MBSE Solution Overview

2015

Meet No Magic

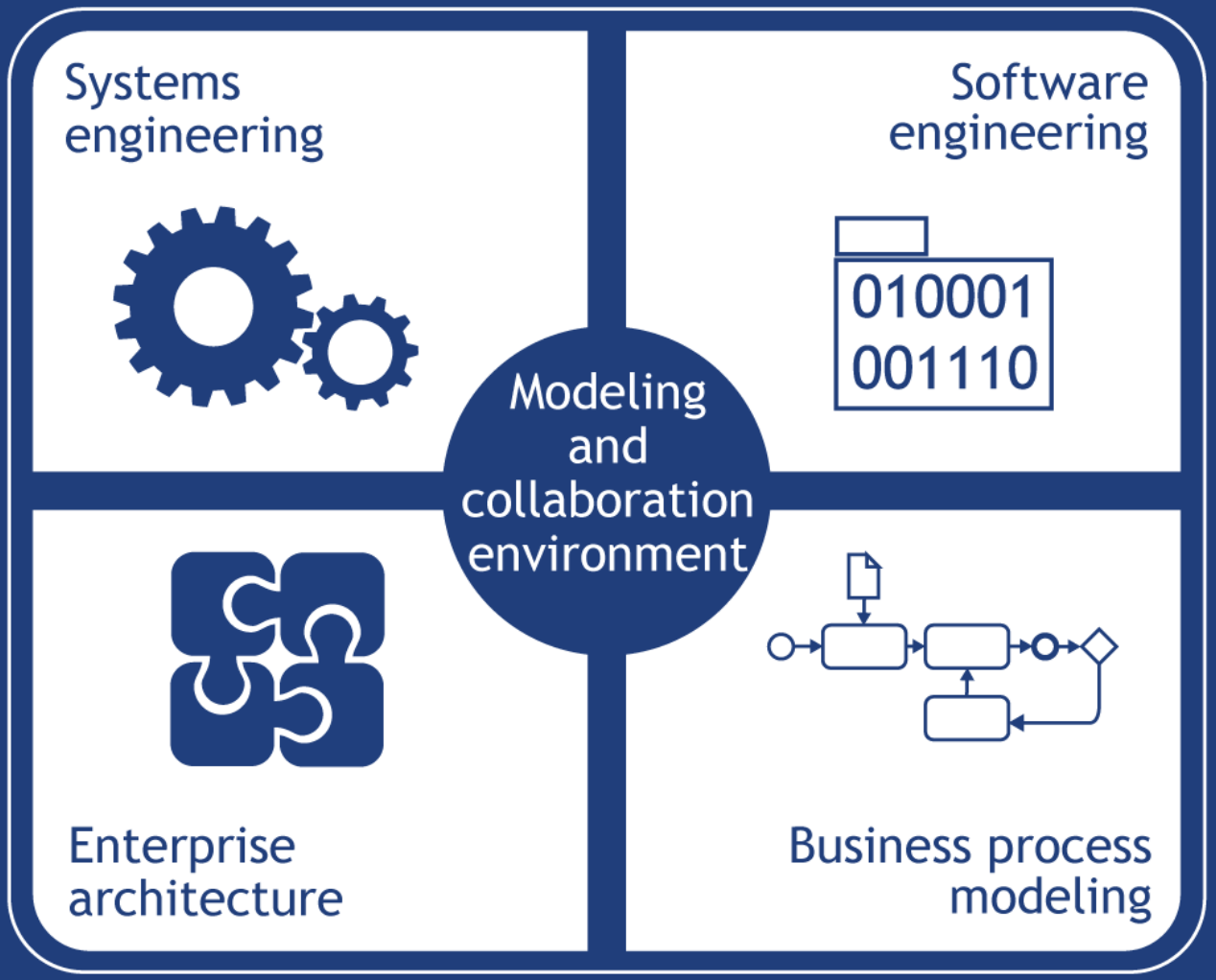
4000+ trainings

1000 000+ installations

10 000 companies

in **90** countries

Solutions for Enterprises from No Magic

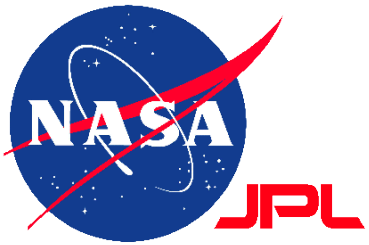


They Trust Us

NORTHROP GRUMMAN

SIEMENS

LOCKHEED MARTIN



Raytheon

EADS

MITRE

ONTARIO SYSTEMS

BAE SYSTEMS

EUROPEAN SPALLATION SOURCE

KONGSBERG

BOMBARDIER

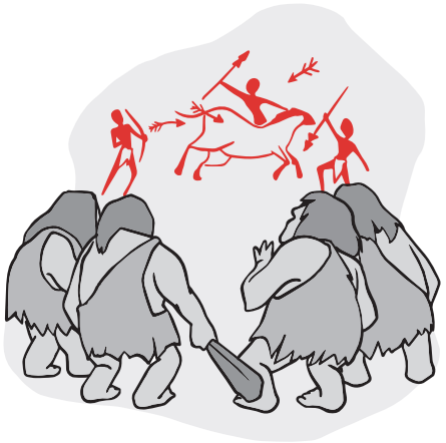
NAVSEA WARFARE CENTERS

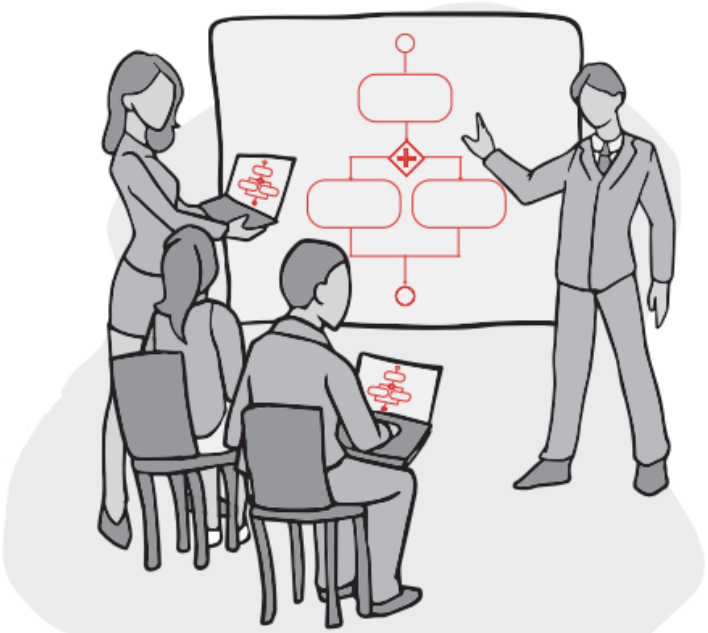
BOSCH

Sandia National Laboratories

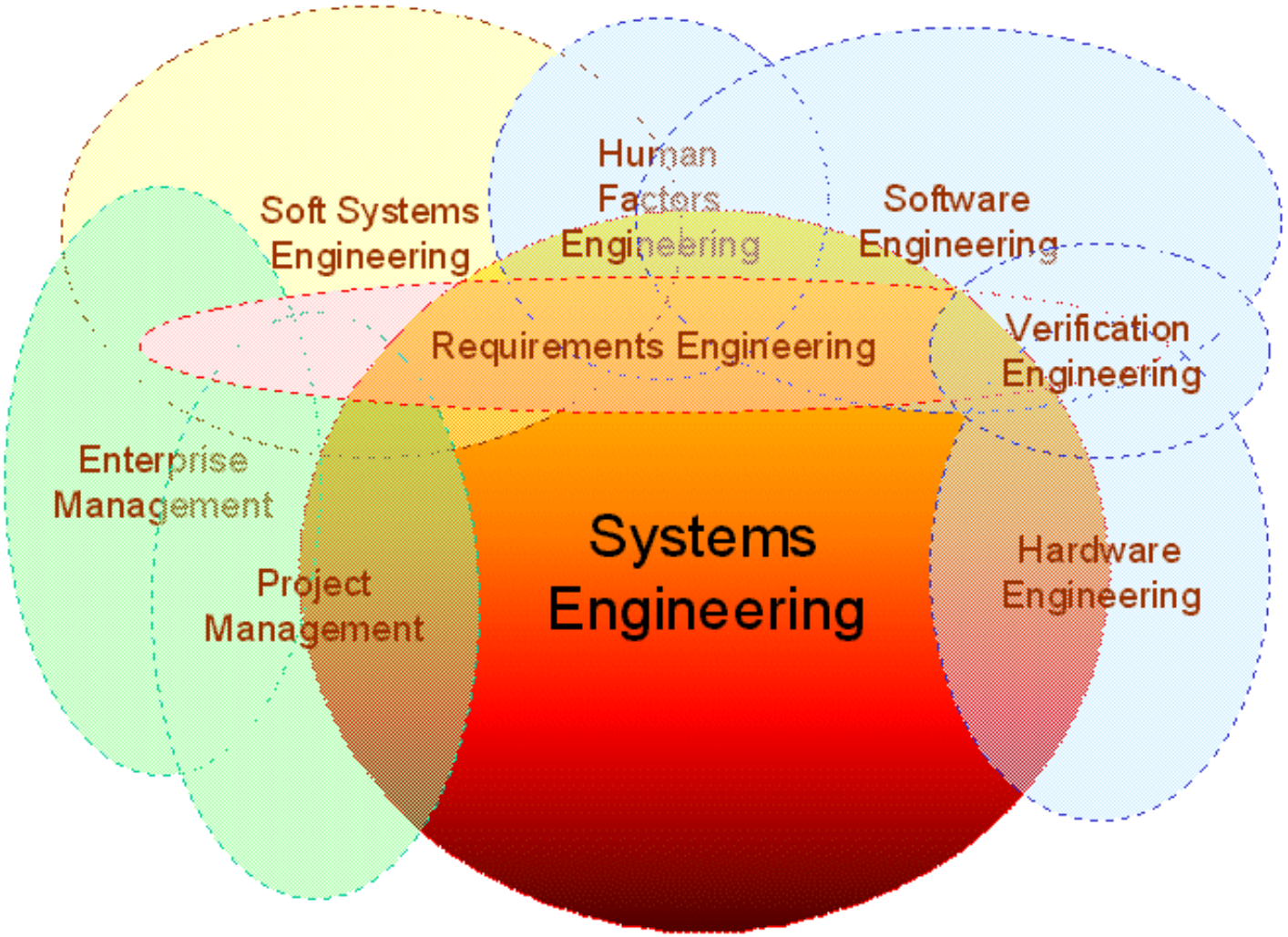
Why Modeling?

