mars Science Laboratory (2012)



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JPL Computer Aided Engineering (CAE)

- Computer Aided Engineering provides the Laboratory's Engineering Staff and Scientific communities with integrated tools environments and technical expertise
- Four Environments:
 - Systems Environment
 - Software Environment
 - Mechanical Environment
 - Electrical Environment

SSwE Team

Systems Environment team

Web Services team

Software Environment team

*Development Operations
team*



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JPL OpenCAE Vision

Provide an open portfolio in a shared environment that seamlessly connects engineers developing missions and systems.

- Open - Processes, code, apps, services and artifacts are accessible by JPL users as well as vendors and partners
- Shared - The diverse community of users, developers partners and vendors are able to contribute
- Connected - Collaboratively construct and analyze the same precision products needed to develop Missions and Systems at JPL using the CAE environment.



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JPL OpenCAE Mission

Develop the CAE environment from a user centered architecture leveraging vendor partnerships using robust life cycle processes.

- Vendor partnerships – Crucial feedback and insight into how Vendor products are serving the needs of engineers and developers
- User centered – Architecture for CAE is driven by the needs of the practitioners and projects
- Life-cycle process – Provide the integrity of the the applications services and support



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JPL OpenCAE provides the engineering environment

- An environment for engineering tools to work together
- Incorporate tooling from systems, software, mechanical, and electrical domains
- Platform integrates heterogenous data sources
- Emphasize standards for data interchange
- Case studies inform the architecture of the engineering environments
- Multi-model environment



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CAE is built in following a commodity capability model

Project Specific Developed
Capability

Line / Project Capability Adaptation

OpenCAE Commodity Environment

COTS
Capability

Managed
Services

In-House
Capability

Open Source
Capability

SaaS

OCIO Services

Capability developed specifically by a flight project to address a specific need not available otherwise.

Capability developed by the line or project to extend the Open CAE Environment for line practices /flight project need.

CAE capabilities are primarily commoditized – well-scoped capabilities with well-determined life-cycle costs in terms of budget and resources.

Constituent Commodities used to compose the CAE Commodity Environment



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Model-Based Engineering applied by Projects for delivering Engineering Products

Projects:

- Europa Clipper
- Europa Lander mission concept
- InSight
- Mars 2020
- Mars Sample Return (MSR)
- Thirty Meter Telescope
- Ground Data Systems
- Psyche
- MAIA

Products:

- MELs, PELs
- Resource allocation analysis
- System decomposition,
- Libraries / Reusable models

*Not just spacecraft
missions!
Not just early phases of
design!*



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Systems Environment Overview

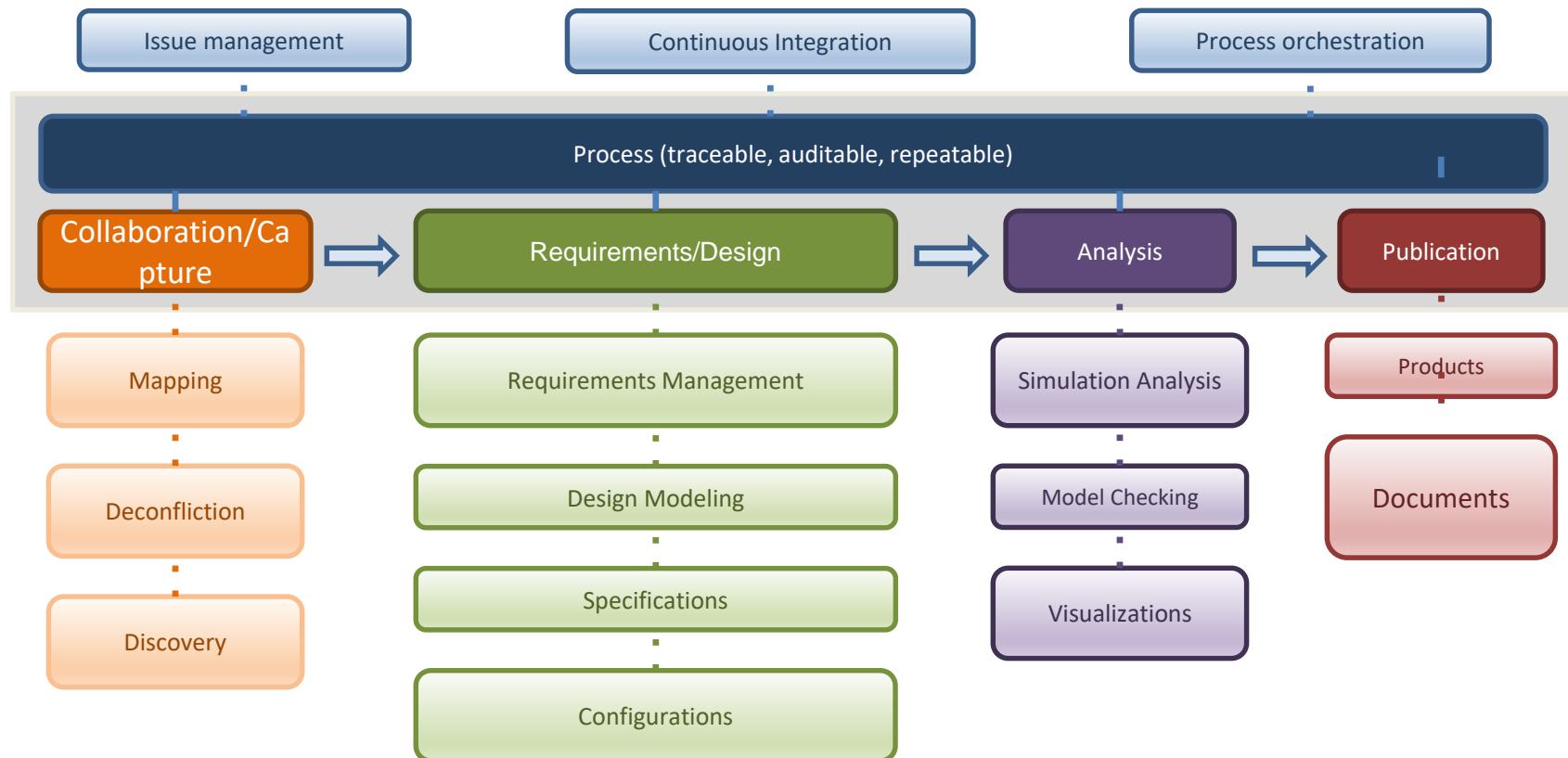
- Support **systems engineering activities** from requirements capture and management, traceable to architectural and design, and finally a wide range of analysis capabilities, data search, and integration capabilities.
- Provides **integrated life-cycle support**. The environment provides transparent interconnection and data propagation between already used tools and new tools.
- Supports a **formalized application of systems engineering** (leveraging models) to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.
- **Broader than MBSE** and supports systems modeling, behavior, analysis, and tool integrations across the portfolio of CAE tools.
- **Multi-Paradigm-Modeling** (polyglot) environment that has support and compatibility for OWL, SysML, BPMN, Modelica, Matlab, Mathematica, Python etc.
- Other platforms can make use of the environment to take advantage of its capabilities and built in integrations.



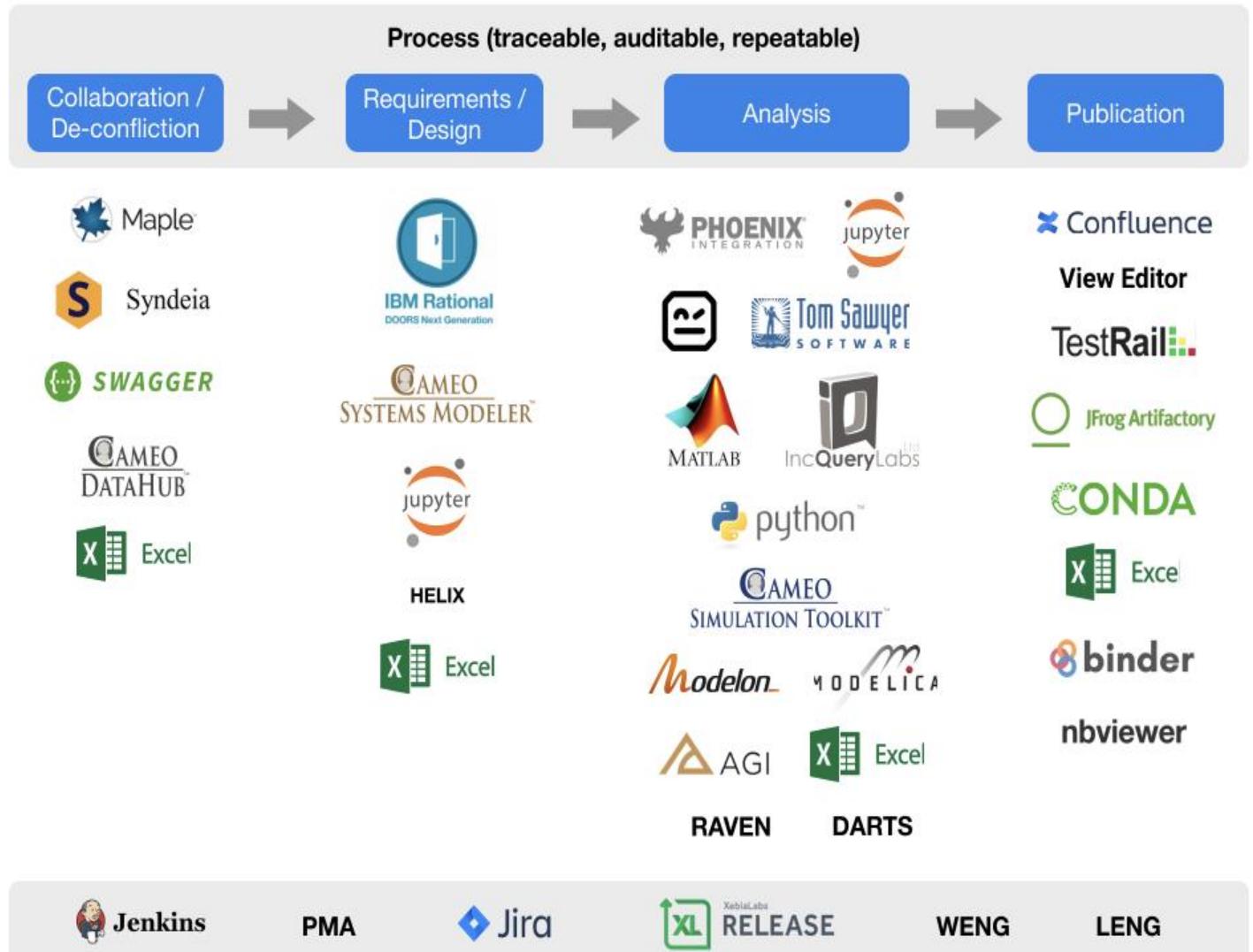
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OpenCAE Systems Environment supports a range of capabilities in an integrated Pipeline

