Product and Systems Lifecycle Management Center

Defining Executable Design & Simulation Models using SysML

Frontiers in Design & Simulation Research 2006
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Atlanta, GA

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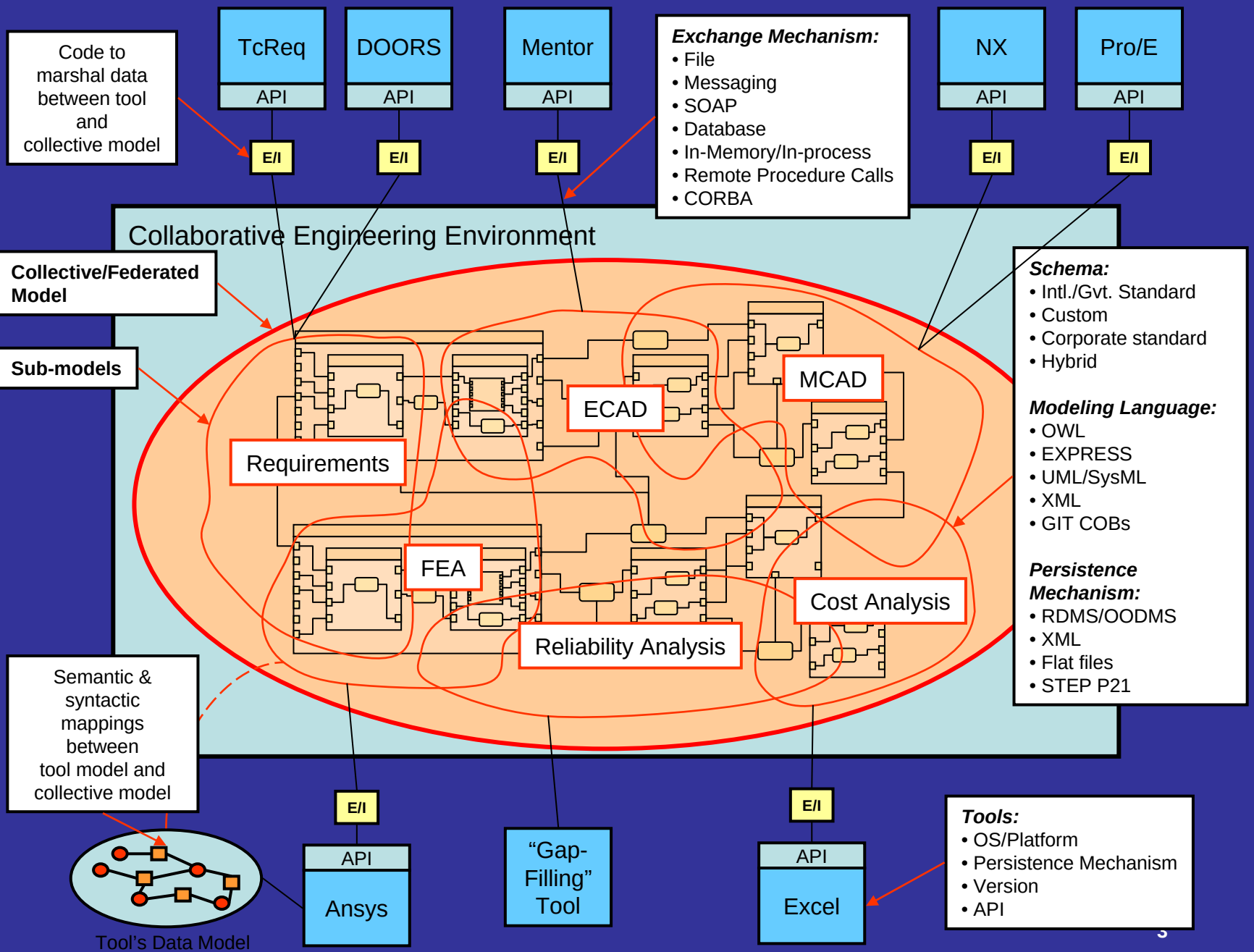
Georgia Institute of Technology

