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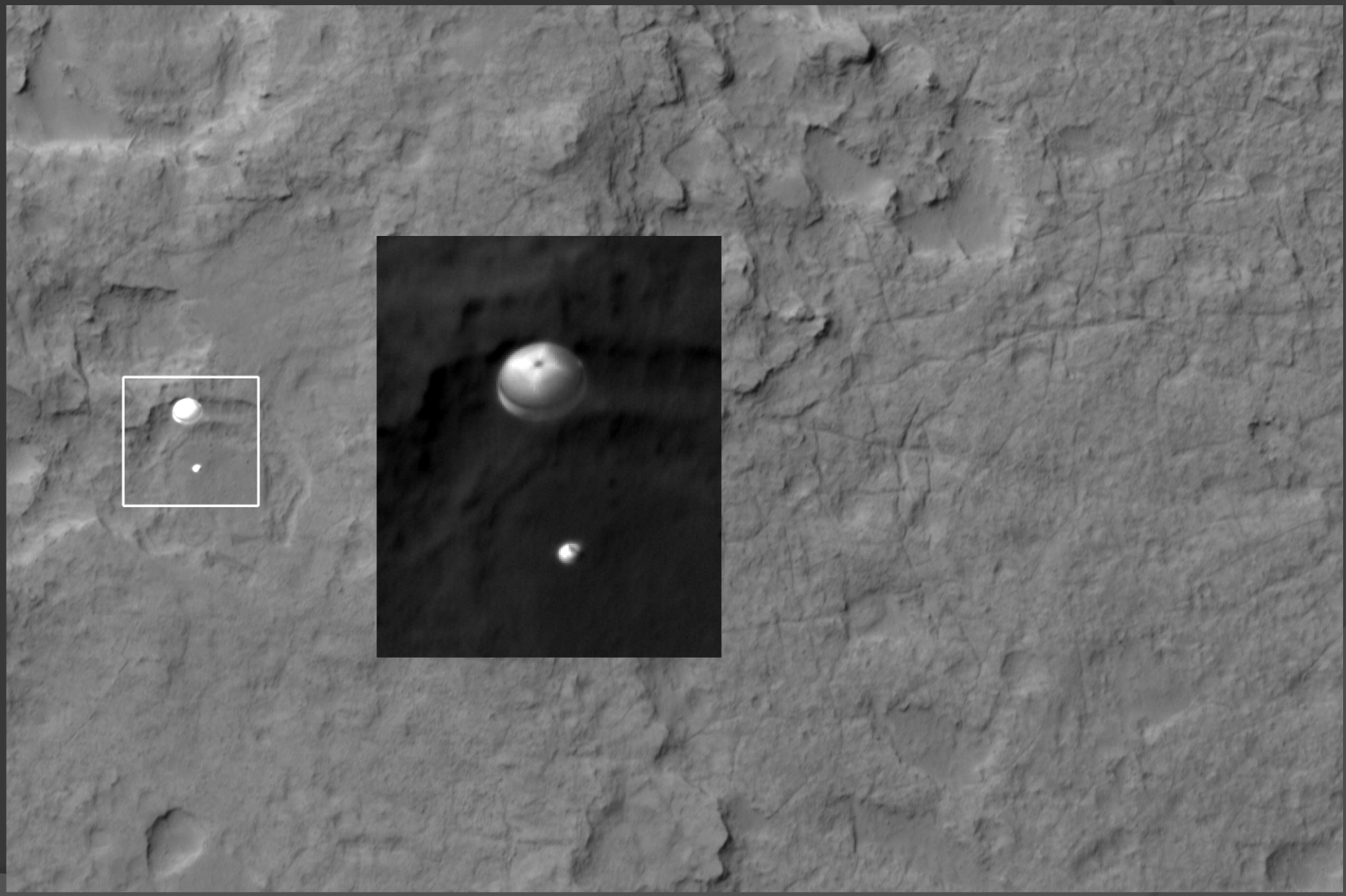
INCOSE SPACE SYSTEMS CHALLENGE TEAM AND JPL MBSE

Congratulations to Mars Science Lab!



Outline

- MBSE Basics
- Challenge Team Efforts
- MBSE Adoption at JPL
- Future Challenges

Systems Engineering and Models

SE AND MBSE

Driving Idea: Systems Engineering Specifications

- Systems Engineers in the Space Domain produce information
  - Functions
    - Describing the Problem
    - Trades
    - System Functional and Behavioral Design
    - Specifying System Components and Integrations
    - VnV
    - Deployment and Fielding
    - Operational Support
  - Products
    - Analysis (Simulation, Tests, etc)
    - Reports on Analysis
    - Plans
    - Design Descriptions
    - Interface Descriptions
    - Requirements

Role of Languages in MBSE Enterprise

- SysML (Systems Modeling Language)
  - Unifying the Qualitative and Quantitative
  - Descriptive Information
  - *Designed* to serve as *System Specification*
  - "Machineable"
    - Compatible with a variety of execution and analysis strategies
- Authoritative Source of information

An Example Systems Engineering Scenario

- Determining science target coverage and power requirements with navigation and behavior analysis simulation tools
  - Satellite Toolkit, Matlab/Simulink
- Challenges
  - How do you extract all the rich detail from these simulations into System Specification?
    - DOORS? Documents/Slides/Spreadsheets?
  - How do you assert mutual consistency between models?
    - Meetings? Emails?
- Need an equally rich mechanism for expressing the system design
  - Human readable
  - Machine readable

MBSE for Space Systems

INCOSE SPACE SYSTEMS CHALLENGE TEAM

INCOSE Space Systems Challenge Team

- 5 years of MBSE Investigations and Demos
  - Objectives
  - Successes
  - Challenges

INCOSE Space Systems Challenge Team

- Produce a Space Systems example of MBSE
  - real-world
  - Sharable
    - INCOSE is an International Organization
- Broad Team
  - NASA, CSA
  - Industry
  - Academia (MIT, GIT)