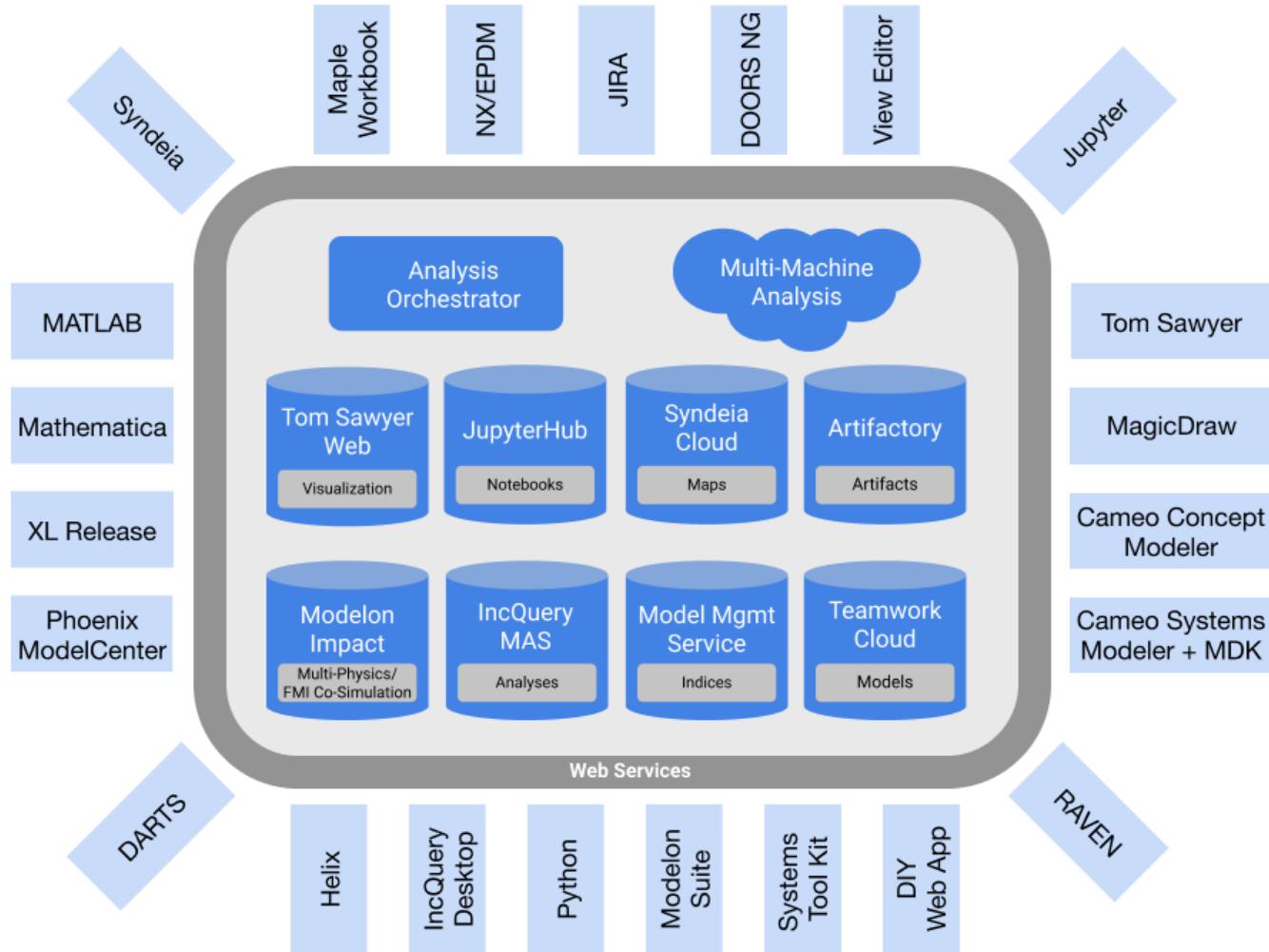


OpenCAE Systems Environment Pipeline



OpenCAE

Systems Environment Overview





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OpenCAE Systems Environment supports various Modeling Languages

Graphical



Hybrid Graphical/Text



Code/Text



Information





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OpenCAE Systems Environment Provides A Wide Range Of Capabilities for the SE Functions

	SE Function	Systems Environment Capability	Systems Environment Tools
1	Architecting	Collaborative Workspace, Data Model Design, System Modeling, Fault Protection, Design Communication, Capture Operational Scenarios, System Block Design, Visualize System Architecture	Cameo Systems Modeler, Cameo Concept Modeler, Tom Sawyer
2	Requirements	Requirements Tracking and Management, Requirements Management, Requirements Design	DNG
3	Analyze and Characterize	Capture Spacecraft Behavior, Data Transformation, Large Dataset Analysis, Shared Computing Resources, Process Automation, Multi-Domain Modeling & Simulation, System Analysis, Model Checking Flight System and Software Behavior, Analysis Result Distribution	Systems Modeler, Tom Sawyer, Modelica, STK, Maple Workbook, Jupyter, Jenkins, PMA, Cameo Simulation Toolkit
4	Technical Resources	Subsystem Data Aggregation, Data Entry, Master Equipment List (MEL), Power Equipment List (PEL)	System Modeler, Maple Workbook, Cameo Simulation Toolkit, STK
5	Interfaces	Design Communication, Systems Integration Testing, Command Dictionary Management	DNG, Cameo Systems Modeler
6	V&V	System Testing, System Integration Testing	DNG, Helix, TestRail
7	Reviews	Collaborative Workspace, Role Capture, Track Model Analytics, Decision Traceability, Document Generation, Mission Operation System Coverage Reporting, Data Visualization	Smart Bear Collaborator, View Editor
8	Risk Management	Connect Requirements to Engineering Artifacts, Safety and Reliability Analysis	JIRA Risk Plugin
9	Change management	Process Orchestration, Issue Management, Connect Requirements to Engineering Artifacts, System Configuration Management, Analysis Parameter Tracking, Manage Engineering Change Requests	DNG, MMS, TWC, Syndeia, Artifactory
10	Task Planning	Process Orchestration	JIRA, XL Release



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CAE offers project and domain specific adaptions

- CAE provides the same environment to all its customers (engineers and scientists)
- Embedded roles work directly on projects to adapt the standard environment specific to the project goals or methodology
 - This includes but is not limited to:
 - Project specific integrations
 - Project specific configurations
 - Project specific customizations
- Embedded roles capture needs in general case studies which inform the CAE architecture
- This has been demonstrated for example on M2020, Europa Lander, Europa Clipper, Psyche, Mars Sample Return, Thirty Meter Telescope



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The Systems Environment is widely used across – numbers are for 2019

Category	Number	Notes
User engagements	145	TWG, Office hours, Lab-wide talks, trainings
Apps+services	30	Number of apps - 7 Number of Services - 9 Number of client apps - 14
Environment Users	838	TWC users: 499 Jupyter users 299 Syndeia users: 40
Server projects	192	TWC projects: 186 Syndeia projects: 6
Number of embedded roles	12	
Flight projects	15	
Number of processes	63	
Number of releases	161	



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OpenCAE engages the User Community through the Technical Working Groups TWGs

Technical Working Groups are communities made up of CAE, projects, and line stakeholders, vendors

- For environment and key tools
- Identify use cases, workflows, issues, and roadmaps for each TWG area
- Discuss the state of the tool (versioning/upgrades/etc.) or a particular topic and/or to identify issues requiring support.
- Regular meetings engage stakeholders and vendors for tool-specific questions
- Tool specific WGs are open to everybody whereas the Systems Environment TWG is a moderated group
- TWGs:
 - Current: NoMagic, Intercax/Syndea, MapleMBSE, Tom Sawyer, Jupyter
 - Planned: Modelon, IncQuery



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OpenCAE engages the User Community through various Channels

- OpenCAE Portal
- OpenCAE Systems Environment Office Hours
- Slack channels
- Wikis
- Stack Overflow
- Jira Service Desk
- Videos
- Outlook calendars
- Mailing lists



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Europa Lander Embedded Role

- Need:
 - Generate orderly and palatable diagrams from a system model describing the Lander
 - SE products should never be out of sync with the system model
- Approach:
 - Leverage Tom Sawyer plugin for MagicDraw development effort
 - Supply requirements directly from the project to the vendor
 - Coordinate with CAE development team on the use case for Tom Sawyer integration with DocGen and View Editor

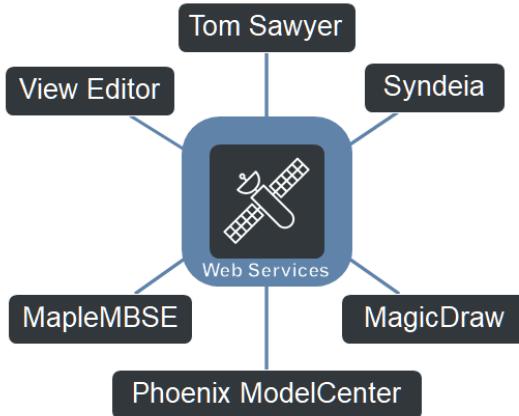


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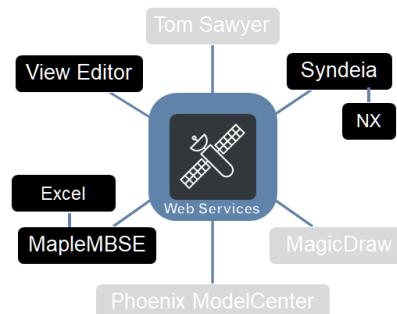
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Europa Lander Environment Adaptation Examples