Evolution of forms of information

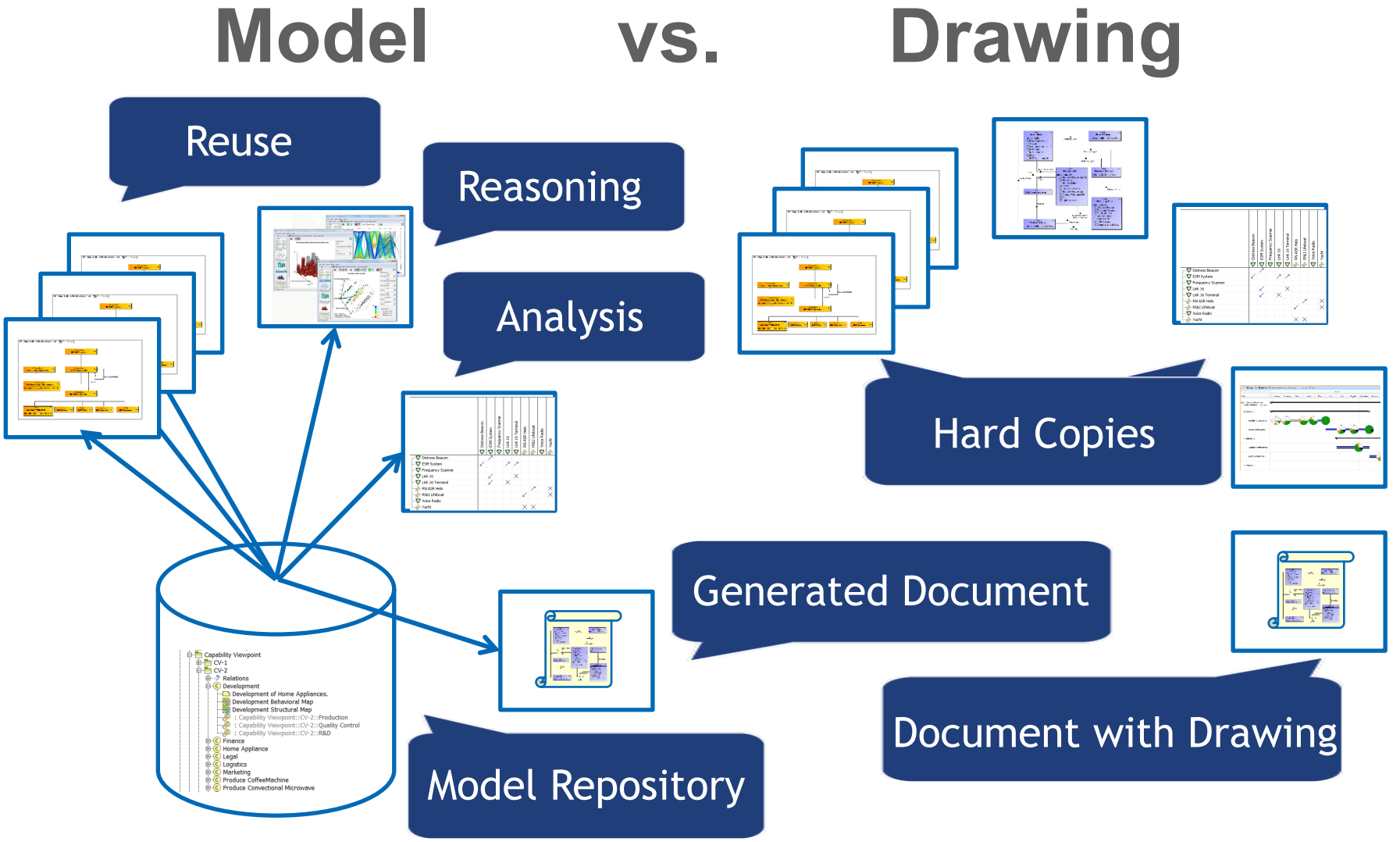




Systems Engineering



Model vs. Drawing



Why Do We Model?

- **Increased productivity:**
  - Improved impact analysis of requirements changes
  - Improved interaction across a multi discipline team
  - Reuse of existing models to support design and technology evolution
  - Auto-generation of documentation
- **Reduced Risk:**
  - Improved cost estimates
  - Early, and on-going, requirements validation and
  - design verification
- **Managed complexity**
- **Preserved knowledge (The Truth is in the Models)**

Why should you care?

Document based approach works, but...

According to some researches, statistically 55% highest level severity defects are made in Requirements Analysis and Design phases.

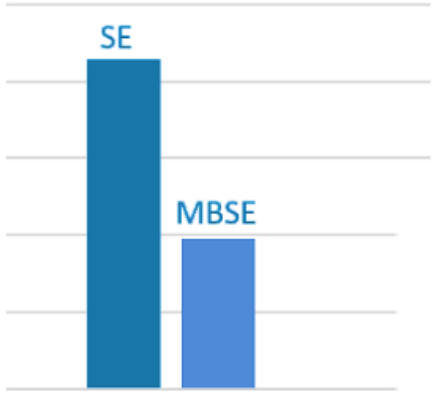
Bombardier claims the percentage is 80%

MBSE Survey Results

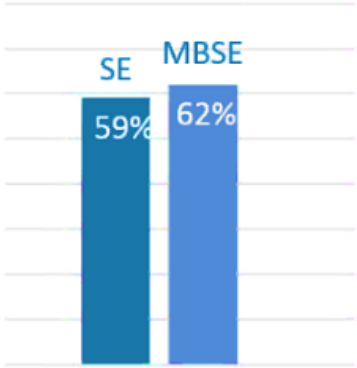
- **SE** (Non-Modelled Systems Engineering)
  - 59% of Projects Delivered on Time
- **MBSE** (Model-Based Systems Engineering)
  - 62% of Projects Delivered on Time

Compared to SE

- 55% Reduction in Total Development Cost per Project
- 16% More Project Delivered on Time



Development Cost per Project



On Time Delivery

(EMF 2013 Independent Survey Results from 667 Systems engineering respondents)

Language. Method. Toolset

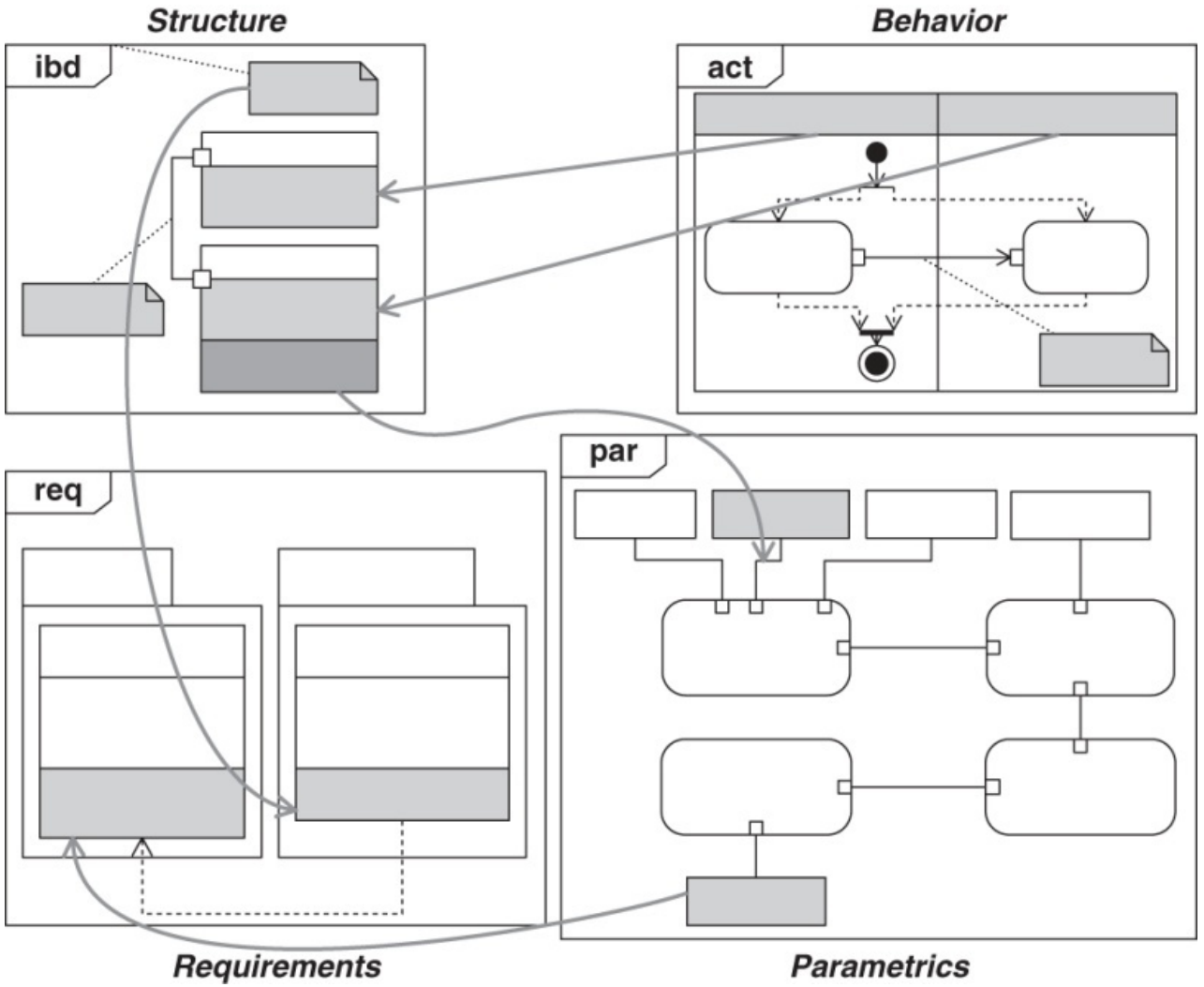
Modeling Solution is a combination of a modeling language(s), a methodology and a modeling tool that together provide a productive infrastructure for applying model-driven development in the context of a particular organization.