Timeline of Activity

- Y1: MIT/GaTech Student FireSat Example
- Y2-4: SysML model of FireSat
  - Space Analysis Library using SMAD (Space Mission Analysis and Design textbook, Wertz and Larson)
  - Basic Model of FireSat
  - Solar Panel Trade
  - Satellite Toolkit Integration
- Y5->: CubeSat: An Architecture Framework and Method for Space Systems MBSE

FireSat MIT/GaTech Collaboration

- Build an integrated model of FireSat
  - SubSystems in Matlab, STK, Excel
  - Integrated with Phoenix Model Center
  - Student Teams Mentored by Industry Experts from INCOSE SSWG
- Successes
  - executable trade model for FireSat
- Challenges
  - Difficult to build
  - SubSystem models were difficult to integrate
  - No architecture of the model integration or key parameters
  - Difficult to Audit for completeness correctness

FireSat SysML Model

- Build SysML model of FireSat
  - Learn SysML
  - Describe FireSat using SysML
  - Compare Model Description against typical document representation
- Successes
  - Models of descriptions from book
  - Model views corresponding to documents
- Challenges
  - Technique of modeling and applying the methodology
  - Table representations
  - Model Analysis
  - Document Production

SysML Space Analysis Library

- Build SysML Space Analysis Library
  - Build Library of analysis from SMAD
  - Build approach to VnV for Library
- Successes
  - Libraries for many analysis types
  - Useful testing approach
- Challenges
  - Deep subject – much could not be captured
  - Executability (significantly improved since)
  - Units and Dimensions (significantly improved since)
  - Presentation of equations

FireSat Solar Panel Trade

- Use Library to replicate Solar Panel Sizing Trade
  - FireSat Model and Library-> executable trade
- Successes
  - Successfully built executable trade
  - Hard-linked to requirements
  - Powerful view of driving systems properties
- Challenges
  - Executability (improving since)
    - Debugging
    - Scaling

FireSat Integrated Modeling

- Integrate FireSat SysML Model with Satellite ToolKit
  - Exchange Orbit Scenario properties
- Successes
  - Basic Exchange of Parameters
  - Direct comparison of MBSE in SysML and STK
  - Explicit link between models and requirements
- Challenges
  - Integration
    - Complicated
    - Difficult to Scale

CubeSat: Framework and Method

- Build a Modeling Framework and Method for CubeSats
  - CubeSat Domain-Specific Terms
  - SE Framework for Modeling CubeSat Missions, Spacecraft, and Ground Systems
  - Example Application using RAX Mission
- Successes
  - First version of Framework
  - Early version of multiple executable demos
- Challenges
  - Resources
  - Executability
  - Integration