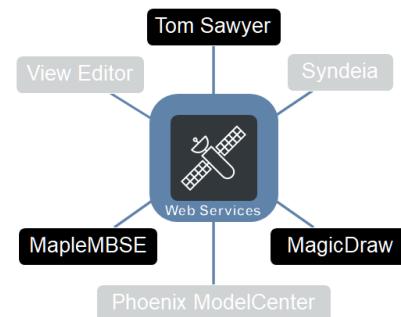
Selected Subset



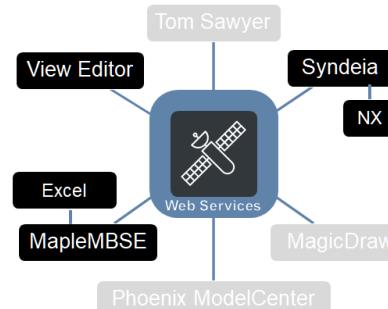
Compositional System Design



System Block Diagram



Master Equipment List





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M2020 Embedded Role

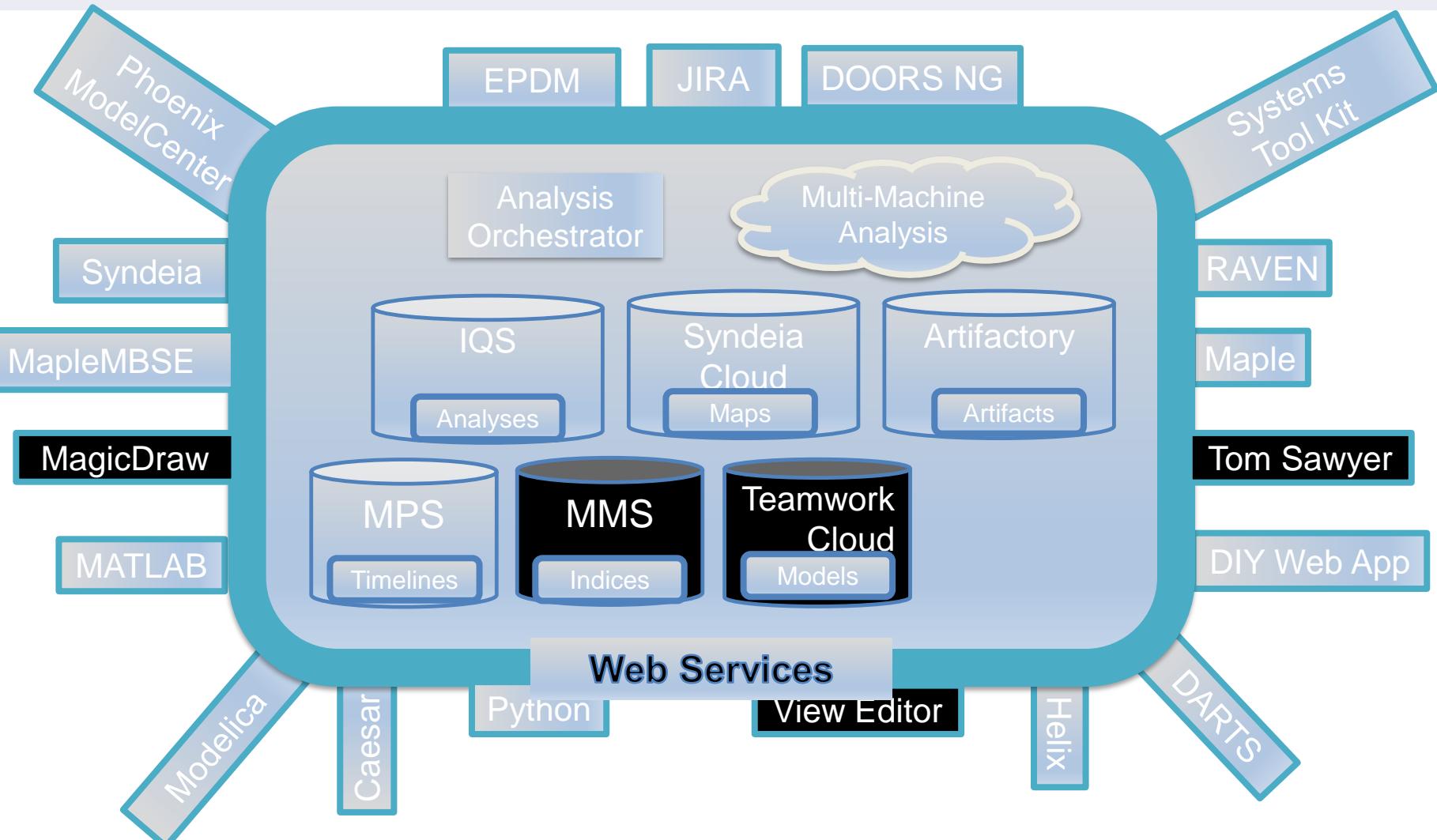
- Ground Data System (GDS) Consolidation
- Flight System Model integrity
- Integration for generated artifacts
- Customized documents support
- Testing and Deploying various customizations of CAE Systems Environment



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M2020 Subset of Systems Environment



OpenCAE DevOps



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NESC MBSE Pathfinder Embedded Role

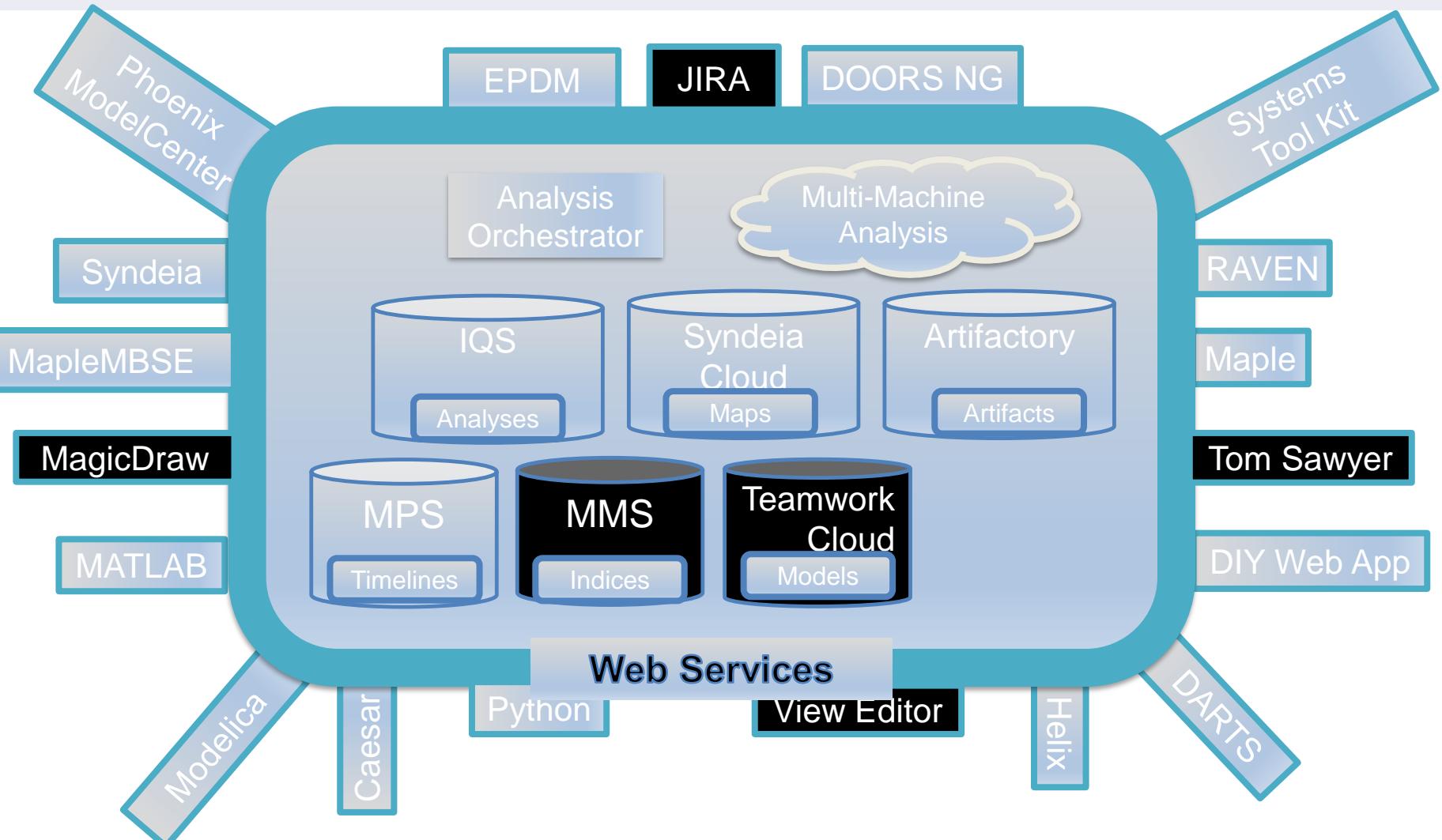
- Apply Best Modeling Practices
- Investigate and use various workflows in environment in a restricted environment
- Specified Training and Tutorials
- Team meetings and evaluation support
- On Call Support



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NESC MBSE Pathfinder subset of Systems Environment





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Europa Clipper Embedded Role