Language

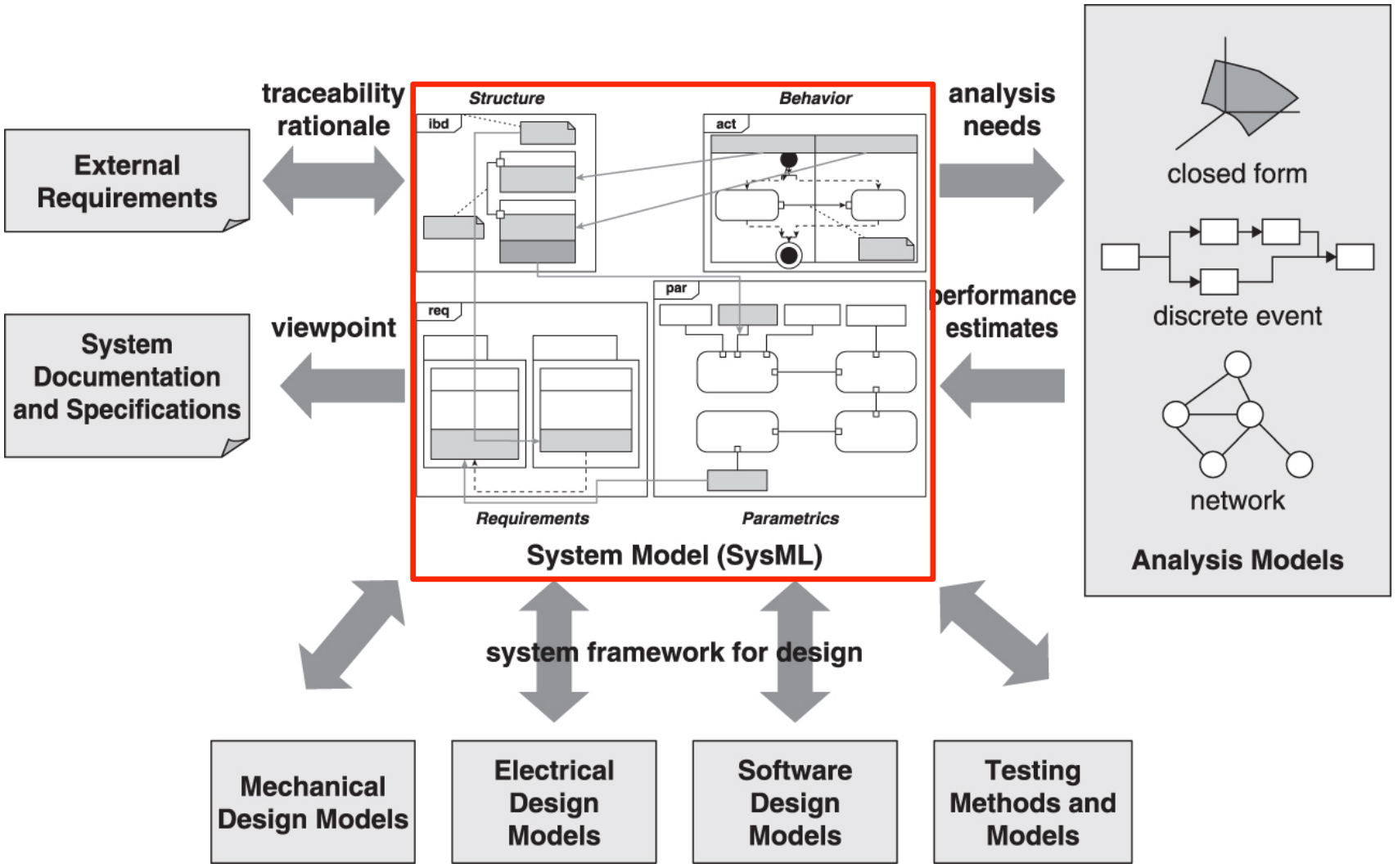
- OMG Systems Modeling Language (SysML) is a graphical modeling language for **specification**, **analysis** and **design**, **verification** and **validation** of systems.
- Developed by OMG and INCOSE in May 2006
- Dedicated for modeling complex systems that may include hardware, software, information, personnel, procedures, and facilities.
- Supported in multiple modeling tools
- Interoperable

SysML is critical enabler for MBSE

The Four Pillars of SysML



System Model as an Integration Framework



The modeling language is just the language, and must be combined with a methodology to be useful

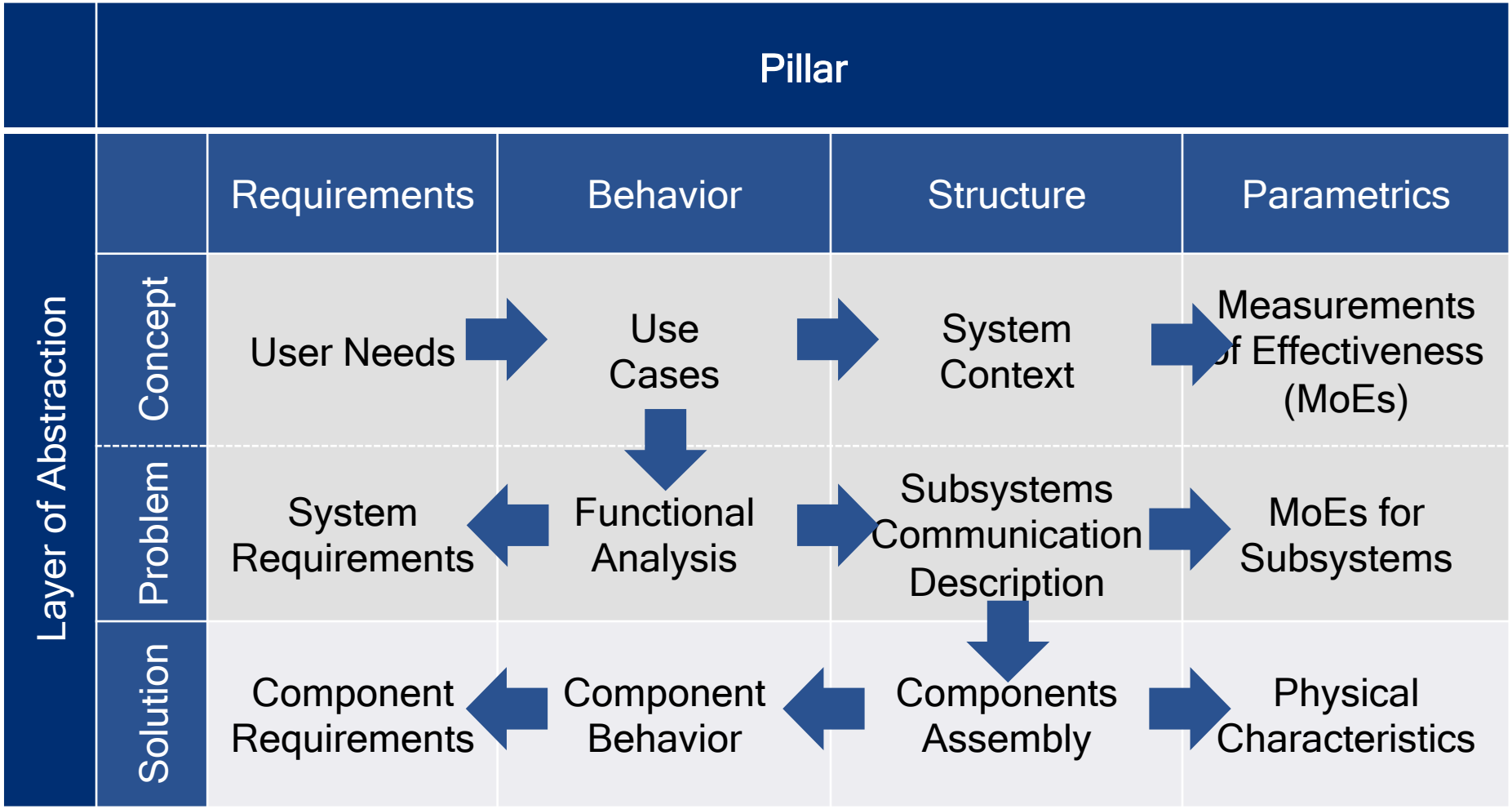
Method/Framework

- **This opens discussions of:**
  - how to structure the model
  - what views to build
  - which artifacts to deliver
  - and in what sequence

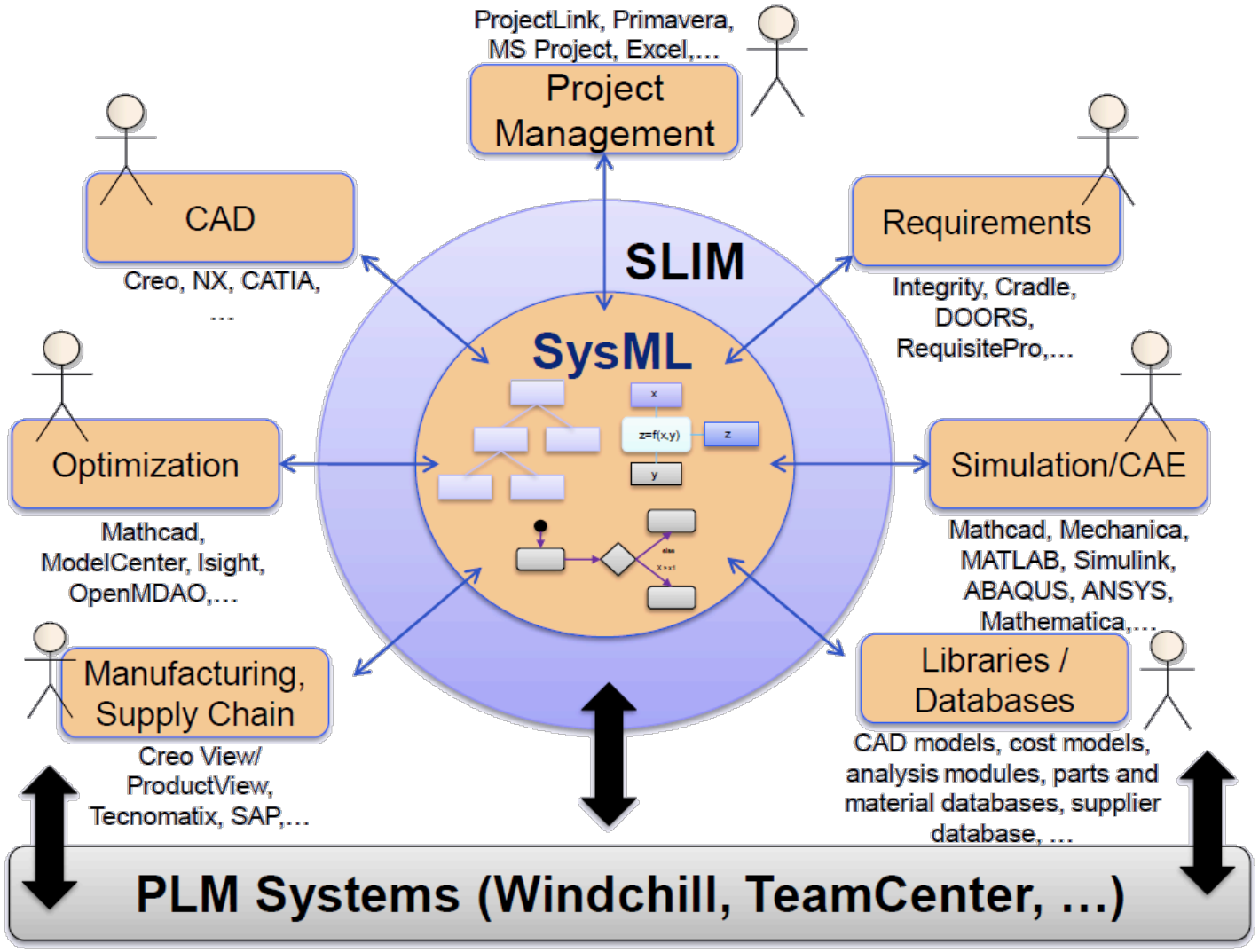
Every company deals with the same issue differently. Some use:

- defense architecture frameworks: DoDAF, NAF, **MODAF**
- MBSE methods: **OOSEM**, **Harmony**, **SYSMOD**, **FAS**; however, saying there is no need for an architectural framework just doesn't work.