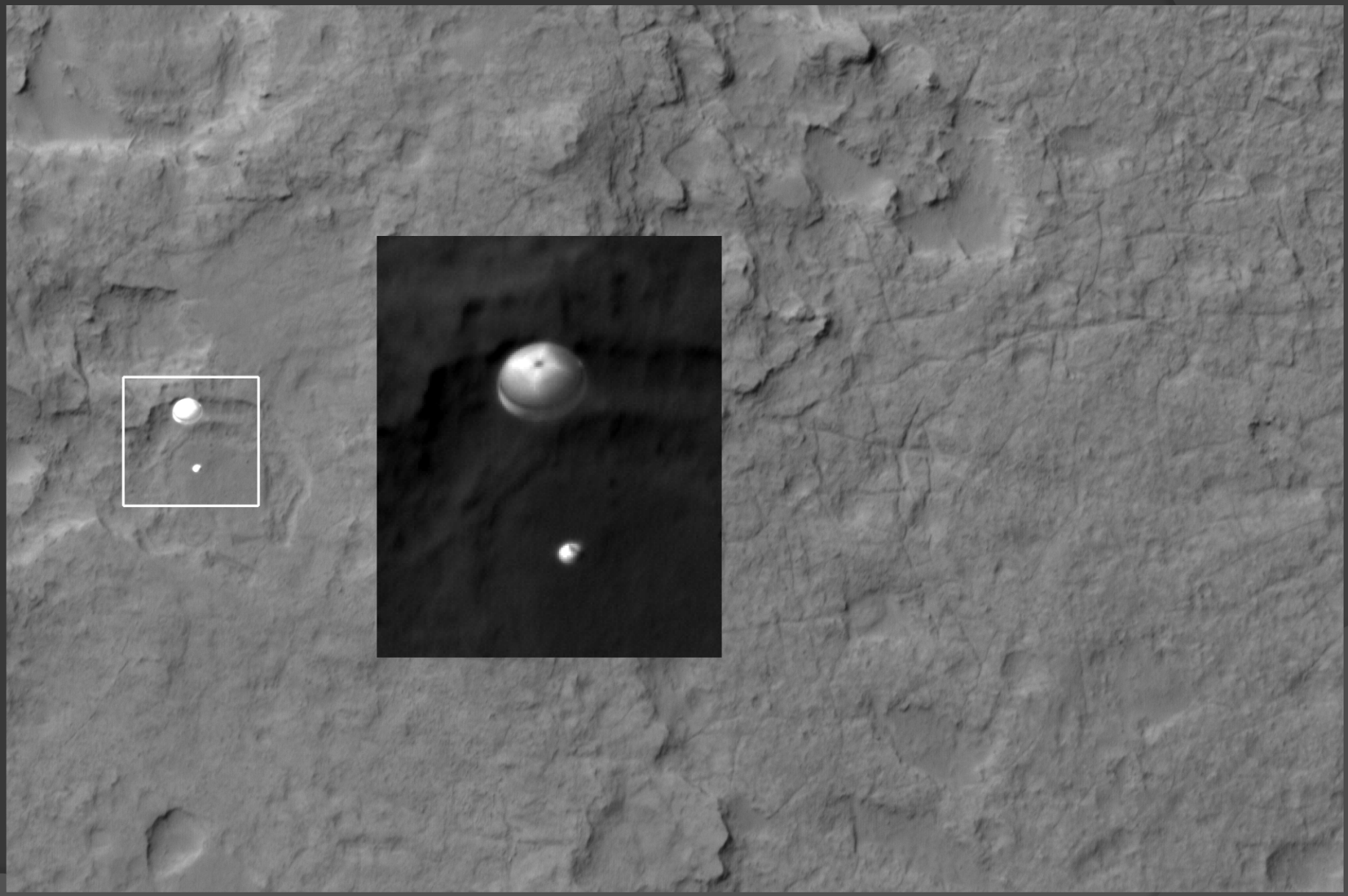
Consensus of Team

- Modeling with SysML
  - Everything was hard at first
  - Methodology is critical to a model that hangs together
  - SysML simplified construction of basic things like functions and properties
  - SysML tastes like early CAD apps
  - Libraries of model analysis were effective in making solar panel trade
  - Integration with STK
- Document Comparison
  - Model unified properties between views
  - Simplified understanding of the System
  - The common SysML language improved communication between teams and simplified collaboration
  - Automated reports allowed for more time to focus on engineering

Practitioners and Community

MBSE AT JPL

Modeling is critical to Land on Mars



JPL has Sophisticated Modeling Already

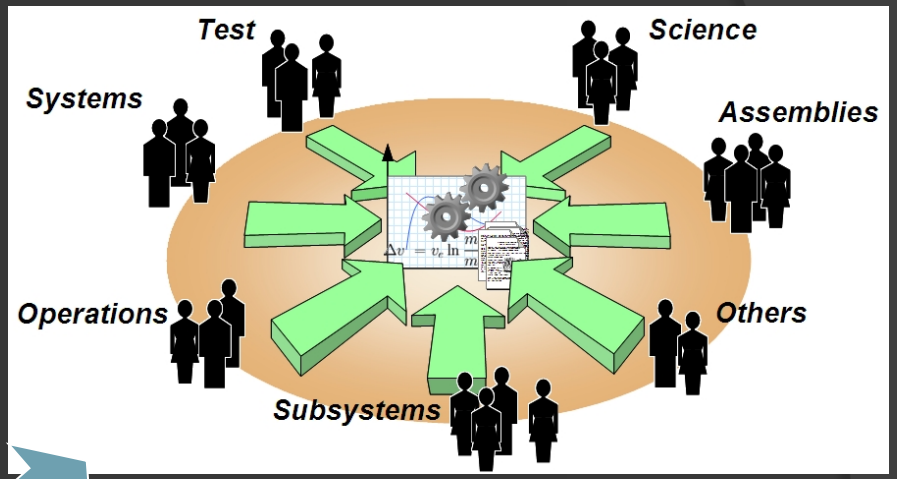
- Entry Descent and Landing dynamics models
- Solar System navigation
- Spacecraft Autonomy
- Detailed physics
- And many more…

Effects of Challenge Team and JPL MBSE Adoption

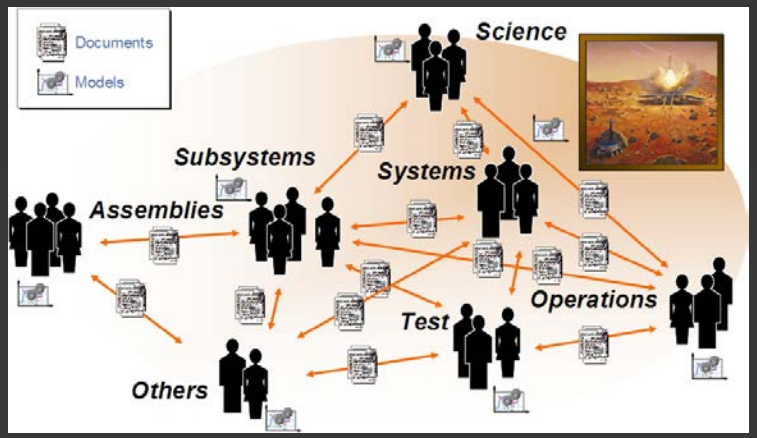
- Enabled Grass-Roots Effort
- Early Examples
- Experience
- Experimentation

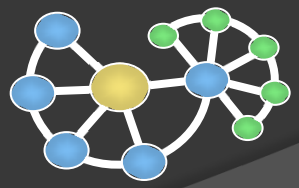
An Integrated Model-Centric Engineering Vision at JPL

Mission: To advance from our current document-centric engineering practices to one in which structural, behavioral, physics and simulation-based models representing the technical designs are integrated and evolve throughout the life-cycle, supporting trade studies, design verification and system V&V



