Defining Executable Design & Simulation Models using SysML

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Agenda

- Collaborative D&S
- Envisioned Approach
- Recent Work
- Related GIT PSLM Center Work
- Summary
- Q&A
Collaborative D&S Environment

Exchange Mechanism:
- File
- Messaging
- SOAP
- Database
- In-Memory/In-process
- Remote Procedure Calls
- CORBA

Schema:
- Intl./Gvt. Standard
- Custom
- Corporate standard
- Hybrid

Modeling Language:
- OWL
- EXPRESS
- UML/SysML
- XML
- GIT COBs

Persistence Mechanism:
- RDMS/OODMS
- XML
- Flat files
- STEP P21

Tools:
- OS/Platform
- Persistence Mechanism
- Version
- API
Collaborative D&S

System Definition

- TestCase-001
- TestCase-002
- TestCase-003

- Non-causal Intra-System Constraints
- Parameter Sharing/Negotiation
- Non-Causal Inter-System Constraints

- Key Performance Parameters
- Measures of Effectiveness
- Trade Studies

- Instances that meet requirements and constraints

- Key Performance Parameters
  - MOE-002
  - MOE-003
  - MOE-004
  - MOE-001

- Key Performance Parameters
  - MOE-001= 90
  - MOE-001= 95
  - MOE-001= 85
Collaborative D&S

System Definition

Test Case-001 → Req-001 → S
Test Case-002 → Req-002 → S
Test Case-003

Current tools address requirements coverage, but not validation.

Lack of tools for defining executable, system-level, collaborative simulation models in a declarative way.

Lack of tools for executing them.

Solution Space

S-100: MOE-001 = 90
S-200: MOE-001 = 95
S-300: MOE-001 = 85

System Definition:

Collaborative D&S

Product and Systems Lifecycle Management Center

Collaborative D&S

Solution Space

Current tools address requirements coverage, but not validation.

Lack of tools for defining executable, system-level, collaborative simulation models in a declarative way.

Lack of tools for executing them.
External Tool Access

System Model

$S$

$S_a$

$a_1$

$a_2$

$C_1$

$S_b$

$b_1$

$b_2$

Repository

Repository

Design Tool

Analysis Tool
Simulations are hard to reproduce due to versioning, set-up parameters, assumptions, idealizations, etc.
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Envisioned Approach

SysML

PLM Tools

Simulation Execution

SysML as front-end for graphically modeling executable D&S scenarios

Automatic generation of code to solve constraints, execute simulations, and validate requirements

Integration with PLM Tools for fine-grained product configuration management

Constraint network management, access to information in external tools and simulation execution

Composable Objects Framework
SysML Front-End

### Structure
- **Product and Systems Lifecycle Management Center**
- **SysML Front-End**
- **TestCase.java**
- **Requirement.java**
- **System.java**
- **Attribute**
- **Constraints**
- **Methods**

### Behavior
- **Event.java**
- **StateMachine.java**
- **Activity.java**
- **Sequence.java**

### Requirements
- **Requirement.java**
- **testCase.java**
- **TestSequence.java**

**Relationships:**
- **uses**
- **generates**
- **validated**
- **publish/subscribe**
Integration with SysML Systems

SysML Tool

SysML Diagrams

SysML Tool Plug-In

generate

Componentized, meta-solving framework

Java Classes

Execution Client

uses

extend

API/Base Classes

COB Services

Graph Management

Persistence

Versioning Control

Tool Access

COB Framework

Connector

Tool

Connector

Tool
Integration With PLM Systems

Composable PLM Entities

PLM Services (configuration management, access control, workflow, tool access...)

Tool

Traditional COTS and in-house end-user tools (authoring, viewing, solving...)

Traditional PLM items now replaced by COB-based versions (parts, assemblies, documents, requirements, files, analysis results...)

Fine-grained Relations (formula-based, buffered, black-box, ...)