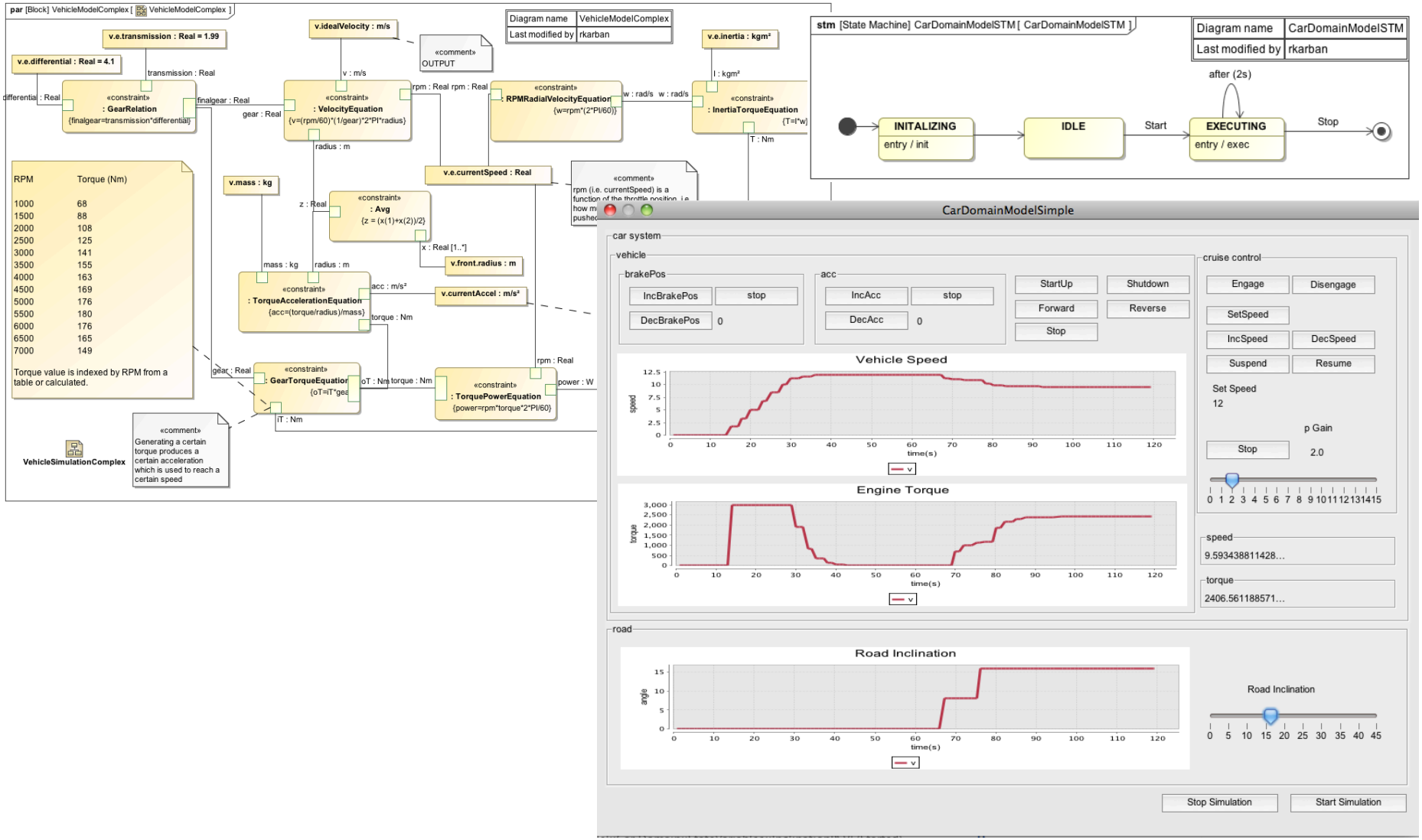
MBSE Grid



System Lifecycle Management



Cruise Control Example



Engineering analysis

- Evaluate design alternatives
- Select the best set of parameters
- Verify system constraints
- Perform requirement compliance analysis
- Perform what-if analysis
- Execute SysML Testcases

Trade Studies

- **Examining** various design alternatives by comparison
- Serve as a basis to integrate with more advanced analytical tools and techniques in accordance with the INCOSE Model-Based Systems Engineering (MBSE) vision in which all the analysis is carried out in the context of design models.

Rotary Pump variants

Requirement

#	Name		Flow Rate : Real	Mass : Real
1	Variant 1	200.0	0.2	200.0
2	Variant 2	180.0	0.19	202.0
3	Variant 3	300.0	0.5	500.0
4	Variant 4	150.0	0.14	250.0
5	Variant 5		0.34	300.0

«requirement»
Energy Consumption
Id = "1"
Text = "Energy consumption should not exceed 7 Wh"

«refine»

«constraint»
Check Energy Consumption
constraints
{r = ec < 7}
parameters
ec : Real
r : Boolean

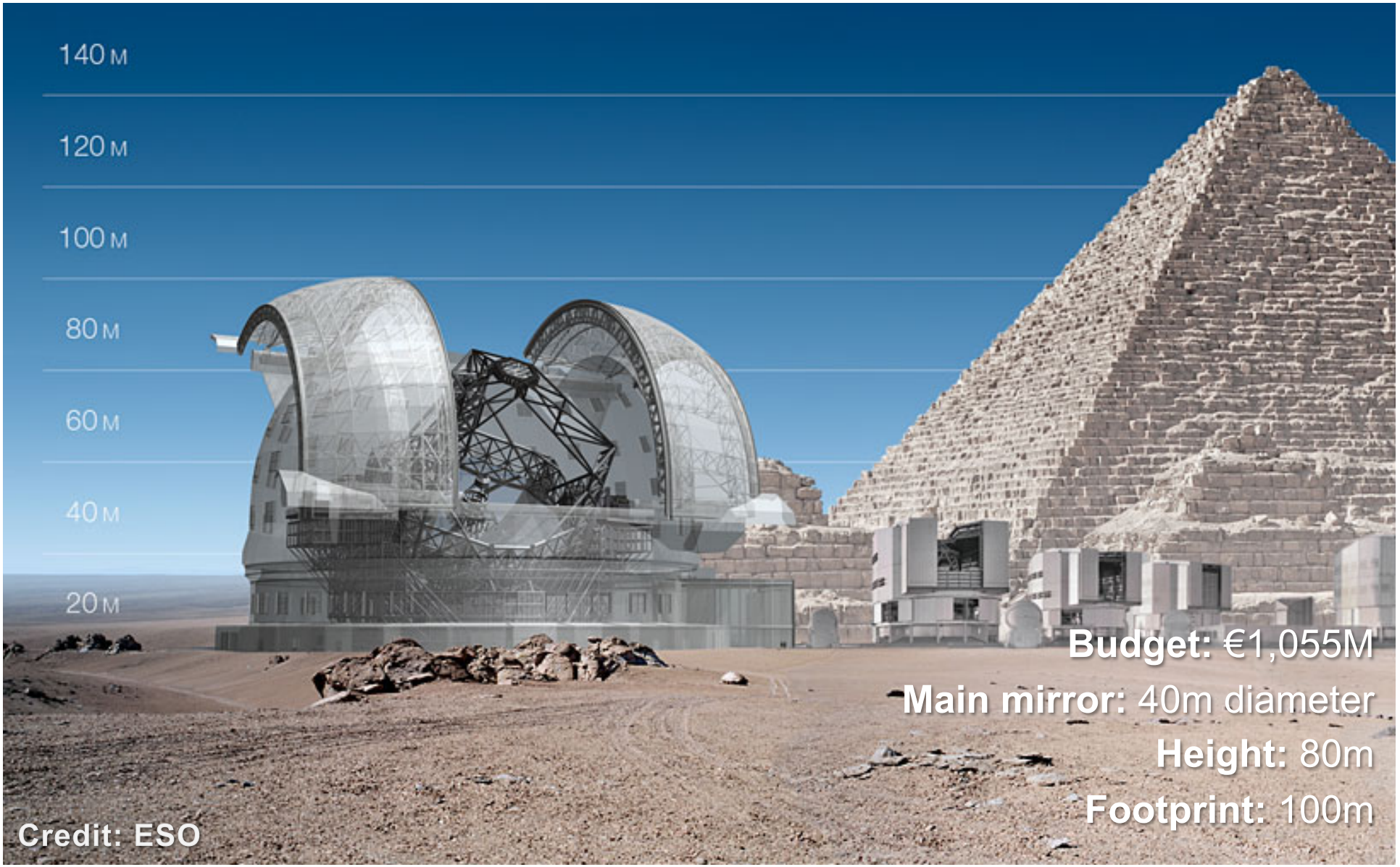
Energy consumption tests

Formal Constraint

#	Name	: Coffee Machine	Time To Fill : Integer	Energy To Fill : Real	Satisfied : Boolean
1	Case 1	Coffee Machine 1 : Coffee Machine	16	8.88888888888889	false
2	Case 2	Coffee Machine 2 : Coffee Machine	16	8.0	false
3	Case 3	Coffee Machine 3 : Coffee M		5.0	true
4	Case 4	Coffee Machine 4 : Coffee M		9.583333333333332	false
5	Case 5	Coffee Machine 5 : Coffee M		6.111111111111111	true