Future: Reusable model-driven with integration & simulation capability





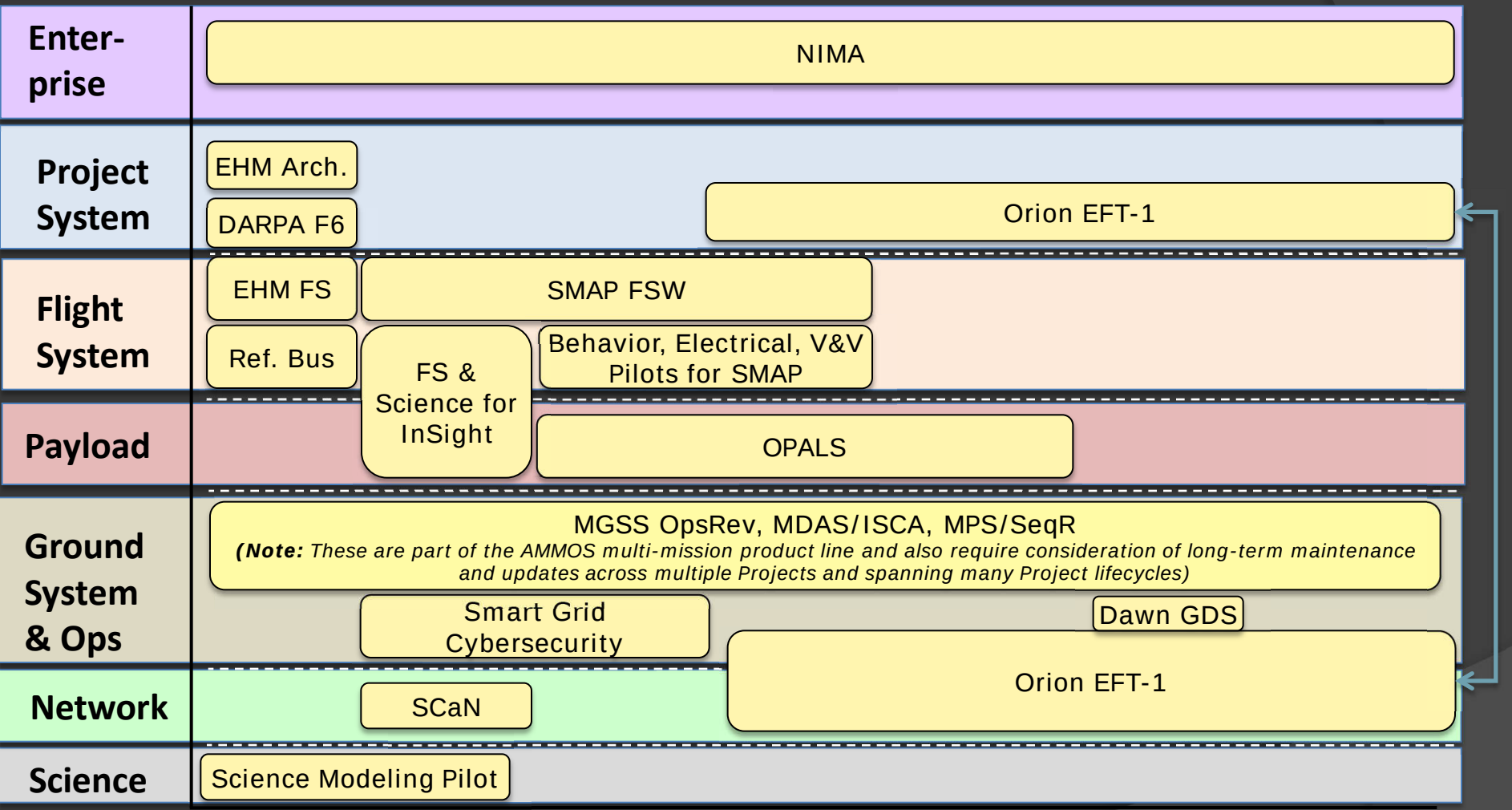
Today: Document driven & standalone models

Modeling Early Adopters

- Open Community of Modeling at JPL
- Forum for Innovation
- Driver for Culture Change
- Enabling Engineers that were motivated to improve their practices

JPL Modeling Landscape

By System Type and Lifecycle Phase



Pre-Phase A	Phase A	Phase B	Phase C	Phase D	Phase E	Phase F
Concept Studies	Concept & Tech Dev.	Prelim. Design	Final Design & Fab	Assembly, test & Launch	Ops & Sustainment	Closeout

Topics of SE Models

- Problem Statements
  - Scenarios
  - Usecases
- As-is or current system architectures
- Alternatives
  - Architectural choices
  - Component variations
- Detailed designs of systems

Topics of SE Models

- Technical Parameters
  - Mass, Power etc
- System Structure
  - Physical Composition
  - Logical relationships
- System Behavior
  - Functions, Activities
  - Processes
  - States
- Timelines of Interaction
  - Messages
  - Values over time

Model Based Products

- Systems Engineers make Documents
- Generating document from models
  - Consistent
  - comprehensive
  - Low overhead
  - Verifiable
- Generate Formatted Data
  - Executable XML formats, code, scripts
- The Models are always the authoritative source

Integrated Analysis

- Models as data source
  - Simulation
  - Model Checking (mutual consistency, correctness, completeness)
  - Analytic Analysis
- Transformations project model into view compatible with analysis tools
  - QVTo (Query View Transform Operational)
- Automated reports on Analysis
  - Model Views

Benefits Observed at JPL

- Systems Engineers spend more time Systems Engineering
- Models Architected for Reuse
- Rich Variety of Analyses
- Improved Communication

- *Still need to train people to do good systems engineering – with or without models*

Needs: Enterprise-level Engineering Modeling

- Large-Scale System Model Production
- Scalable Integration
- Model Management
- Complex Interactive Analysis
- Knowledge Harvesting