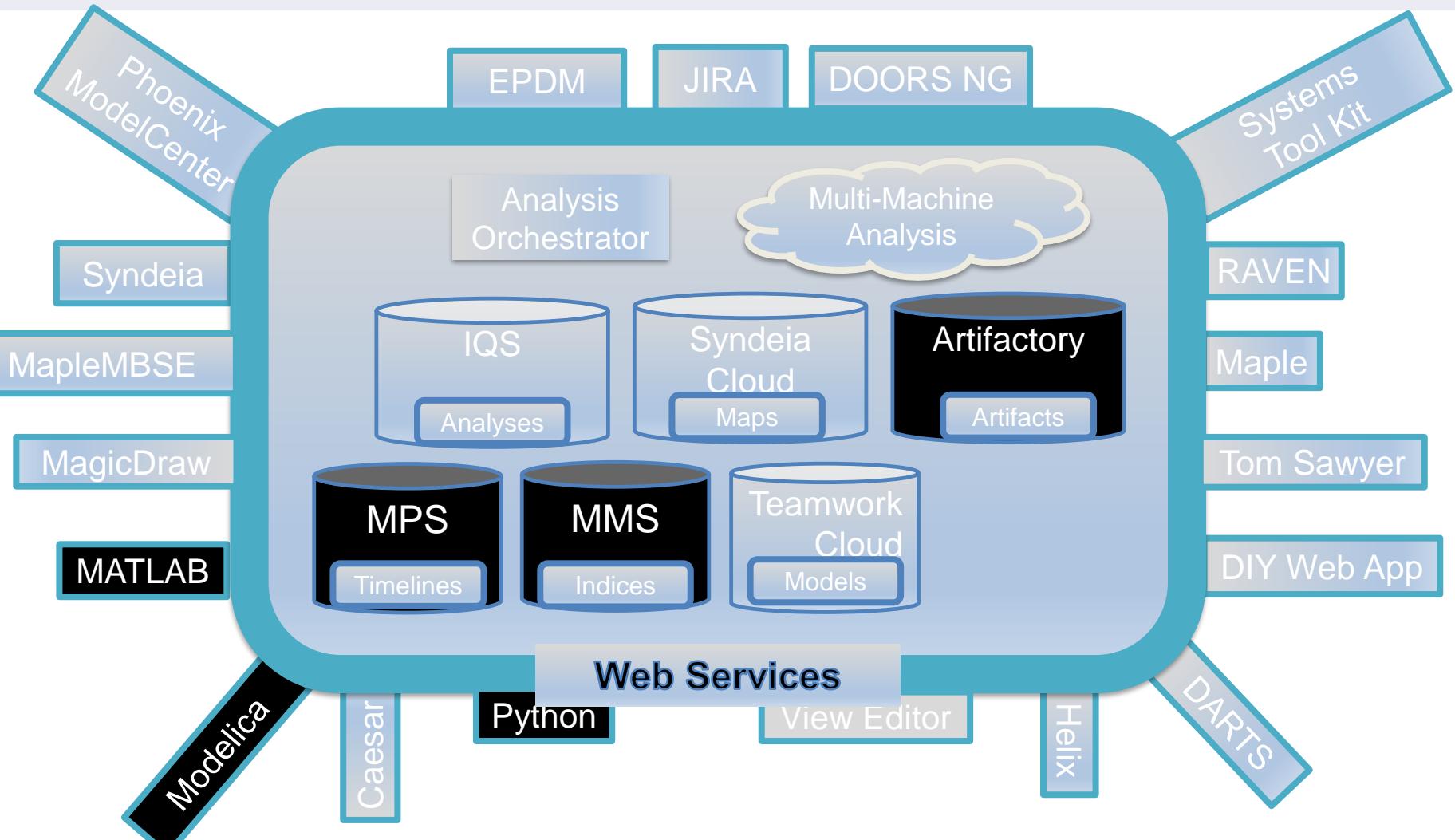
- Need:
 - Publish artifacts to CAE services (MMS, TES, Artifactory)
- Approach:
 - Express the REST API endpoints of these servers in OpenAPI standard specification
 - Use Swagger codegen to generate clients for specific analysis environments
 - Mathematica, MATLAB, Python, Java
 - More than 20 other languages available



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Europa Clipper subset of Systems Environment



OpenCAE DevOps



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Europa Clipper Embedded Role

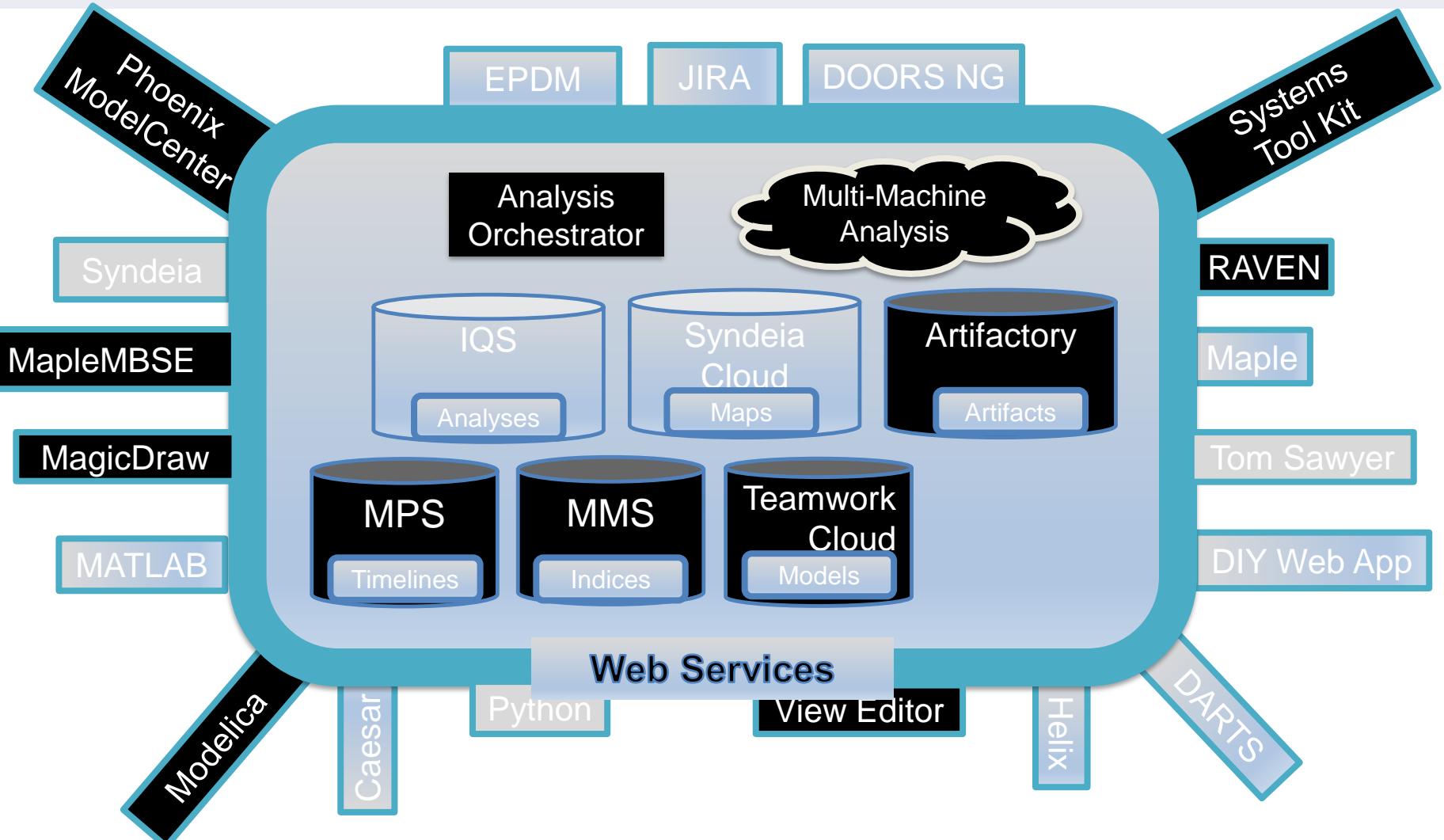
- Need:
 - Formalize analysis workflows related to the Clipper Flight System
 - Want to capture the workflows in a model, but also want them to be executable
- Approach:
 - Use Phoenix MBSEPak plugin for MagicDraw to translate the workflow parameters into Phoenix ModelCenter
 - Configure ModelCenter to use shared components in the Analysis Library of ModelCenter Cloud



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Europa Clipper subset of Systems Environment





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OpenSE Cookbook addresses Systems Engineering Concerns

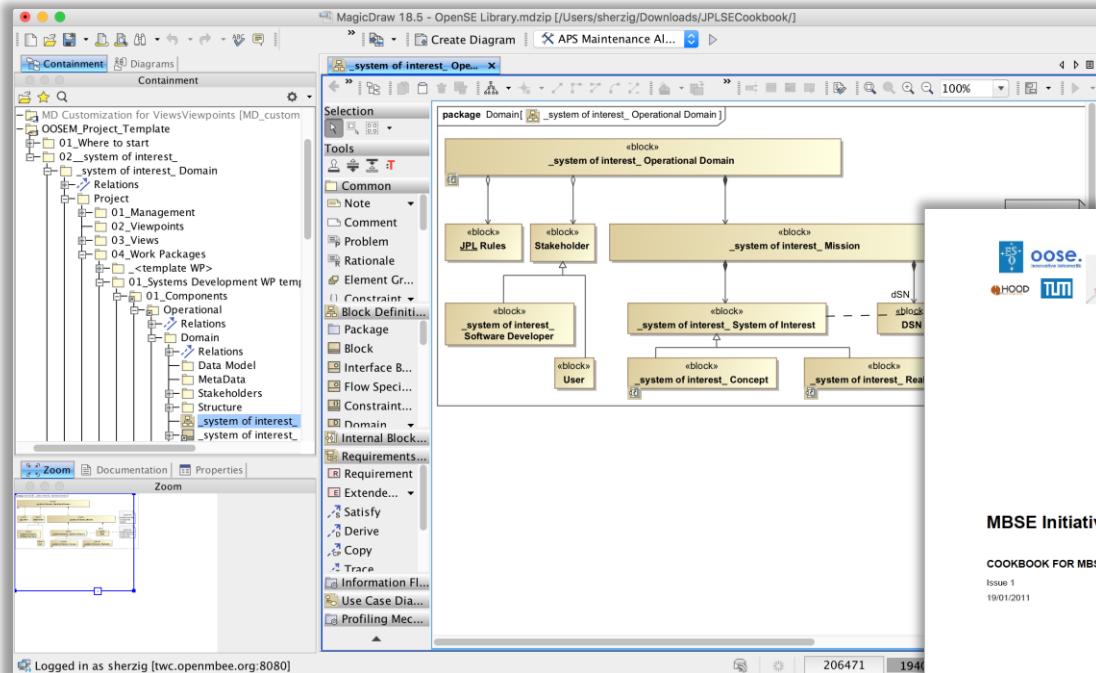
- Provides goal oriented guidance using patterns, e.g.
 - How-to Verify Requirements
 - How-to Roll-up Technical Resources
- Driven by Systems Engineering Workflows
- Enables combining patterns into more complex recipes
- Demonstrates how to build system models with available tooling - How/where do I start?
- Includes known usages in TMT production model as reference
- Commoditizes Executable Systems Engineering