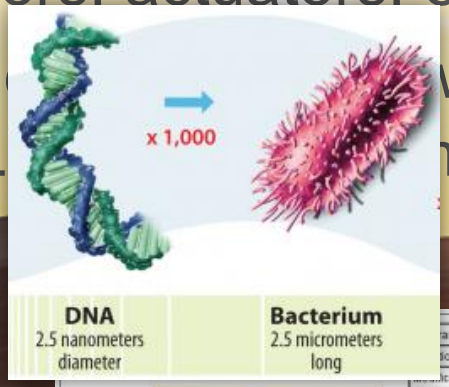
The best alternative

E-ELT


140 M
120 M
100 M
80 M
60 M
40 M
20 M
Budget: €1,055M
Main mirror: 40m diameter
Height: 80m
Footprint: 100m
Credit: ESO

E-ELT Control System

- The Control System (TSC) includes all hardware, software and communication infrastructure required to control the system
- Manages and coordinates system resources (subsystems, sensors, actuators, etc.)
- Magi vas used to model E-EL m



1000 mirrors. The position of the segments must be coordinated to deliver a continuous surface with an error below 100nm

Credit: ESO

Complex Systems Design Challenges

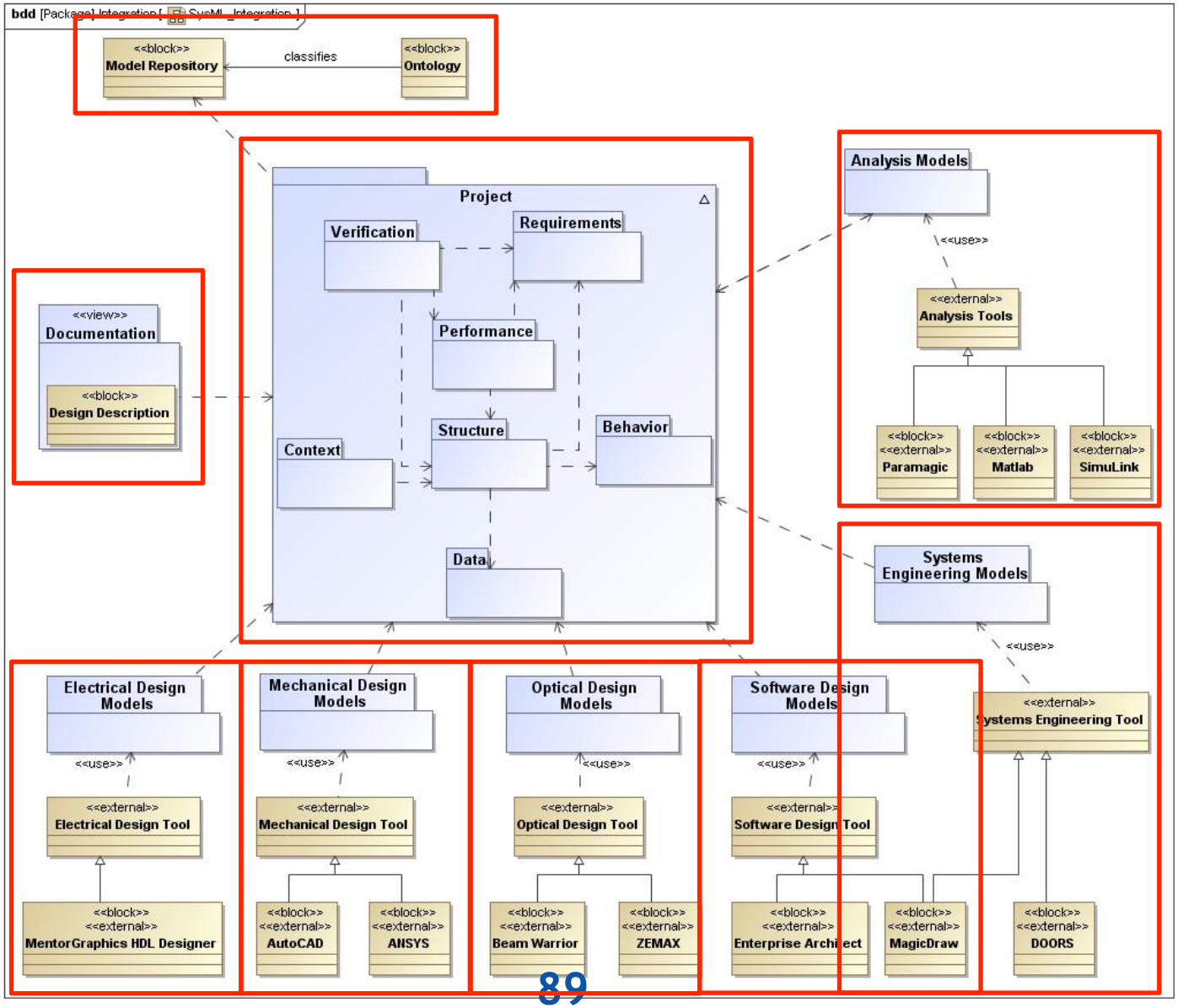
- Geographical distribution
- Large amount of data
- Heterogeneity: different roles, domains, tasks and still everything needs to be integrated
- High technical demands
- Custom work processes and adapting product to them

Team believed that SysML and MBSE would contribute significantly to tackle these challenges

MBSE Was Used For

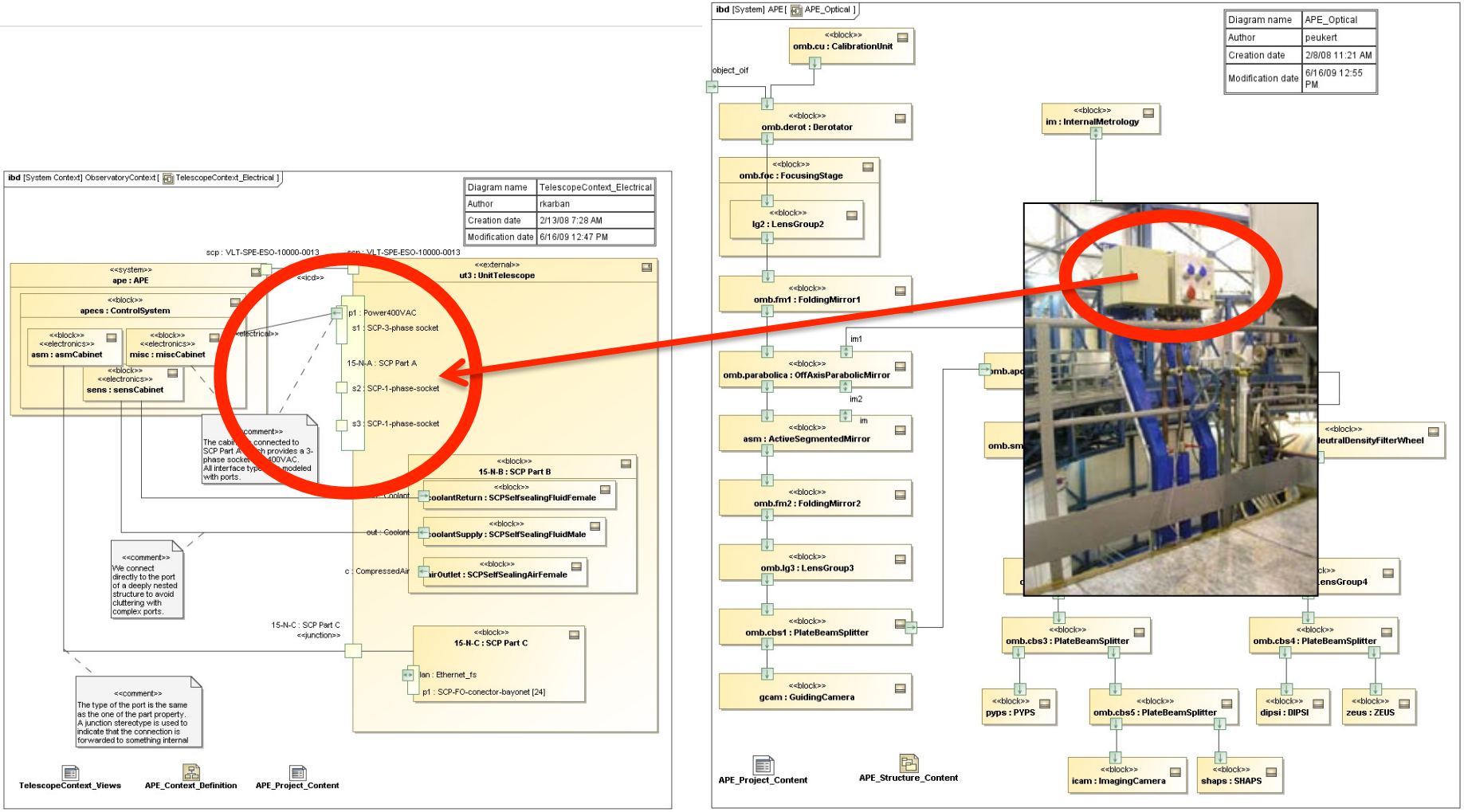
- Define infrastructure (e.g. network)
- Define interfaces to sub-systems
- Provide a cost estimate, power consumption
- Define common standards based on catalogs and design conventions
- Define requirements for subsystems (e.g. data rates, data volume, latency)