MBSE Driven Engineering Enterprise

STEPS TOWARD REALIZATION

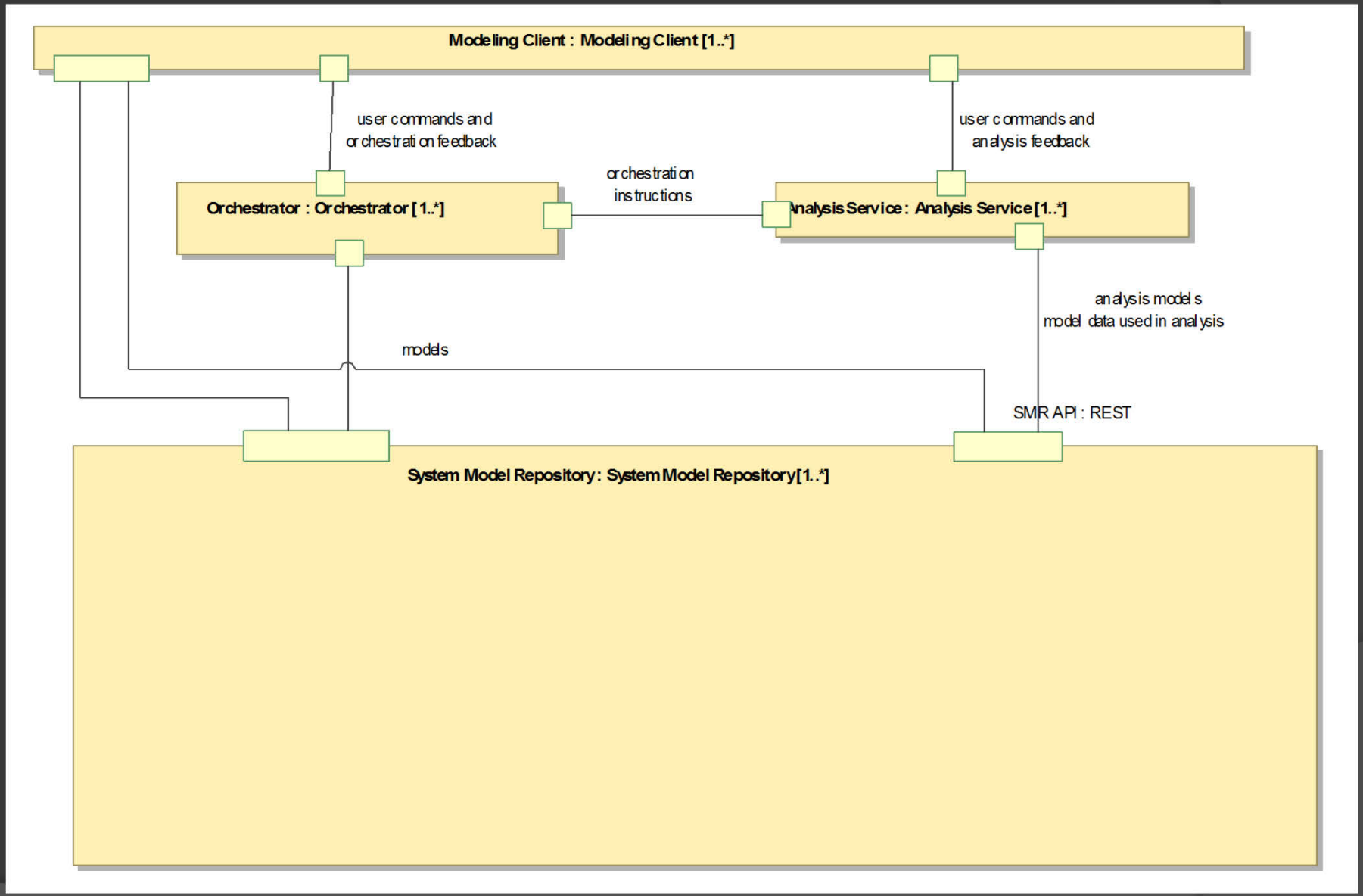
Enterprise Level Modeling

- Teams and Processes
- Model Products
- MBEE: Model Based Engineering Environment

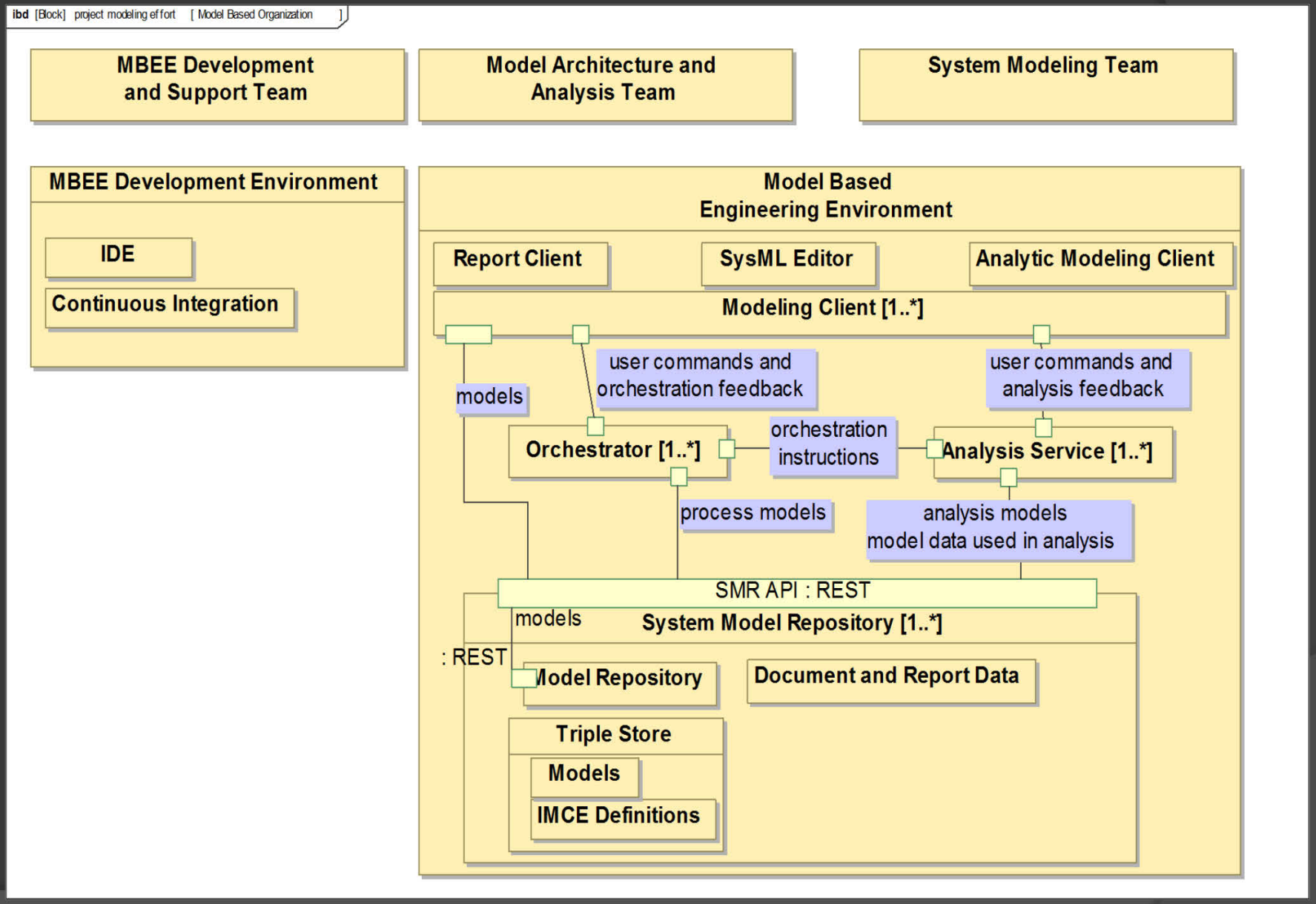
Scenario Revisited

- Model System in SysML
- Generate analyzable products for STK and Matlab
- Publish results into SysML model
- Generate documents and reports for design, requirements, validation
  - Establish a clear set of views of the specification needed to realize the results of the analysis