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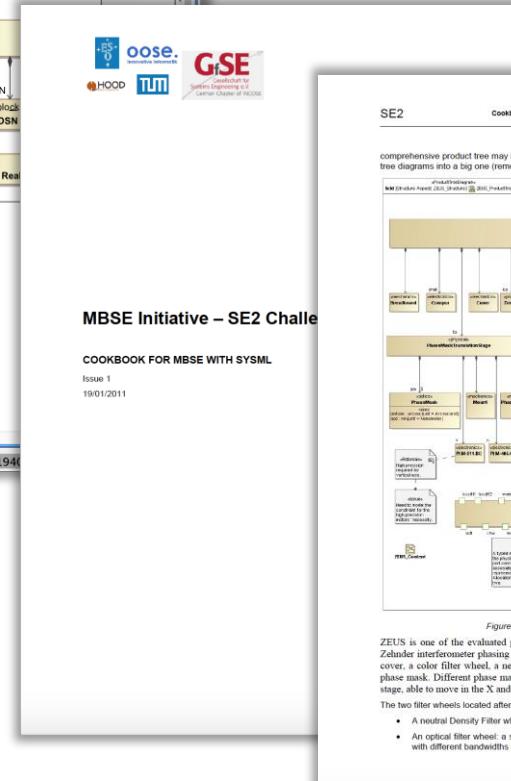
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OpenSE Cookbook and Template Model



Template models to be used by projects as
a starting point, with recommended
organization, model libraries, etc.

“Cookbook” for modeling
methodology & patterns



ZEUS is one of the evaluated phasing sensors (Figure 5) and is based on the modified Mach-Zehnder interferometer principle. It is mounted on a breadboard and consists of a shutter, a cover, a color filter wheel, a neutral density filter wheel, and a translation stage which carries a phase mask. Different phase masks can be switched to the focal position by means of a translation stage, able to move in the X and Y directions:

- A neutral Density Filter wheel: a set of 8 different neutral density filters are available
- An optical filter wheel: a set of 8 different optical filters centered on different wavelengths and with different bandwidths are available

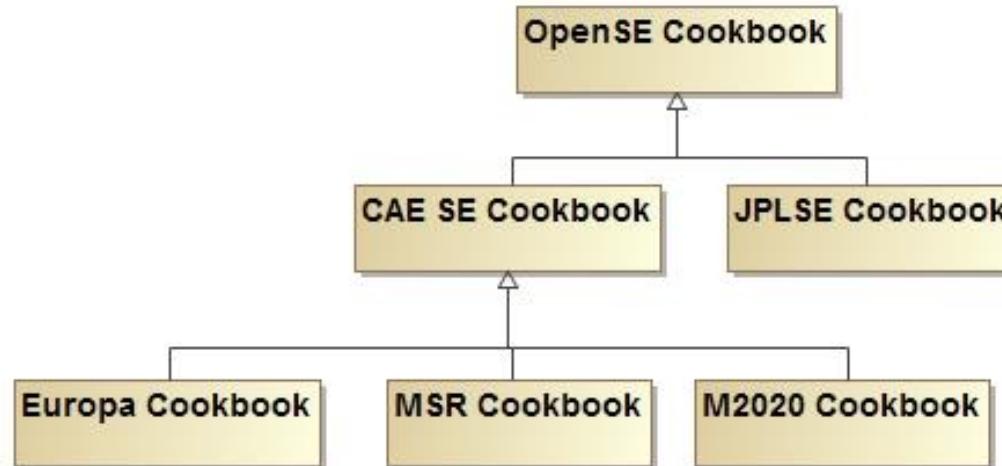


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OpenSE Cookbook promotes re-use

- OpenSE Cookbook contributes to JPL institutional and project specific Cookbooks
- Project-independent modeling patterns as guidelines
- Project-specific modeling patterns for common modeling tasks





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OpenSE Cookbook is used as reference

- OpenSE cookbook and TMT model used as reference model for the OMG SysML 2 standard
 - Demonstrate how SysML 2 will improve, simplify, change model wrt SysML 1.x
- Training material and knowledge transfer
- Promote standards and conventions
- Used by vendors as reference to test and evolve products



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Requirements Verification Recipe

- **Intent**
 - Validate requirements, verify as designed system against requirements and publish analysis results
- **Cookbook Volume**
 - System Requirements Management
- **Educational example**
 - Autonomous Ferry Transportation
- **Known Uses**
 - APS - Post-segment exchange timing requirements
- **Tooling**
 - Cameo Systems Modeler and Simulation Toolkit, View Editor
- **Notes**
 - Property Based Requirements links Requirements Management and System Design



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openmbee.org

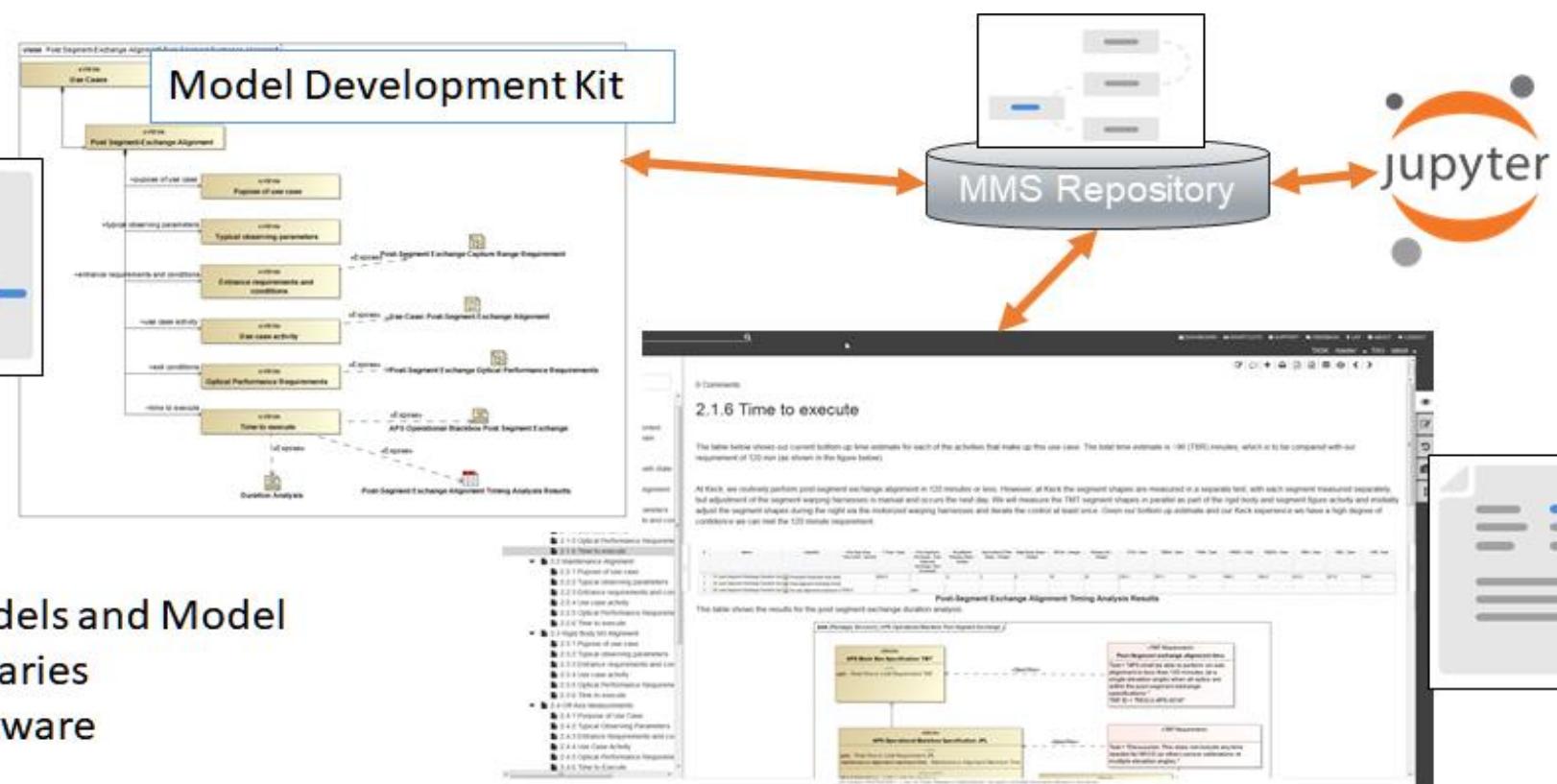
- OpenMBEE is a community for open-source modeling software and models
 - Number of open source software activities
 - Number of open source models
- JPL is a participant and adopter of OpenMBEE software and models
- Along with Boeing, Lockheed, OMG, NavAir, Ford, Stevens, GaTech, ESO
- Vendor participants
- ~350 members



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OpenMBEE Models and Software



- Models and Model Libraries
- Software



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BACKUP SLIDES



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CAE System Environment Applies Industry Standards Via Vendors

1. Information integration and interchange based on international standards and vocabulary for knowledge representation in Systems Engineering
2. Wide range of standards – e.g. FMI, BPMN, UML, SysML, PSSM, PSST, PSCS, fUML, UAF, SCXML, DITA, OSLC, XMI, ALF, ISO 42010, ISO/IEC 19514:2017, OpenAPI
3. Usage of standard APIs
4. Represent knowledge as a graph to query it using view and viewpoint according to ISO 42010
5. Endorsed by INCOSE
6. Widely used in larger and smaller projects around the world in different domains
7. Precise semantics for executability
8. Wide tool support - e.g. PTC, IBM, NoMagic, Mentor, TomSawyer, Papyrus, Phoenix, Intercax, Maple, IncQuery

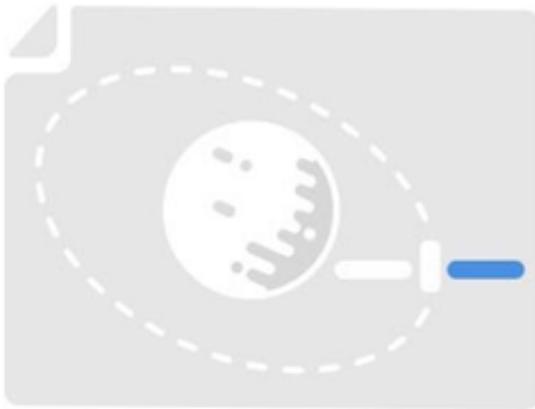




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Precise Engineering Information and Products