MBSE Integrating and Addressing Multiple Aspects of the System



Credit: ESO — No Magic

Multiple Internal Structures, Clear Interfaces

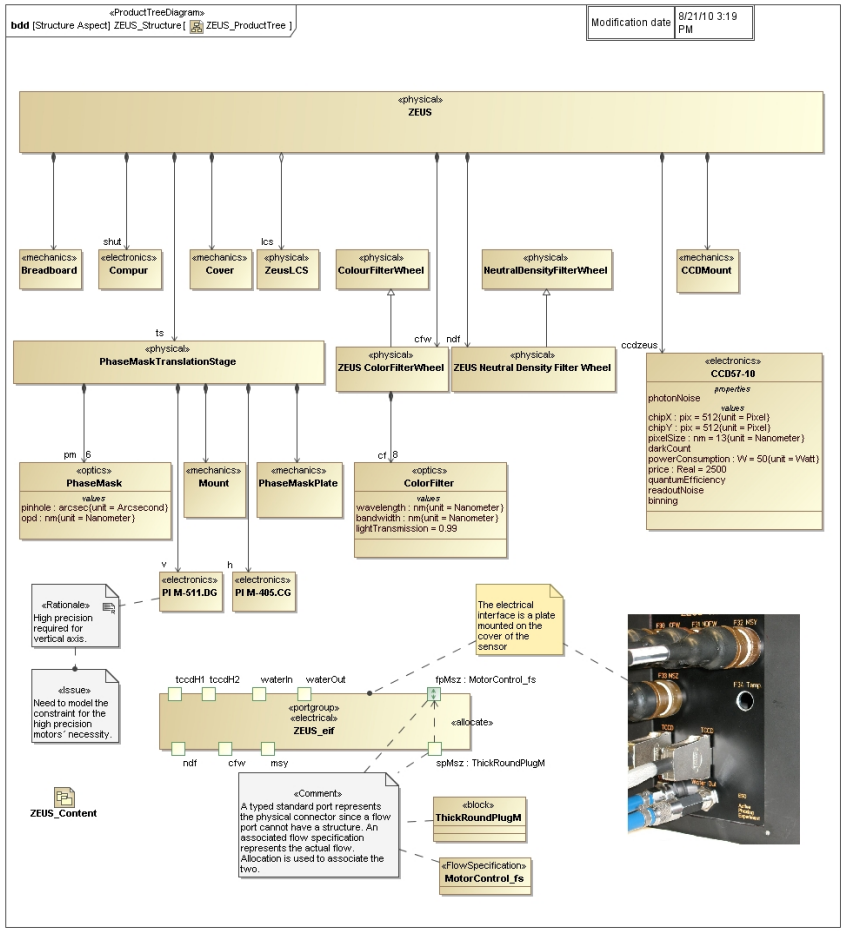


Electrical

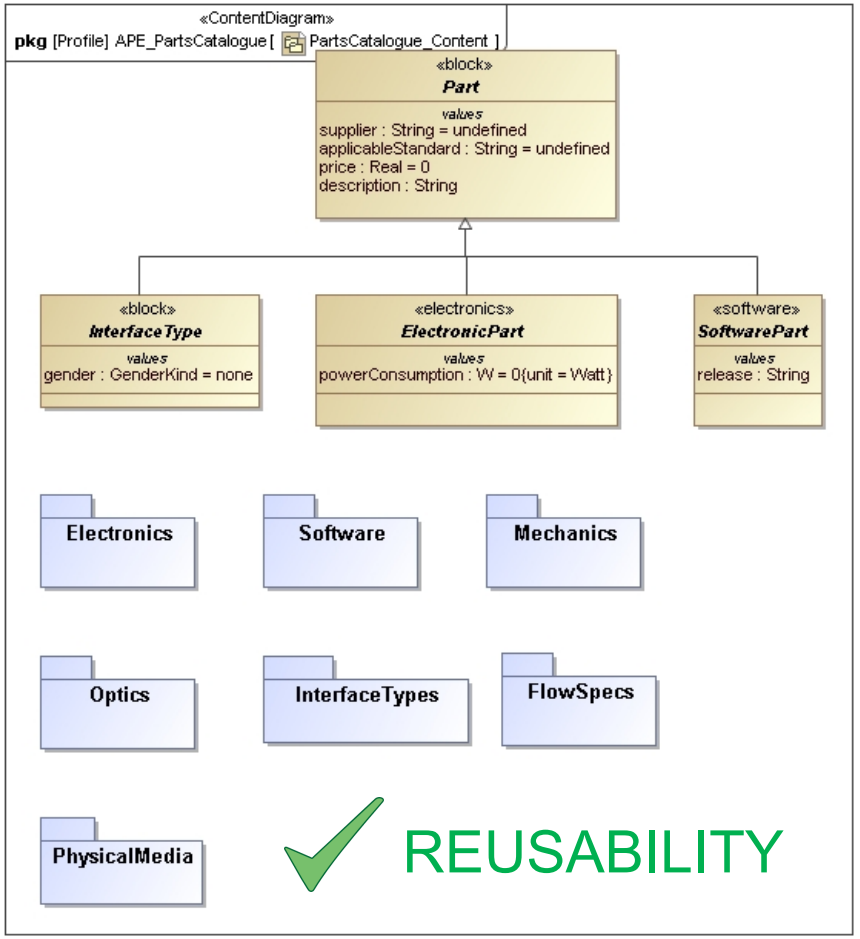
Optical

Credit: ESO

Power Budgets and Cost Estimates from Model-Based Equipment Catalogs



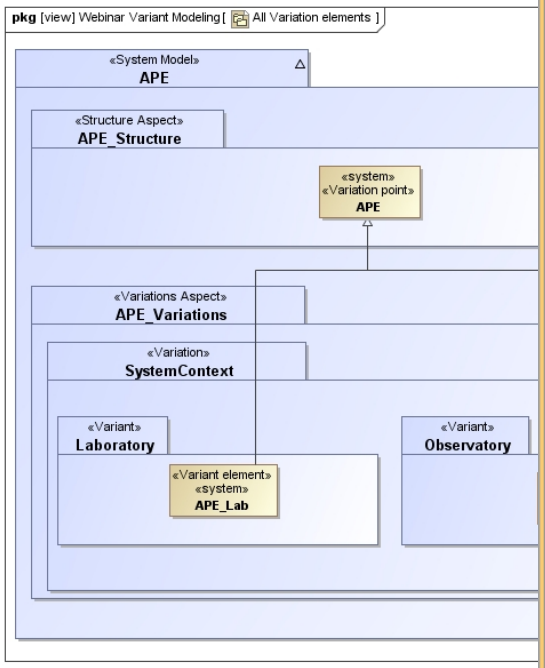
Product Tree

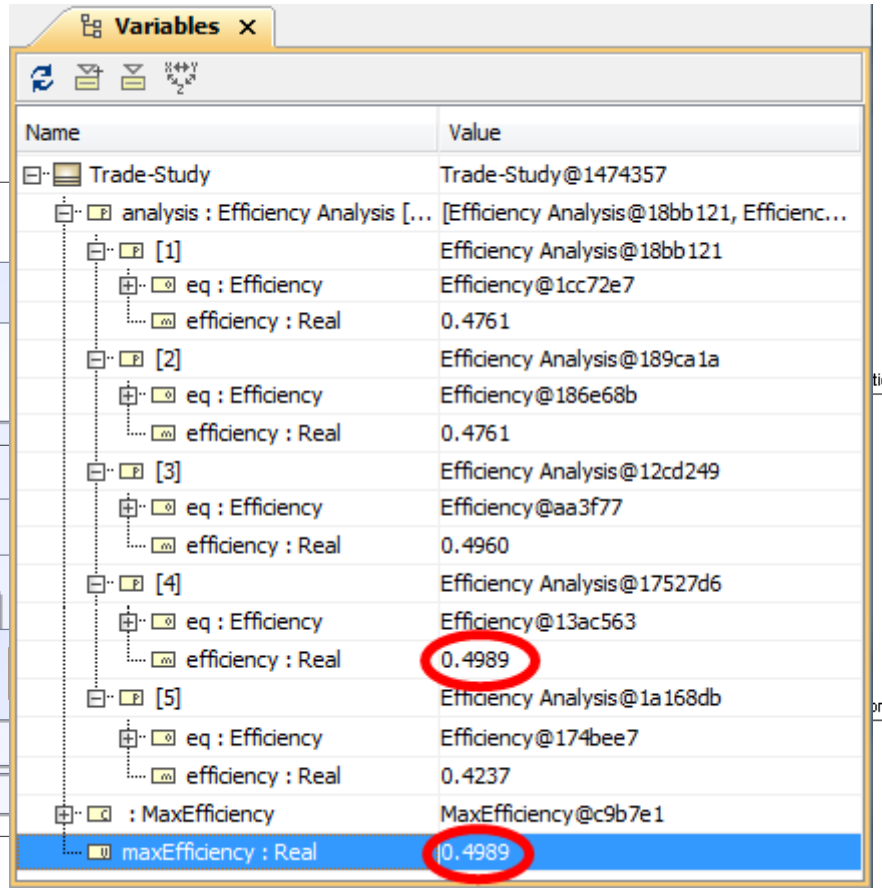


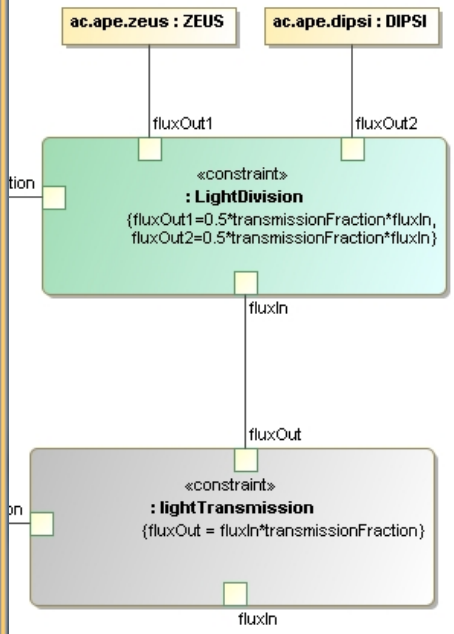
Reusable part catalogs

Credit: ESO

Variants & Trade-off Analysis







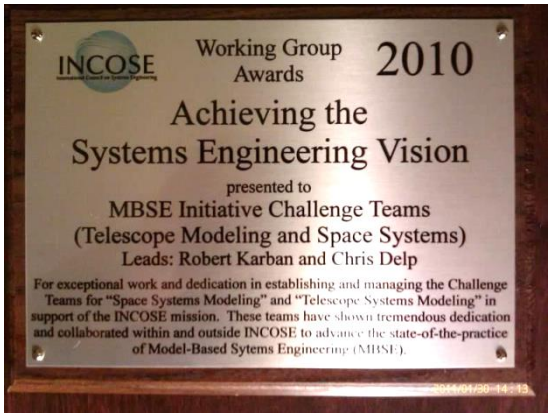
Different system variants

Trade-offs analysis

Credit: ESO

Results

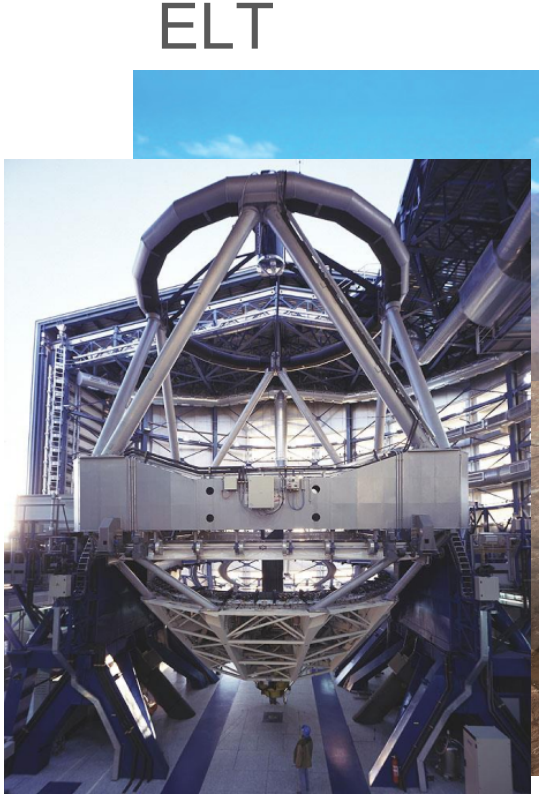
- Preliminary design were delivered
- Demonstrated that SysML is an effective means to support SE and handle complexity.
- Provided input (One of the most influential project for standard and tool development):
  - SysML RTF (SysML 1.3 were created updating interface modeling).
  - Tool vendor (400 official requests). Affected capabilities:
    - Standard support and usability
    - Requirements specification and interchange
    - Documentation generation
    - Model repository
    - Configuration and collaboration tools
    - Activity and state machine simulation
    - Validation and verification
    - Profiling and extendibility