PLM entities referencing external tools models
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Prototype SysML Tool Integration

SysML Tool (Artisan Studio)

Parametric diagrams
Internal block diagrams

Block definition diagrams

SysML Tool Plug-In

COB Browser

read into
uses

COB Files

API/Base Classes

COB Services

Graph Management
Persistence
Versioning Control
Tool Access

Connector
Ansys
Mathem.
Demo: Airplane Wing Flap Link

Analyzable Product Model (APM)

Context-Based Analysis Models (CBAMs)

Analysis Building Blocks (ABBs)

Solution Method Models (SMMs)

1D Extension

Extensional Rod

1D Linear-Elastic Model

System of Equations

1D Torsion

Torsional Rod

2D Extension

Plane Stress

FEA

CAD Tool

Demo: Defining Flap Link Structure
Demo: Requirements
Demo: Verification Test Cases

Test Case

Flap Link Instance

Sequence Diagram

Demo: Generating the COB Files
Demo: Executing the Test Case
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Related GIT PSLM Center Work

- Mechatronics Interoperability Project for Systems (MIPS) (PDES Inc.)
- SysML-based Reference Models for Fluid Power Components (Dr. Chris Paredis)
- Wafer Fabrication Factory Simulation (Dr. Leon McGinnis)
A joint pilot activity of the PDES Inc. AP233 team, the PDES Inc. AP210 Pilot team, and several organizations who are not PDES Inc. members

- Boeing, Eurostep, Georgia Tech, GM, Mentor Graphics, NIST, NASA/JPL, Rockwell Collins, UGS

Mission:

- The vision of the Mechatronics Project is to demonstrate an open, standards-based environment that integrates multi-domain product models and provides a more complete picture of the products being developed and maintained
- The open standards-based capability will leverage the capabilities of existing CAD/CAE/SE modeling tools and demonstrate a next-generation product development environment in which product information is richer and powerful tools continue to evolve and mature.
## MIPS

### MIPS Project Testbed

<table>
<thead>
<tr>
<th>ECAD</th>
<th>MCAD</th>
<th>Solvers</th>
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</thead>
<tbody>
<tr>
<td>IDA-STEP AP210</td>
<td>GIT XaiTools PWA-B</td>
<td>NX/SolidEdge</td>
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<tr>
<td>Eagle</td>
<td>Mentor</td>
<td>Mathematica</td>
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<tr>
<td></td>
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<td>Ansys</td>
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### Requirements Management

<table>
<thead>
<tr>
<th>TcRequirements</th>
<th>IDA-STEP AP233</th>
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</table>

### Collaboration Environments

<table>
<thead>
<tr>
<th>TcCommunity</th>
<th>TcEngineering</th>
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### Enabling Technologies

<table>
<thead>
<tr>
<th>GIT COB Framework</th>
<th>STEP AP233/AP210</th>
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</thead>
</table>

### Product and Systems Lifecycle Management Center

- MIPS
- Product and Systems Lifecycle Management Center
- Manufacturing Research Center
- Plone Solutions
SysML-based Reference Models for Fluid Power Components

Automatically-Generated Modelica Model

```model VerticalLifter
  HyLibLight.Pumps.Tank tank;
  HyLibLight.Pumps.ConMot motor;
  HyLibLight.Pumps.Basic.IdFlowSource source;
  equation
    connect(tank.port_A, motor.port_B);
    connect(motor.port_A, source.port_B);
end VerticalLifter;
```
SysML-based Reference Models for Fluid Power Components

![Diagram showing fluid power components and flow rates through ports.](image-url)
Wafer Fabrication Factory Simulation

Wafer Fabrication Factory

Logic Model (SysML)

Geometric Model (CAD)

Other Models

Simulation Model (eM-Plant)
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Questions or Reactions?
Thank you!