Agenda

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

Collaborative D&S Environment



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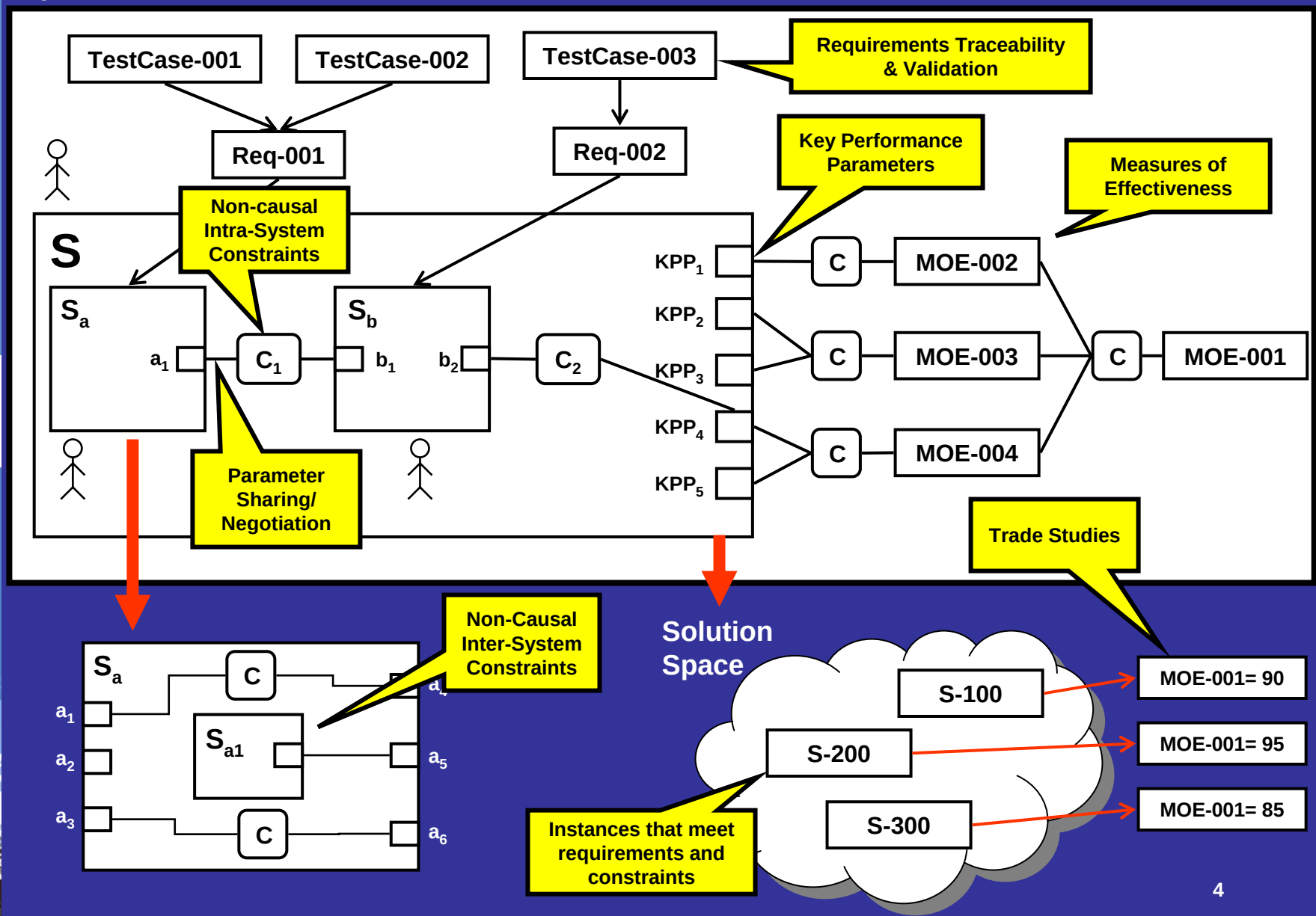
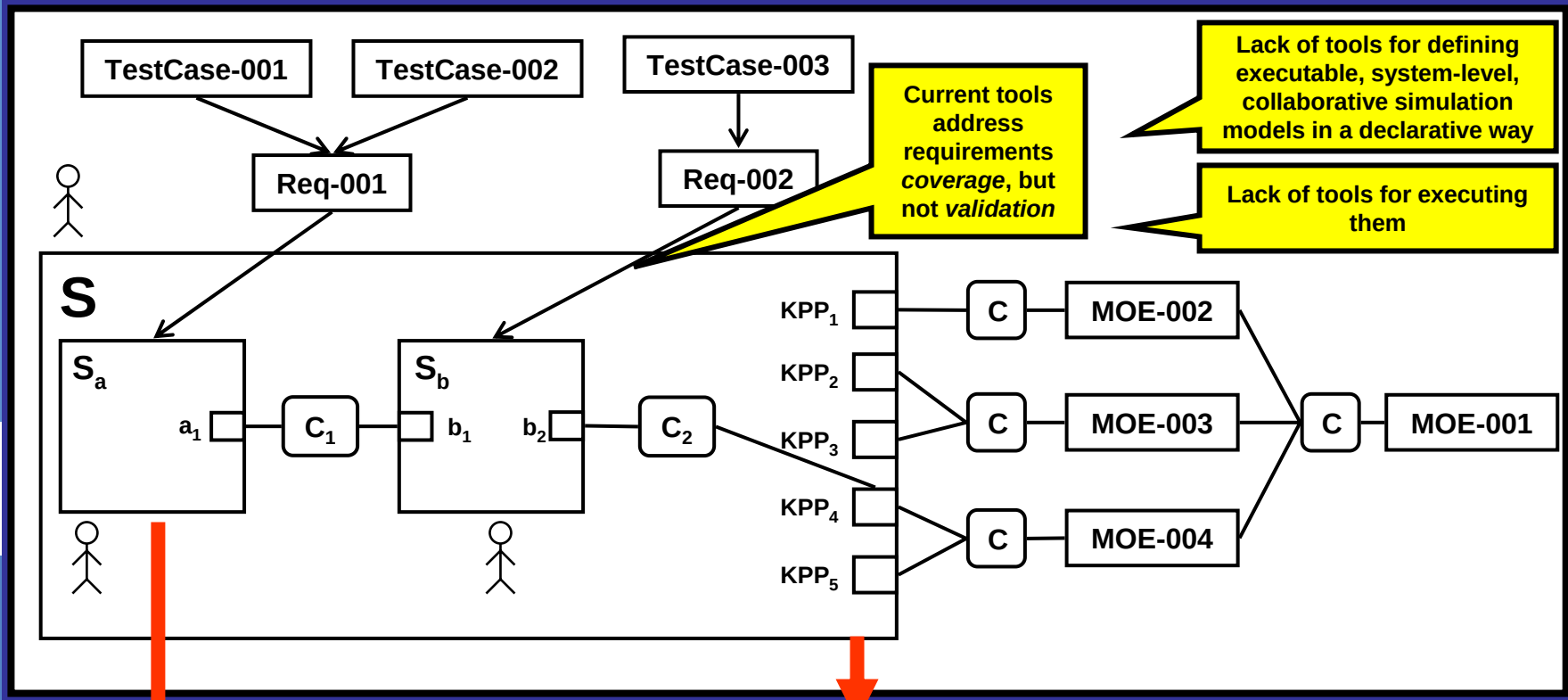
Collaborative D&S