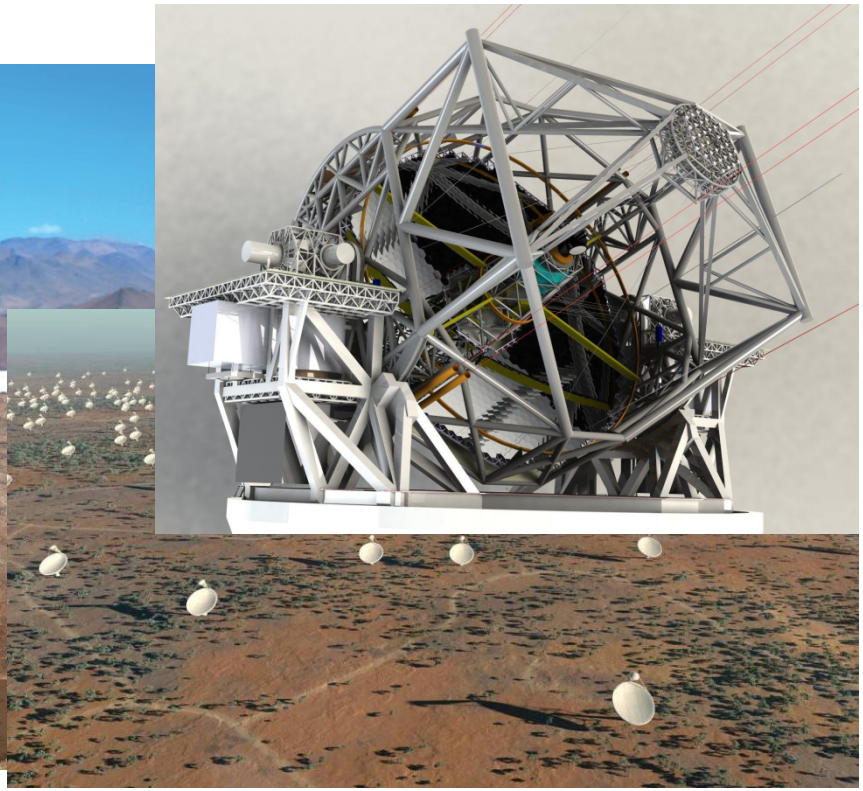


- Cookbook for MBSE with SysML with guidelines where created
- In 2010, INCOSE presented an award to the Telescope Modeling Challenge Team for Achieving the Systems Engineering Vision 2020
- Inflicted impact on other telescope projects.

Other Telescope Projects Using MBSE

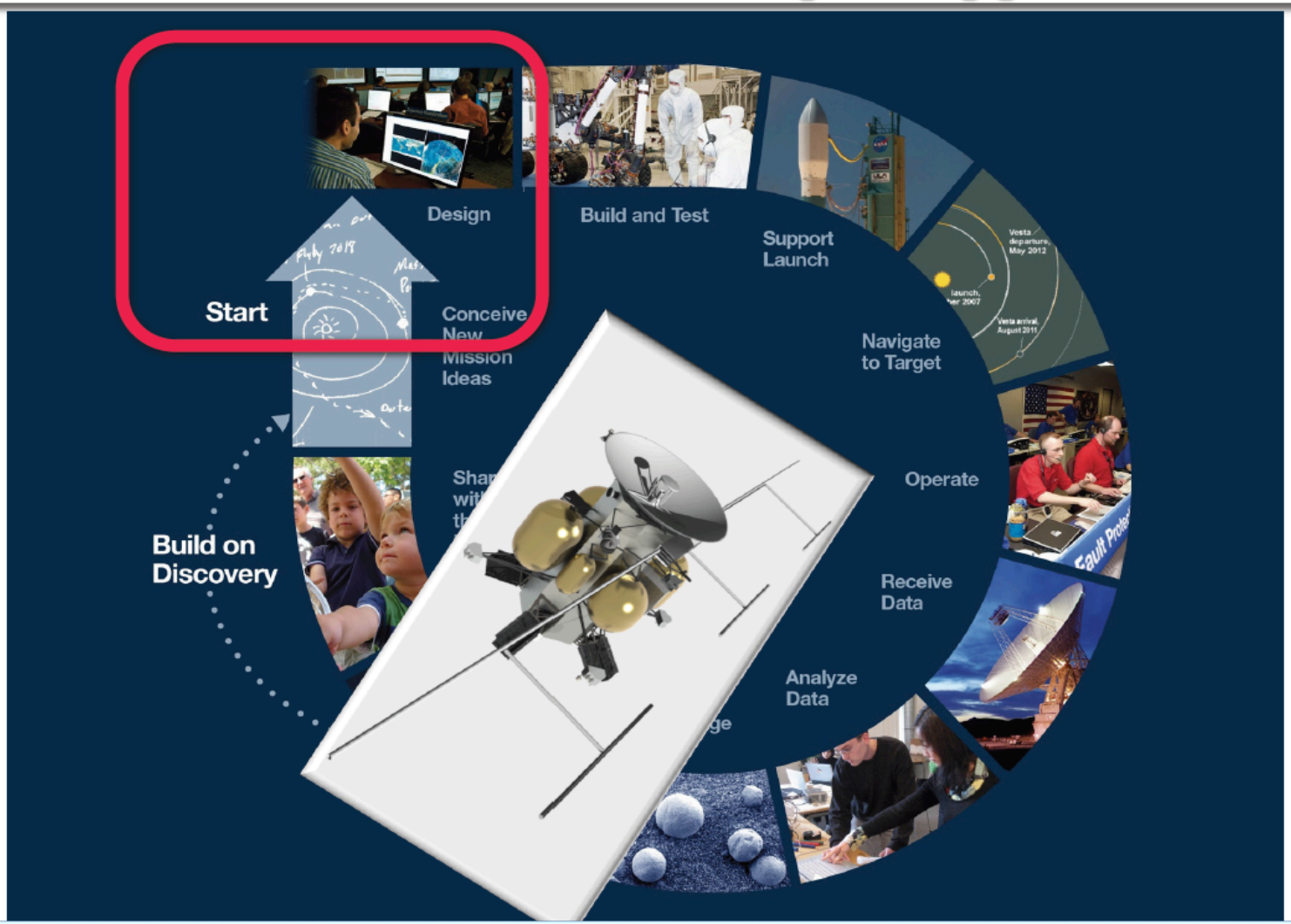
- The Giant Magellan Telescope
- JPL NASA Thirty-Meter Telescope
- The Square Kilometer Array
- European Southern Observatory's (ESO) projects: VLT, E-ELT





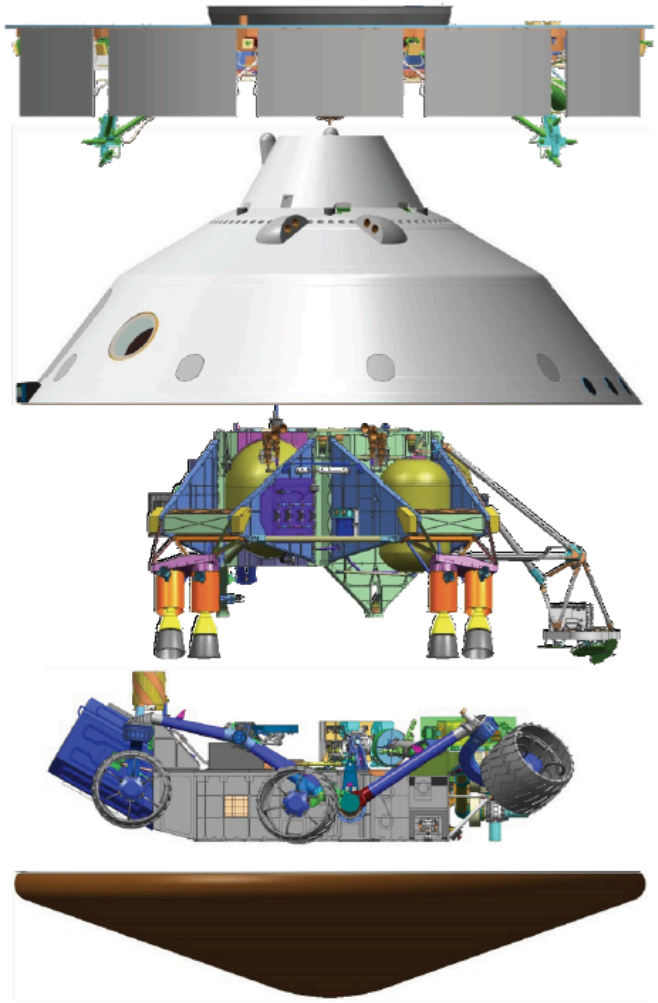
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Mission Formulation: The Europa Clipper