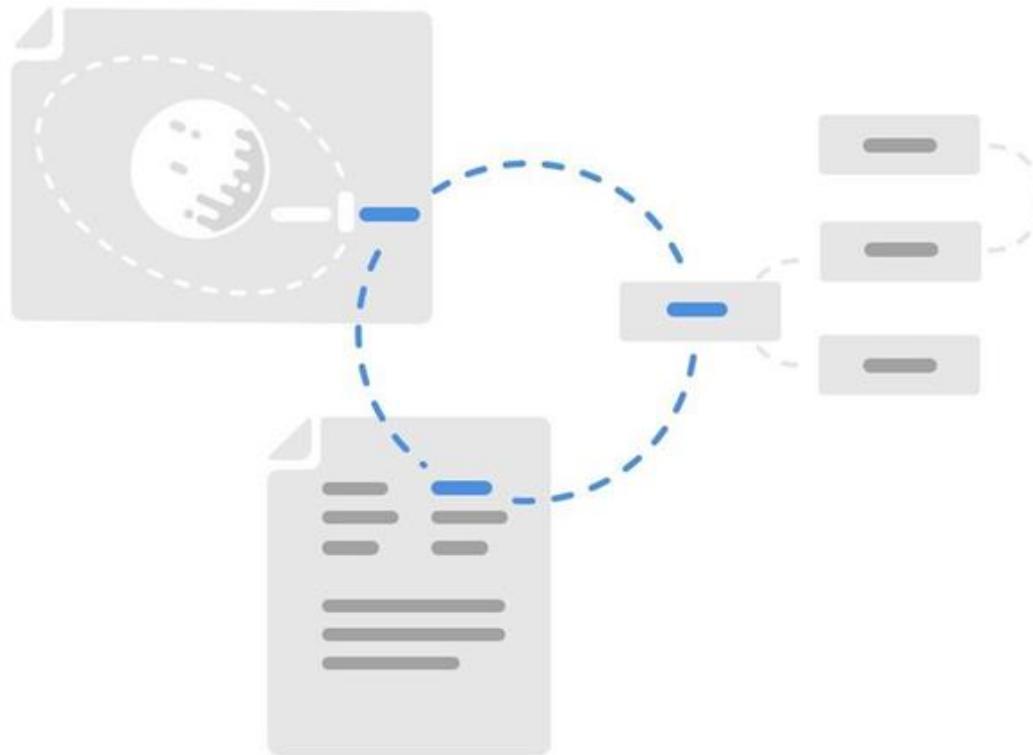




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Engineering Information corresponds to Products





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Linked Data Documents with OpenMBEE





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Plots in ViewEditor with docgen

MagicDraw 19.0 - Docgen #55 [cae-twc-test2.jpl.nasa.gov:10000]

Perspective: Full Featured | Create Diagram | View Readme (Windows) | > |

Containment | Structure | Diagrams | Lock View

Containment

Data (by myraAdmin)
 └── MSSync (by myraAdmin)
 └── Docgen (by myraAdmin)
 └── holding_bin (by myraAdmin)
 └── Migration Tests (by myraAdmin)
 └── Plot Example (by tannerAdmin)
 └── Dinosaur data (by tannerAdmin)
 └── Height (by tannerAdmin)
 └── Year 1 = 2
 └── Year 2 = 3
 └── Year 3 = 7
 └── Year 4 = 9
 └── Year 5 = 13
 └── Weight (by tannerAdmin)
 └── Year 1 = 2
 └── Year 2 = 4
 └── Year 3 = 7
 └── Year 4 = 16
 └── Year 5 = 30
 └── Tests (by tannerAdmin)
 └── View (by tannerAdmin)
 └── Views (by myraAdmin)
 └── TS Profile (by myraAdmin)
 └── LICENSE
Code Engineering Sets

Apache Lic... (by myraAdmin)

Dinosaur Data View X

Selection Tools Common Note abc Text Box Anchor Constraint Contain... Abstract... Dependency Image Shape Diagram O... Views and View... Document View Viewpoint Stakeholder Conform Expose Directed Co... Directed Agg...

package View [Dinosaur Data View]

«view» Dinosaur Data

Notification Window

Notification Window

[2018.07.27:13:50:54] Distro --> End Sync Content Validation Summary
[2018.07.27:13:50:54] Updating/creating 2 elements to generate views.
[2018.07.27:14:19:27] Updating/creating 1 element to generate views.
[2018.07.27:14:19:27] Deleting 1 unused presentation element.

No symbol at (594, 415)

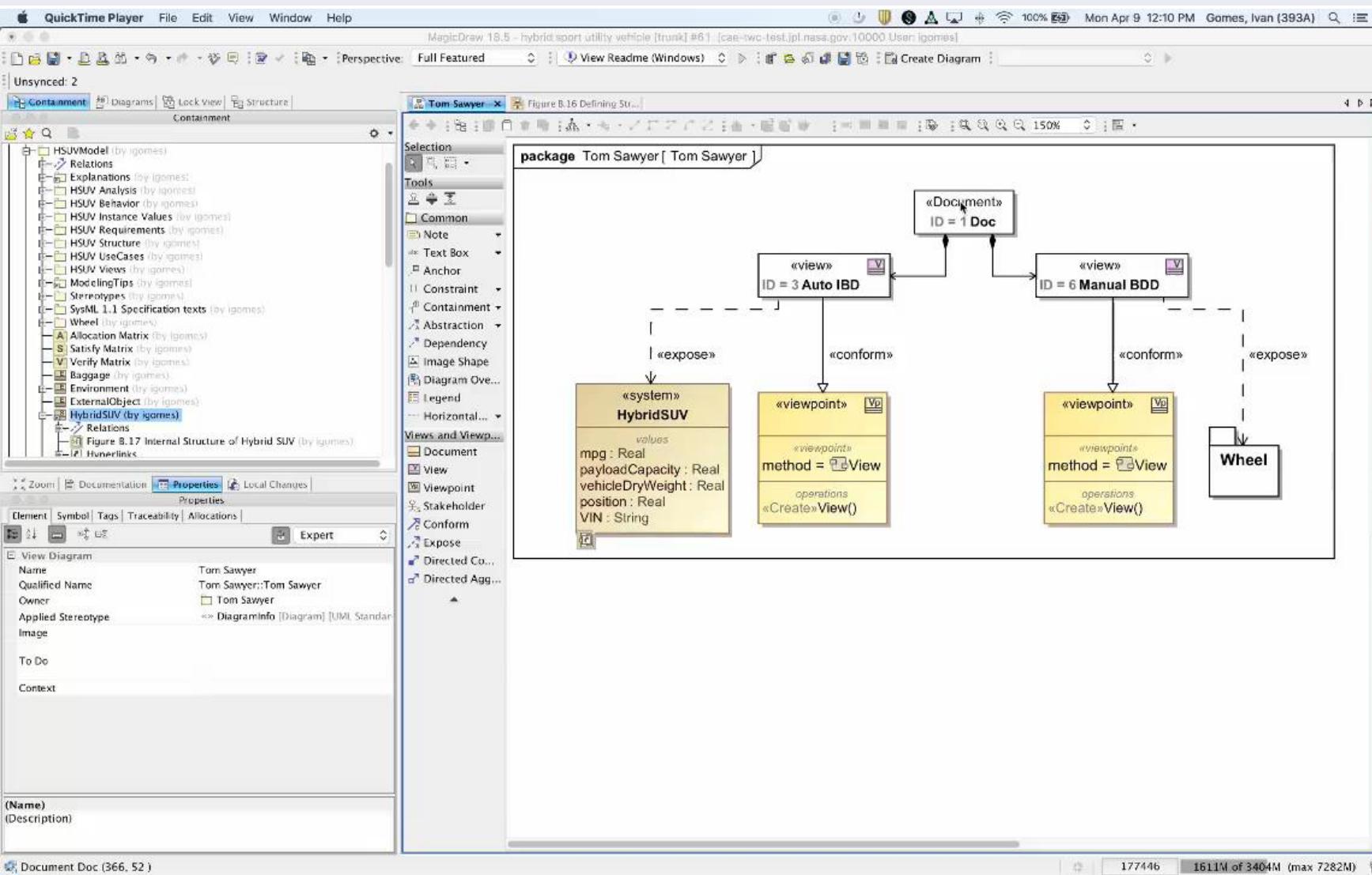
1358M of 1980M (max 3556M)



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Docgen and Tom Sawyer





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Jira – Syndeia - Jupyter

Mapping Modeled Processes to JIRA Issues



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DNG – Syndeia - Jupyter

Mapping Modeled Processes to DNG Requirements

Automated Jupyter Notebook Execution



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MATLAB Integration

VE CAE TEST Switch Org

Secure | https://opencae-test.jpl.nasa.gov/alfresco/mmsapp/mms.html#/projects/PROJECT-ef9294c3-4ad4-42a0-be32-6a80ec76e43a/master/documents/MMS_1530114810819_91f44af8-8d...

Project: MD_19_0_Testing_MDK_3_4_0_rc6 > MATLAB Adapters > MATLAB - Update Documentation Branch: master

DOCLIB 0 Comments

MATLAB - Update Documentation

Monday

Tuesday

Original Documentation



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Model Checking and Validation with VQL

The screenshot shows the MagicDraw 18.5 interface with the 'Containment' perspective selected. The title bar indicates 'MagicDraw 18.5 - IncQuery Activity Diagram Name Demo Start.mdzip [Users/denk/Documents/MDK_Development/IncQuery_Activity_Diagram_Name_Demo/]'. The left-hand navigation pane displays a tree structure under the 'Model' node, including 'Relations', 'Example Package', 'Example Activity' (which contains 'Wrong Name Example Activity'), 'IncQuery_Schema_Active_Validation [IncQuery_Schema_Active_Validation.mdzip]', 'MyRules', 'Queries', 'Quick Fixes', 'IncQuery_Custom_Queries_Profile [IncQuery_Custom_Queries_Profile.mdzip]', 'IncQuery_Schema_Profile [IncQuery_Schema_Profile.mdzip]', and 'Code Engineering Sets'. The main workspace is currently empty, showing the 'IncQuery Results' view which displays 'IncQuery Results' and 'Model Model'. The bottom status bar shows 'Ready', '19229', '955M of 1566M (max 3556M)', and a battery icon.