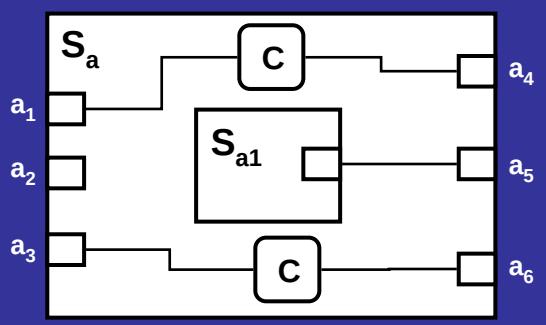
System Definition



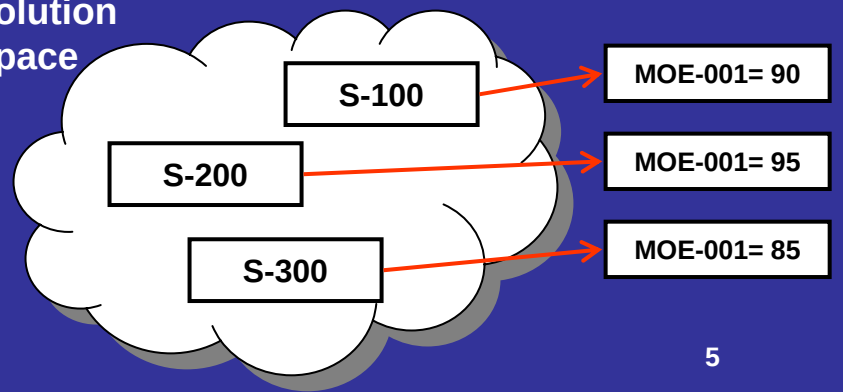
Collaborative D&S

System Definition

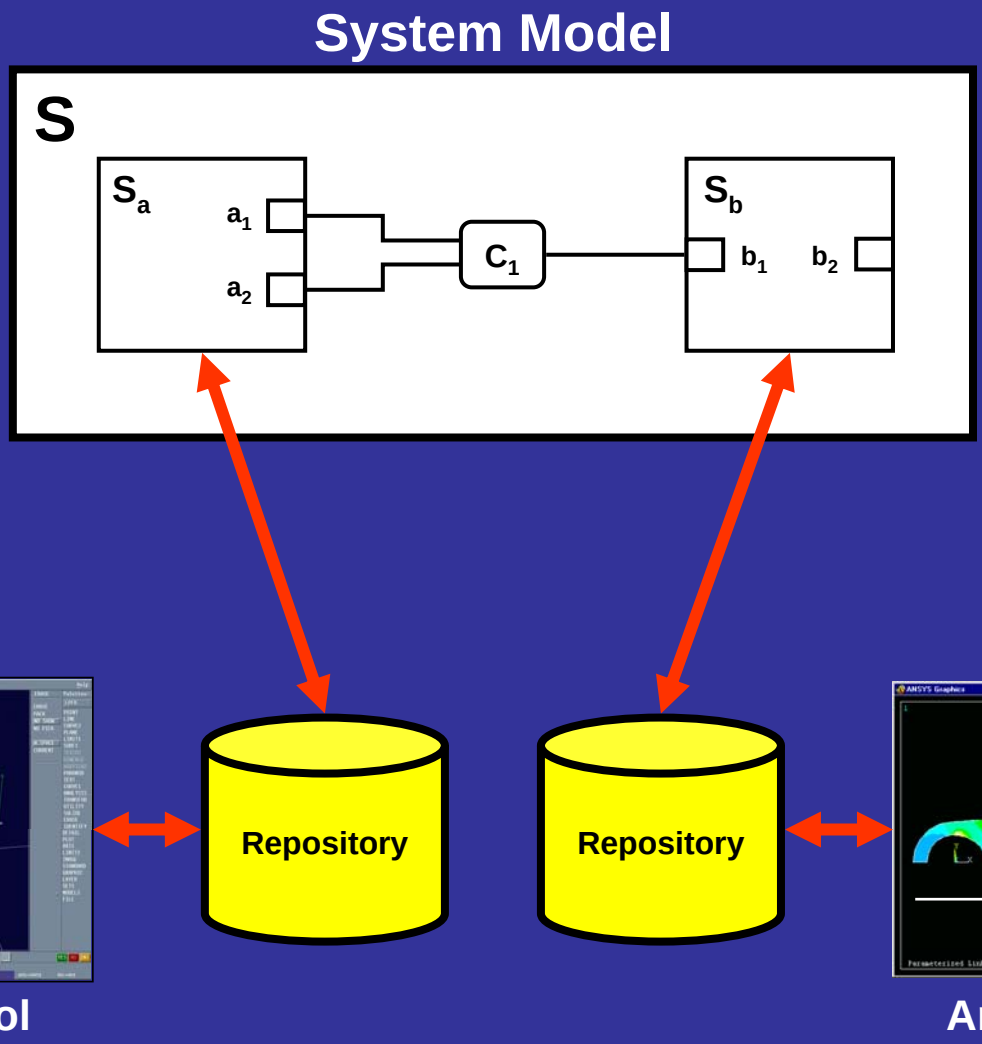