For more information, please visit:
http://www.pslm.gatech.edu
Hyperlinked Slides
stm HSUVOperationalStates

**Off**

- Start
- ShutOff

**Operate**

**Idle**

- Accelerate
- Stopped

**Accelerating/Cruising**

**Braking**

- ReleaseBrake
- EngageBrake

Refines `requirement` PowerSource Management

Nominal states only
**Master Cylinder Safety**

- **Decelerate Car**
  - **rationale**: This design of the brake assembly satisfies the federal safety requirements.

**Master Cylinder Efficacy**

- **requirement**
  - Text: "A master cylinder shall have a reservoir compartment for each service brake subsystem served by the master cylinder. Loss of fluid from one compartment shall not result in a complete loss of brake fluid from another compartment."
  - ID: "S5.4.1"

**Loss Of Fluid**

- **requirement**
  - Text: "Prevent complete loss of fluid"
  - ID: "S5.4.1a"

**Reservoir**

- **requirement**
  - Text: "Separate reservoir compartment"
  - ID: "S5.4.1b"

**Satisfied By**

- **BrakeSystem.m**

**BrakeSystem**

- **block**
  - f: FrontBrake
  - r: RearBrake
  - l1: BrakeLine
  - l2: BrakeLine
  - m: MasterCylinder

- **activateBrake()**
- **releaseBrake()**

**rationale**: The best-practice solution consists in assigning one reservoir per brake line.

- **Satisfied By**
  - BrakeSystem::l1
  - BrakeSystem::l2
Product and Systems Lifecycle Management Center

```
<diagramDescription>
version='0.1'
description="allocation of behavior and connectors to elements of power subsystem"
reference="null"
completeness="partial. Power subsystem elements that have no allocation yet have been elided"
```

```
epc: ElectricalPowerController
allocatedFrom
<activity> ControlElectricPower

allocatedFrom
<connector>c1
<connector>c2
<connector>c3

allocatedFrom
<activity> ProportionPowerLoad

allocatedFrom
<activity> ConvertGasToPower

emg: ElectricalMotorGenerator
allocatedFrom
<activity> ConvertElectricToPower

can: CAN_Bus
allocatedFrom
fp: FS_TRSM
trsm: Transmission

ecu: PowerControlUnit
allocatedFrom
epc: FS_EPC
ice: FS_ICE
etrsm: FS_TRSM

fp: FS_EPC
```

37
### Product and Systems Lifecycle Management Center

#### Link Extensional Model

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Type</th>
<th>Input</th>
<th>Values</th>
</tr>
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<tbody>
<tr>
<td>root</td>
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<tr>
<td>link</td>
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<td>description</td>
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<td>STRING</td>
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<td>designer</td>
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<td>Input</td>
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<td>rb1</td>
<td></td>
<td>rb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rb2</td>
<td></td>
<td>rb</td>
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<td>REAL</td>
<td>Output</td>
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<td>condition</td>
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<td>length</td>
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#### Link (link_extensional_model)

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<tr>
<th>Name</th>
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<th>Active</th>
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<tr>
<td>a1</td>
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<td>&lt;deformation_model.undeformed_length&gt; == &lt;link.effective_length&gt;</td>
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<td>a2</td>
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<td>&lt;deformation_model.area&gt; == &lt;link.shaft.critical_cross_section.basic_area&gt;</td>
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<td>a3</td>
<td>Y</td>
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<td>&lt;deformation_model.material_model.youngs_modulus&gt; == &lt;link.material.stress_strain_model.linear&gt;</td>
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<tr>
<td>a4</td>
<td>Y</td>
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<td>&lt;deformation_model.material_model.name&gt; == &lt;link.material.name&gt;</td>
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<td>a5</td>
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<td>&lt;deformation_model.force&gt; == &lt;associated_condition.reaction&gt;</td>
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<td>a6</td>
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<tr>
<td>a7</td>
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<td>&lt;stress_mos_model.determined&gt; == &lt;deformation_model.material_model.stress&gt;</td>
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</tbody>
</table>


Product and Systems Lifecycle Management Center
red = idealized parameter