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Jupyter REST Integration

CAE SSwE
Systems Environment
Data integration, processing
and publication using Jupyter
and REST services



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Jupyter Robot Framework Integration

The screenshot shows a Jupyter Notebook interface with the following details:

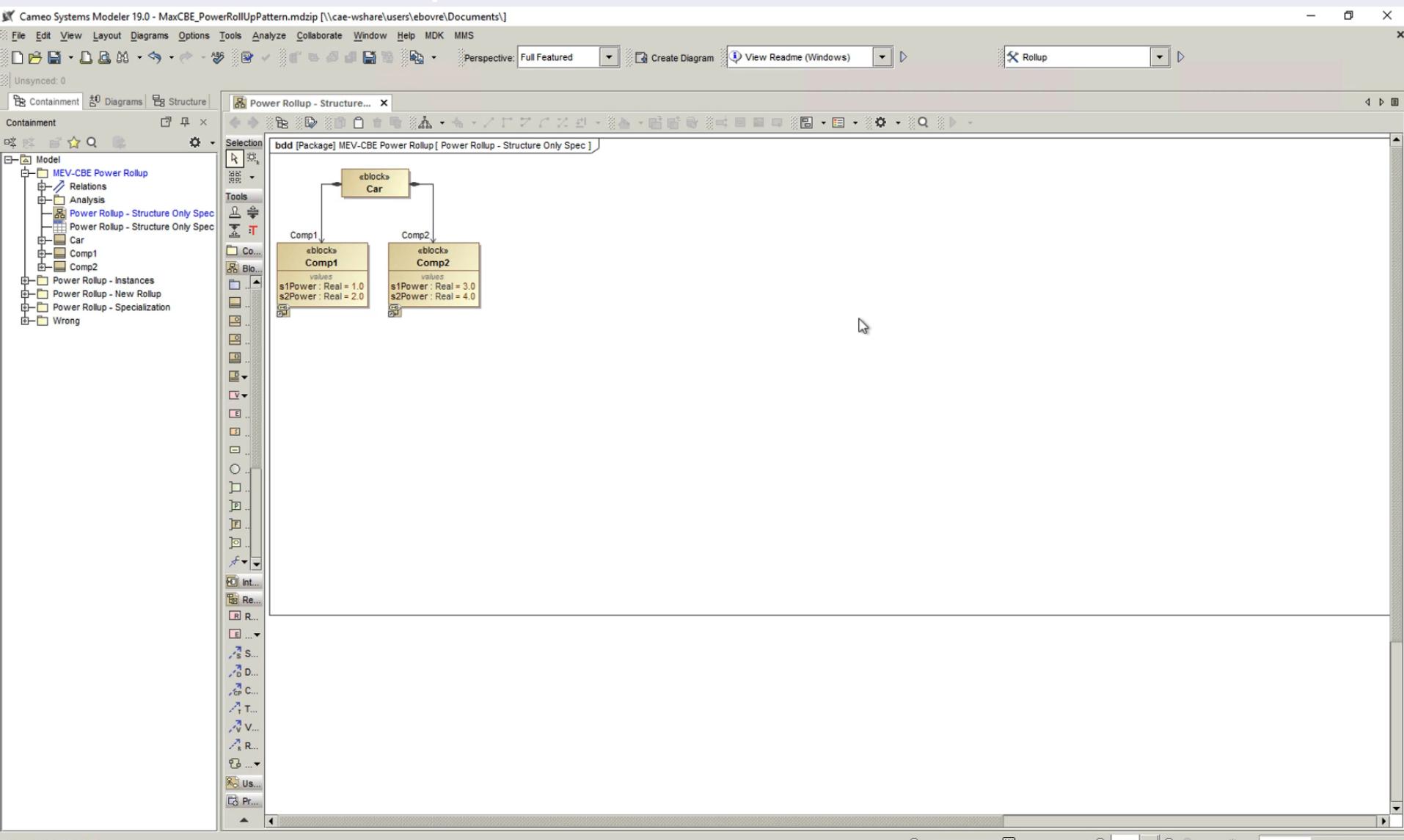
- Title Bar:** "jupyter RobotFrameworkExample Last Checkpoint: 34 minutes ago (unsaved changes)"
- Toolbar:** File, Edit, View, Insert, Cell, Kernel, Widgets, Help, Trusted, Robot Framework
- Code Cells:**
 - In []: *** Settings ***
 - Library SeleniumLibrary
 - Library SeleniumScreenshots
 - Suite teardown Close all browsers
 - In []: *** Keywords ***
 - Open url [Arguments] \${url}
 - Open browser \${url} browser=headlesschrome
 - Set window size 800 600
 - In []: *** Test Cases ***
 - Show the new Robot Framework logo
 - Open url https://twitter.com/robotframework
 - Page should contain Robot Framework
 - Capture and crop page screenshot robotframework.png
 - ... css=.ProfileAvatar-image
 - In []: *** Test Cases ***
 - Show Plone logo
 - Open url https://plone.org
 - Page should contain element css=.navbar-brand
 - Capture and crop page screenshot plone.png
 - ... css=.navbar-brand
 - In []: *** Test Cases ***
 - Demonstrate failing test
 - Open url https://plone.org



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CBE and MEV Power Rollup



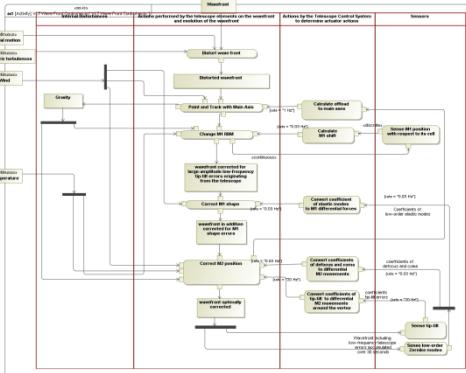


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Complexity increases

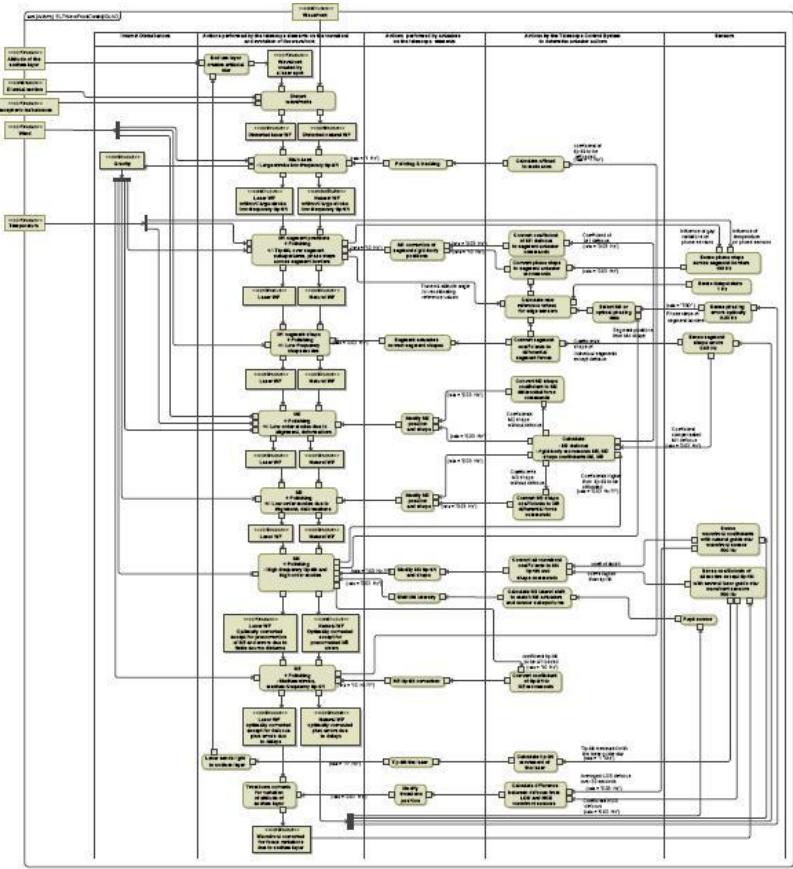
VLT Wavefront control



- 600 tons of steel and glass
- 200 actuators, 3 mirrors
- 2000 I/O points
- Small data volume
- Some interacting, distributed control loops (0.01Hz->50Hz)
- Overall function and performance of the telescope is allocated to the control system