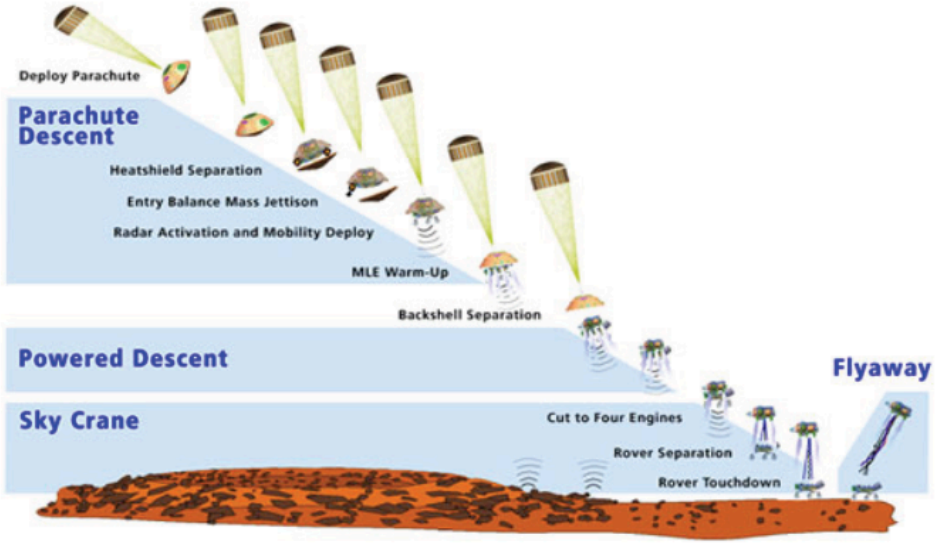
http://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:06-iw14-mbse_workshop-application_of_mbse_at_jpl_through_the_lifecycle-nichols-lin-final.pdf

MBSE Motivation and Background – Coping with Complexity



Mars 2020 challenge: Engineer an inherently complex mission and system with lower cost and changes to science and rover payloads

All we have to do is repeat the miracle (at even lower cost)…

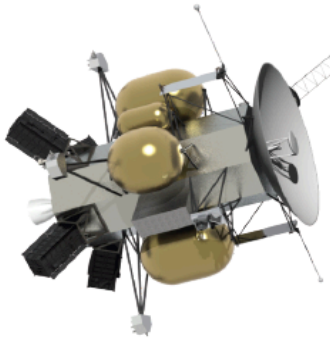


Background

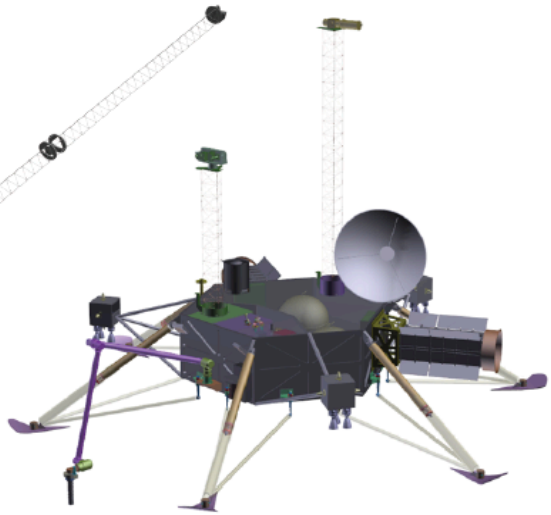
The Jupiter Europa Orbiter (JEO) mission concept was deemed to be of extremely high science value, but un-affordable, by the NRC Decadal Survey, which requested a de-scoped option

- A one year study developed mission options (Orbiter, multiple flyby [Clipper], and Lander) that retain high science value at significantly reduced cost

Multiple-Flyby in Jupiter Orbit
(The Europa Clipper)



Europa Orbiter



Europa Lander

Europa Clipper: Benefits Realized Through MBSE

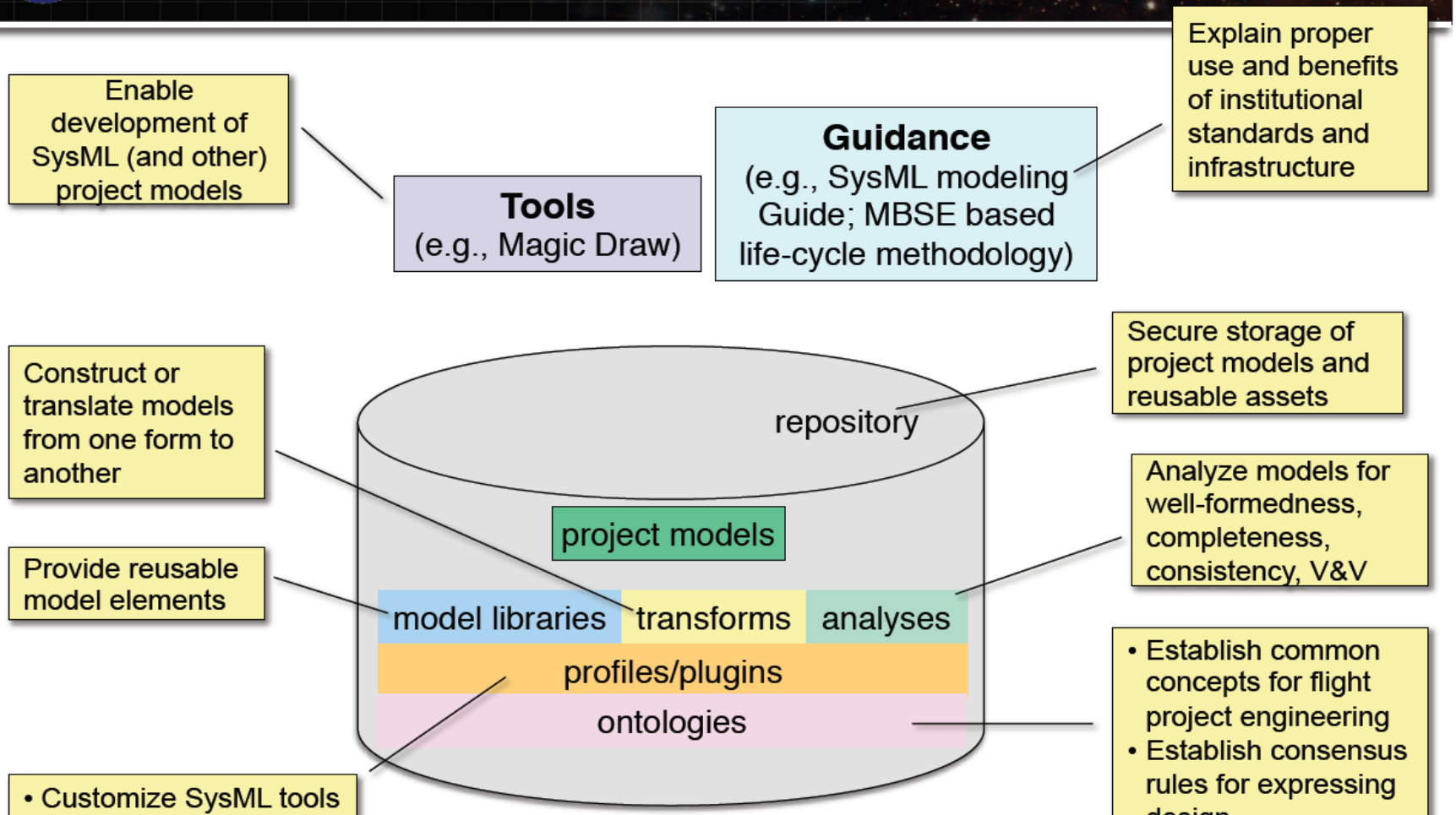
- Communication of technical information within project and among disciplines is more efficient and accurate
  - Not limited by foreseeable levels of increasing system complexity
  - Easily integrated with existing discipline tools (MBSE is the *keystone* for full Model Based Engineering)
- Re-use and evolution of alternate system design elements
  - 3 full mission studies in the time it usually takes for 1 or 2
  - 5 parallel configurations maintained
- Improved control over the evolution of system designs
- Consistent, rapid generation of technical margins and normalization of risk assessment
  - Identical automated analyses are applied to all configurations and versions
- Efficient generation of project documentation
  - Ensuring consistency of documentation by drawing from same system model
- Bridges from college education to project best practices
  - Recent graduates are arriving with knowledge of and expectation of using MBSE methods

V&V Demonstrated Value

- **Simulations derived directly from models enable us to validate operations concepts and validate scenarios early in the project lifecycle, reducing the cost of later remediation**
  - Validate the model itself
  - Validate the design
- **V&V products developed as views developed from an integrated model**
  - provide greater inheritance from plans, to testbed procedures, through integration procedures, to operational procedures than existing products
  - are more intuitive to modify and execute than text based procedures
  - The procedure can become the script for configuring and running the unit under test
- **All of the above save time and money during the development cycle and reduce defects**

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Modeling Infrastructure Elements



What JPL MBSE Practitioners Say (1 of 3)

- **It Enhances Communication**
  - A single, authoritative source of information keeps team on same page
  - Promotes accurate, efficient, consistent communication within a project
  - More complete transmission of concepts & rationale from proposal to implementation
  - Based on my task and MBSE experience with the task "My first move would be to develop a system model."
- **It Improves Productivity**
  - "Europa team was able to study 3 distinct mission concepts for the resources usually sufficient to study only 1 or 2, and the high quality of all 3 studies was lauded by the Hubbard Review Board and by NASA HQ."
  - "Development of the initial system model … took a fraction of the time it would otherwise have, by reusing modeling patterns and analyses learned earlier on EHM."
  - Time-consuming project documents/reports become trivial to generate

What JPL MBSE Practitioners Say (2 of 3)

- **It Improves Quality**
  - Earlier detection of inconsistencies due to clearer semantics
    - Example: 35 inconsistencies identified in Exploration Missions E-E Test
  - "One thing that I've found is that the process of modeling leads to 'escape discovery'. …capturing the details leads to a greater understanding of the system and makes errors or potential problem areas 'pop out'."
  - Promotes early/on-going requirements validation and design verification
  - Standard documents are kept consistent and up-to-date
- **It Supports Integration**
  - Provides consistent definition of system to integrate with discipline models, including cost models and science margin models

What JPL MBSE Practitioners Say (3 of 3)

- **It Helps Manage Complexity**
  - "We are able to evaluate 100s-1000s of consistent, structured, and transparent design options and explicitly compare cost/benefit in a fraction of the time and cost of conventional methods."
  - Different views address the concerns of different stakeholders
- **It Enables Reuse of Institutional Knowledge**
  - MBSE enhances reuse of intellectual property (model elements embody hard-earned technical expertise)
- **It Attracts Early Career Talent**
  - MBSE forms a bridge from college education to JPL best practices
  - MBSE methods are beginning to be taught in universities to engineering students
  - Early adopters are dominated by the early career hires

How to Start With MBSE?

Investment! MBSE is not silver bullet.

So how to build a Sustainable Modeling Culture:

1. Think big, start small, and evolve, i.e. pilot project.
2. Establish a Center of Excellence, i.e. dedicated core team, training.
3. Adopt best practices (e.g. Cookbook), tools (de facto No Magic, Inc. products), method, and language (de facto OMG SysML)