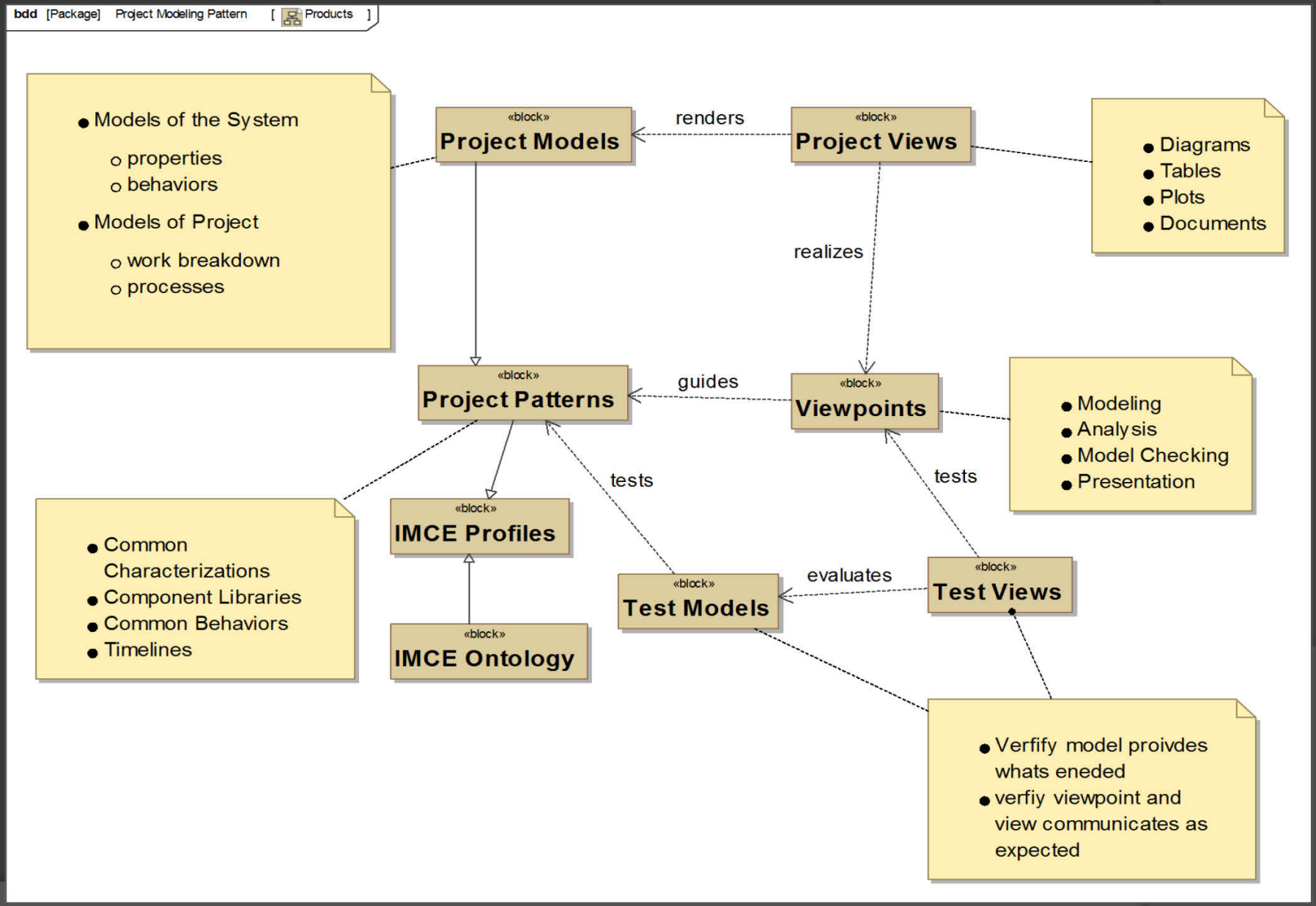
Model Based Engineering Environment



Model Based Organization



Products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Models of the System
properties
behaviors
Models of Project
work breakdown
processes
«block»
Project Models
renders
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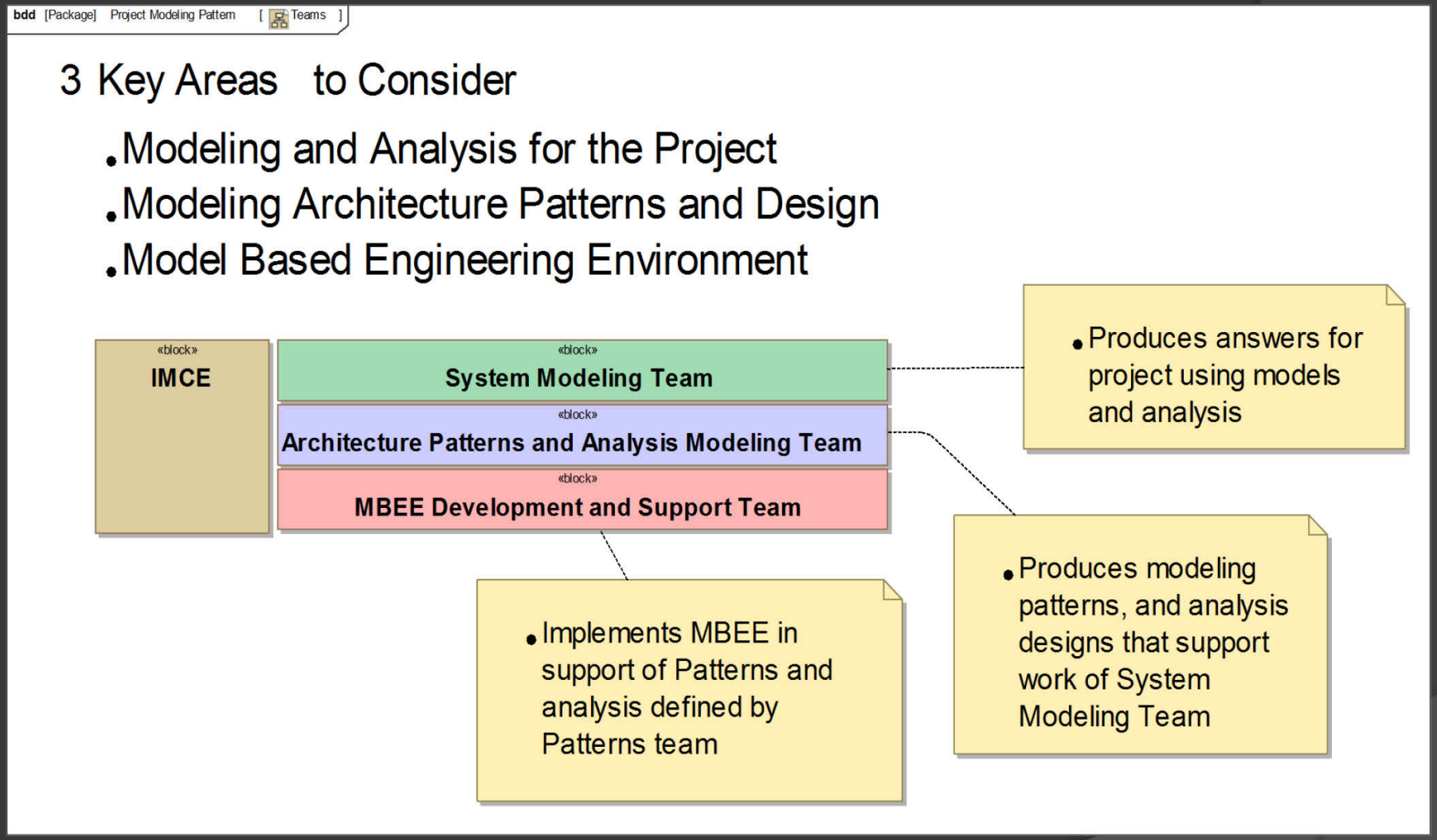
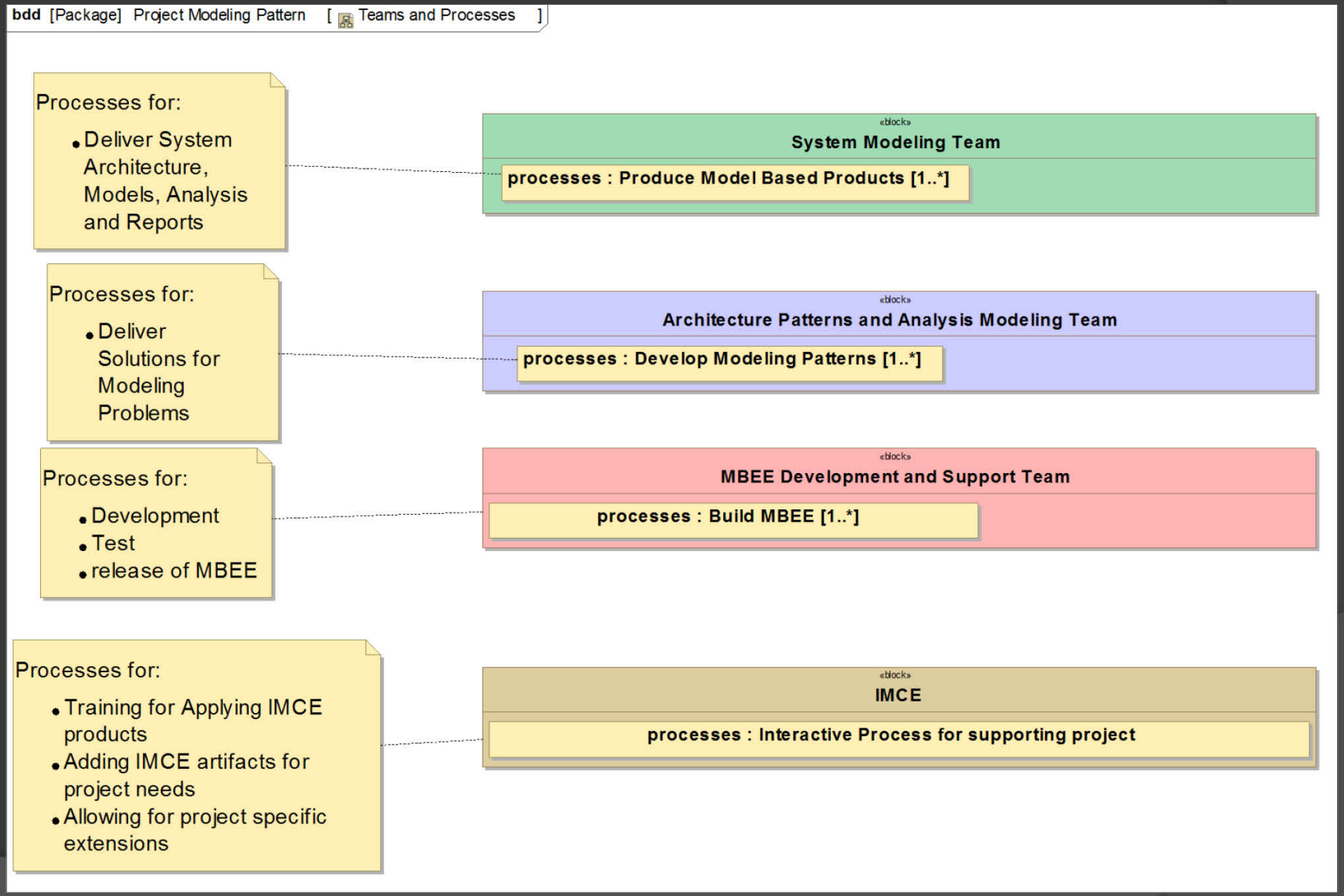
Project Views
Diagrams
Tables
Plots
Documents
realizes
«block»
Project Patterns
guides
«block»
Viewpoints
Modeling
Analysis
Model Checking
Presentation
tests
tests
Common Characterizations
Component Libraries
Common Behaviors
Timelines
«block»
IMCE Profiles
«block»
IMCE Ontology
«block»
Test Models
evaluates
«block»
Test Views
Verfify model proivdes whats eneded
verfiy viewpoint and view communicates as expected