- 100
- 200
- 450
- Large
- only eng
- Multi
- loops (0
- Ove
- telescop

E-ELT Wavefront control

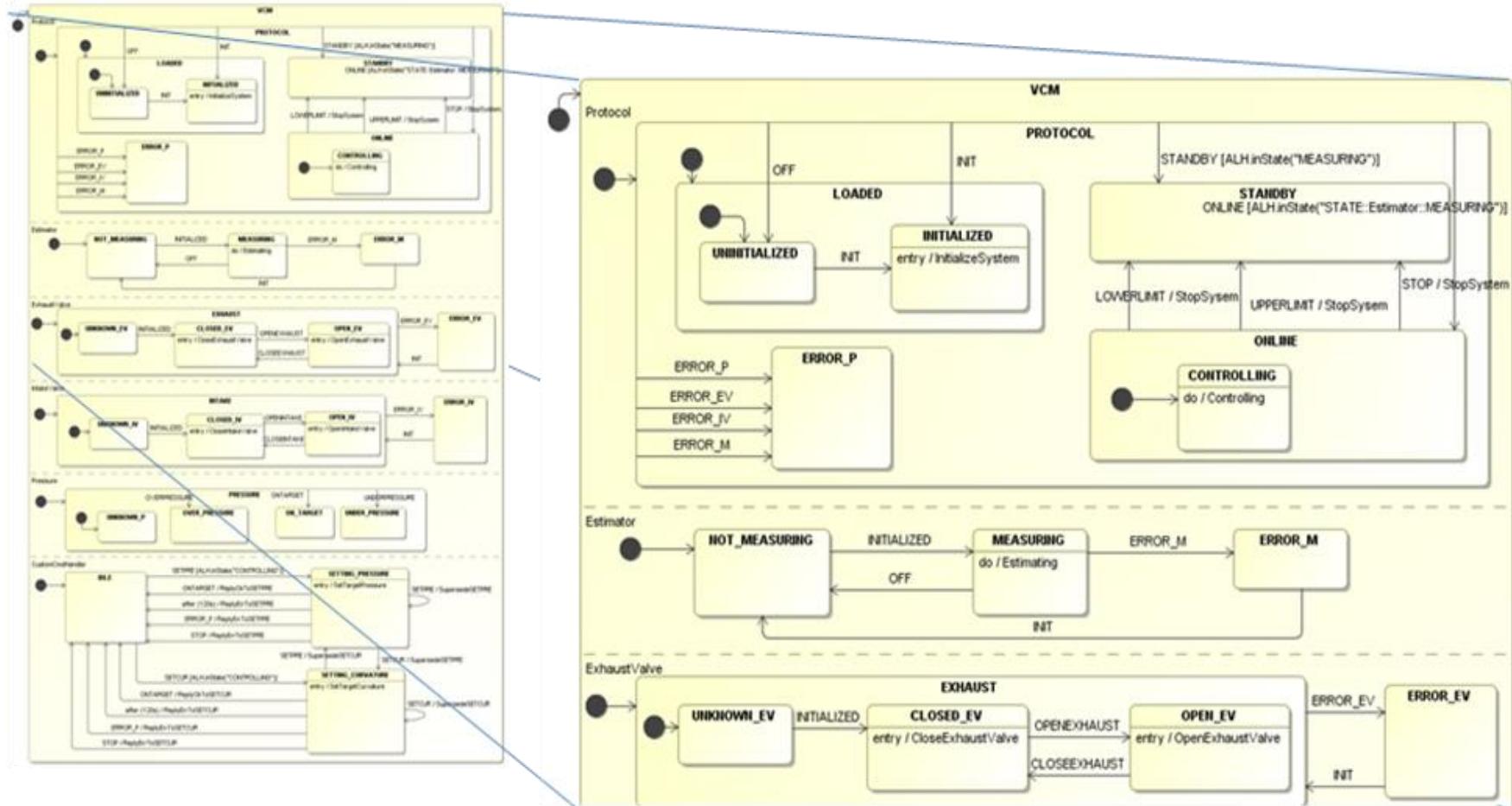




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VCM – model checking

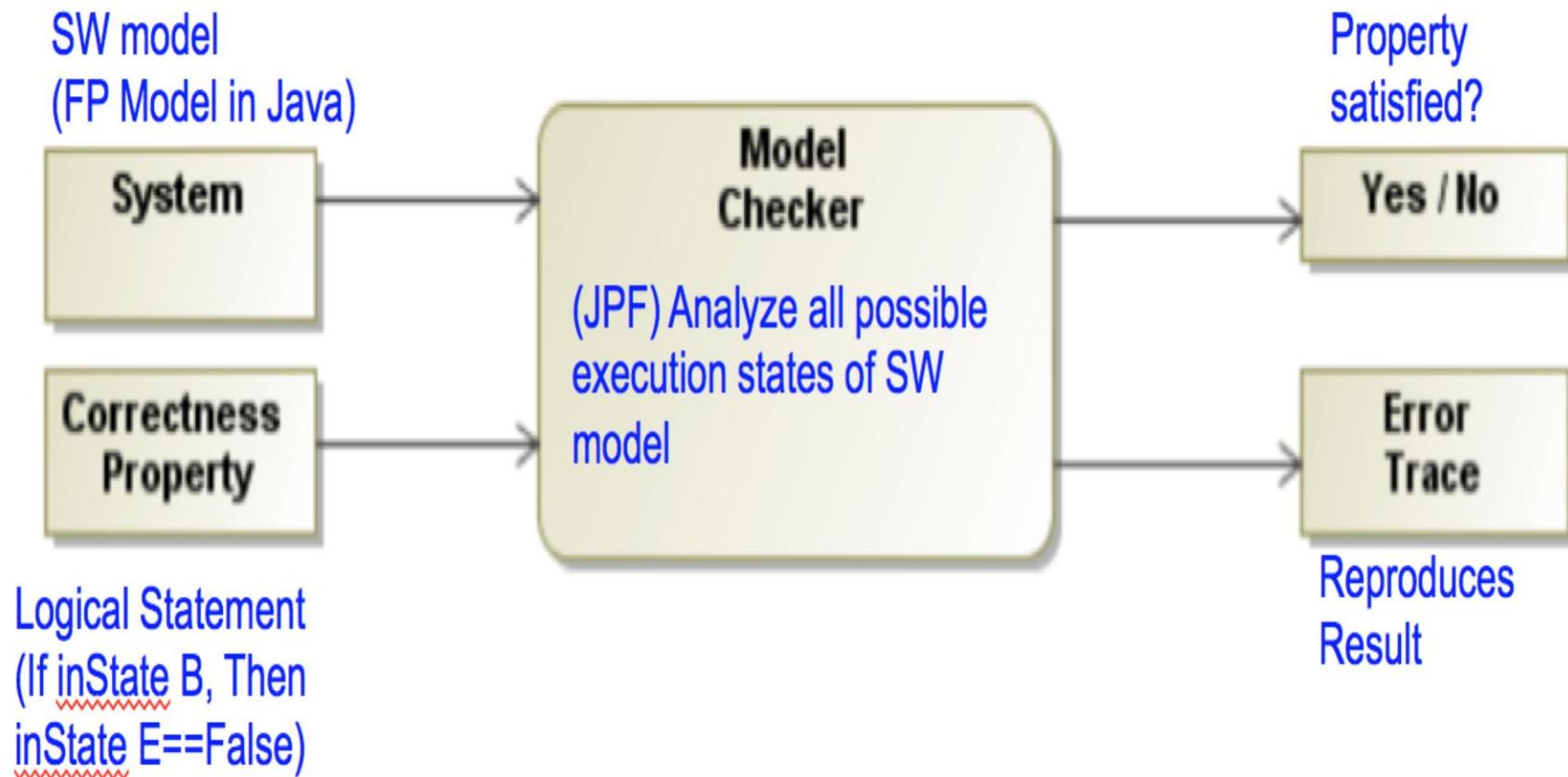




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Transformation Example: Model Checking

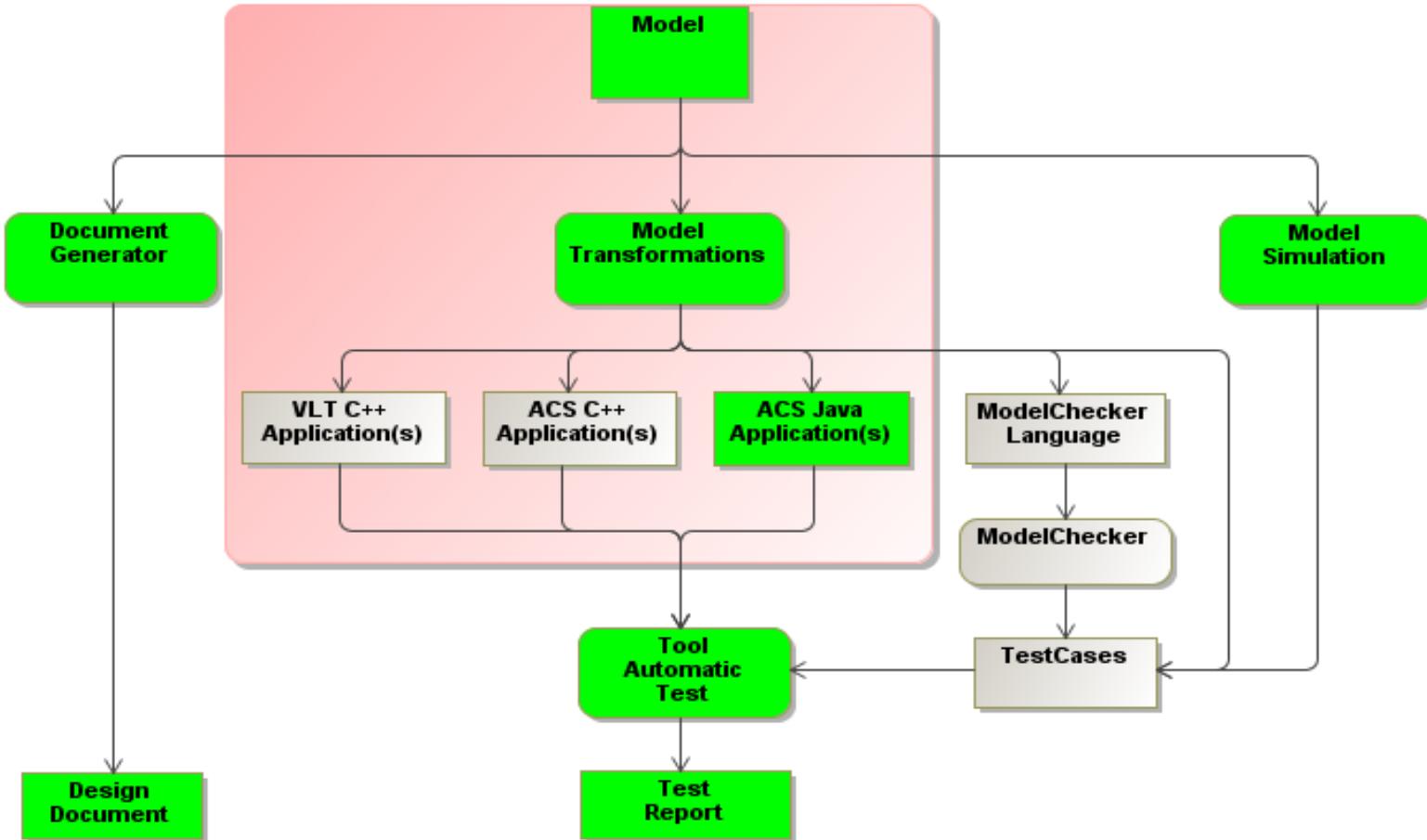




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Model Driven SW Development





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