Solution Space

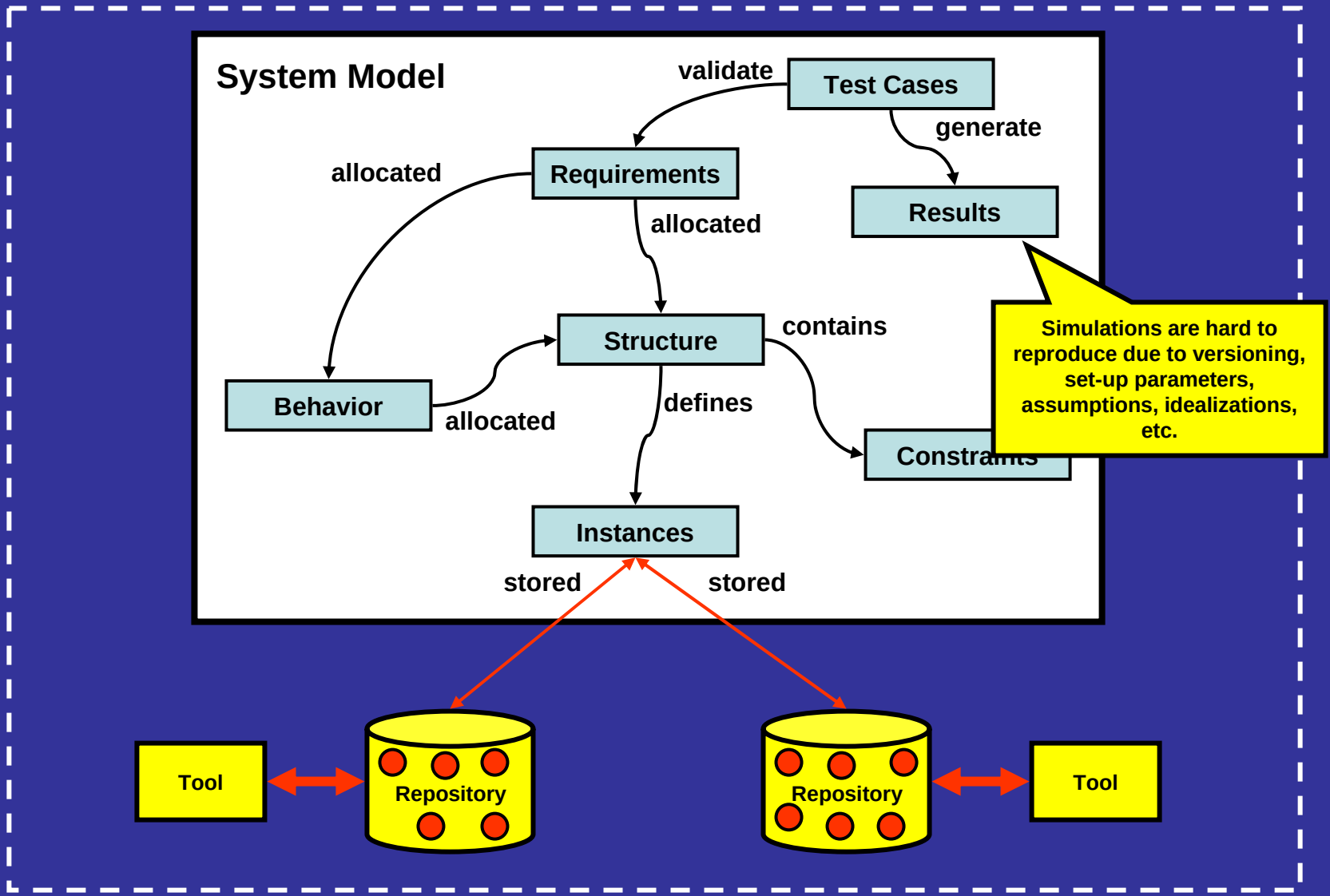


External Tool Access



Configuration Control

Configuration Control