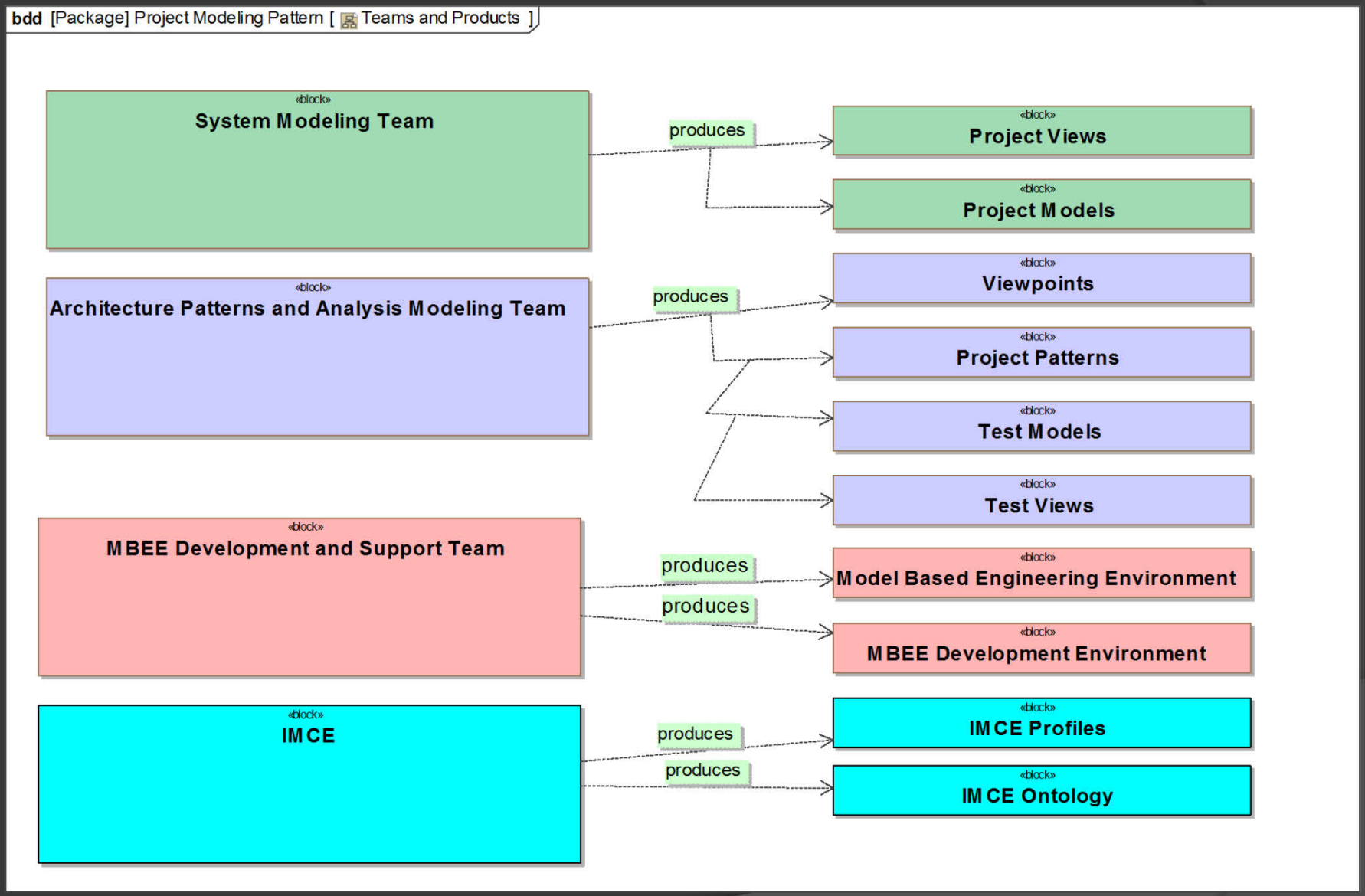
Teams


bdd [Package] Project Modeling Pattern [Teams]
3 Key Areas to Consider
.Modeling and Analysis for the Project
.Modeling Architecture Patterns and Design
.Model Based Engineering Environment
«block»
IMCE
«block»
System Modeling Team
«block»
Architecture Patterns and Analysis Modeling Team
«block»
MBEE Development and Support Team
• Produces answers for project using models and analysis
• Produces modeling patterns, and analysis designs that support work of System Modeling Team
• Implements MBEE in support of Patterns and analysis defined by Patterns team

Teams and Processes



Teams and Products



What Enterprise MBSE Enables

- Reliable Information
  - Mutually Consistent Models
  - Authoritative Source
- Rich Heterogeneous Analysis
- Multi-disciplinary Collaboration

MBSE and Culture Change

- Still about doing excellent Systems Engineering
- Social and collaborative approaches
  - Bring down barriers
  - Enable engineers to succeed
  - Enable management recognition