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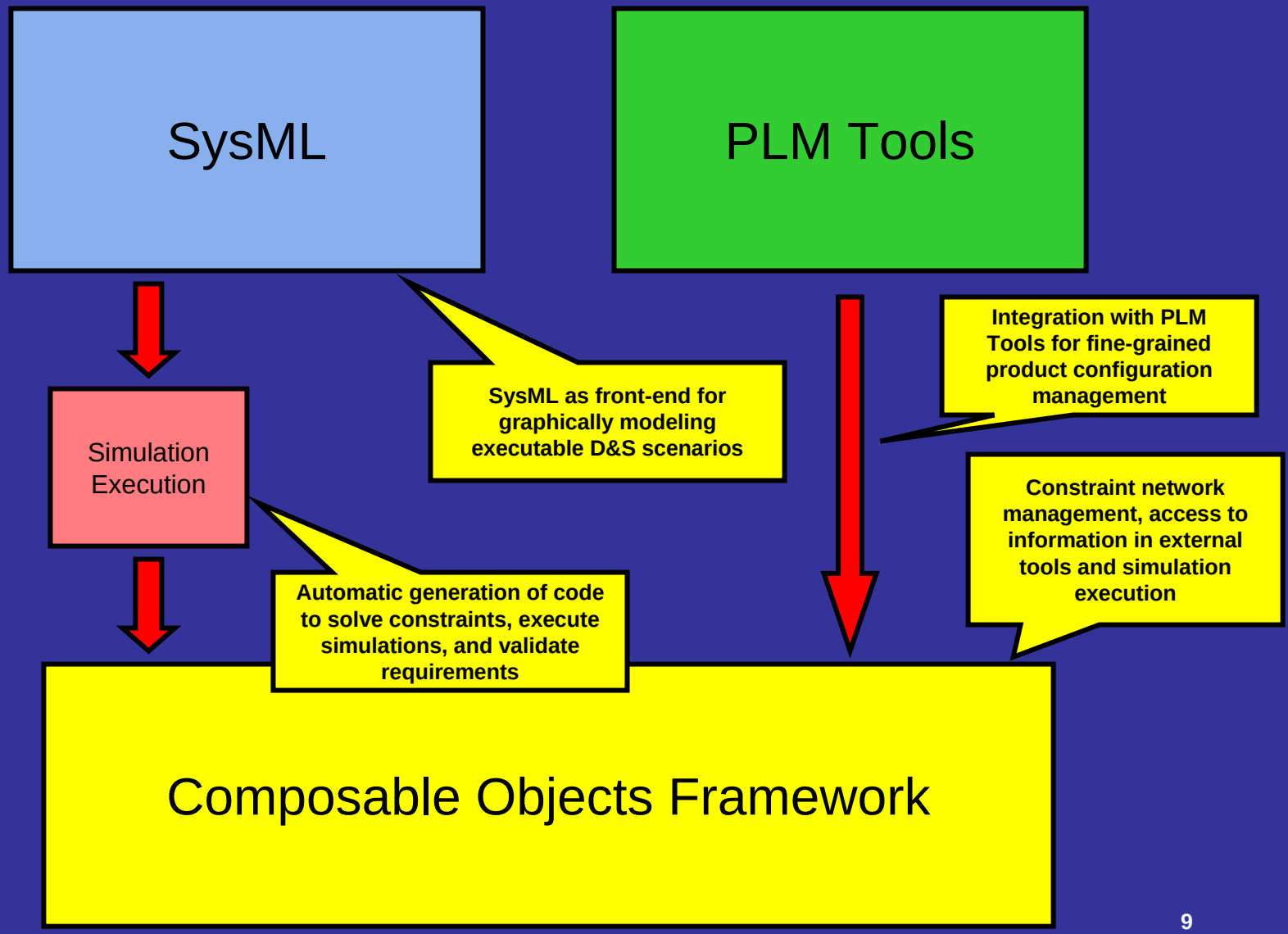
Envisioned Approach



SysML Front-End

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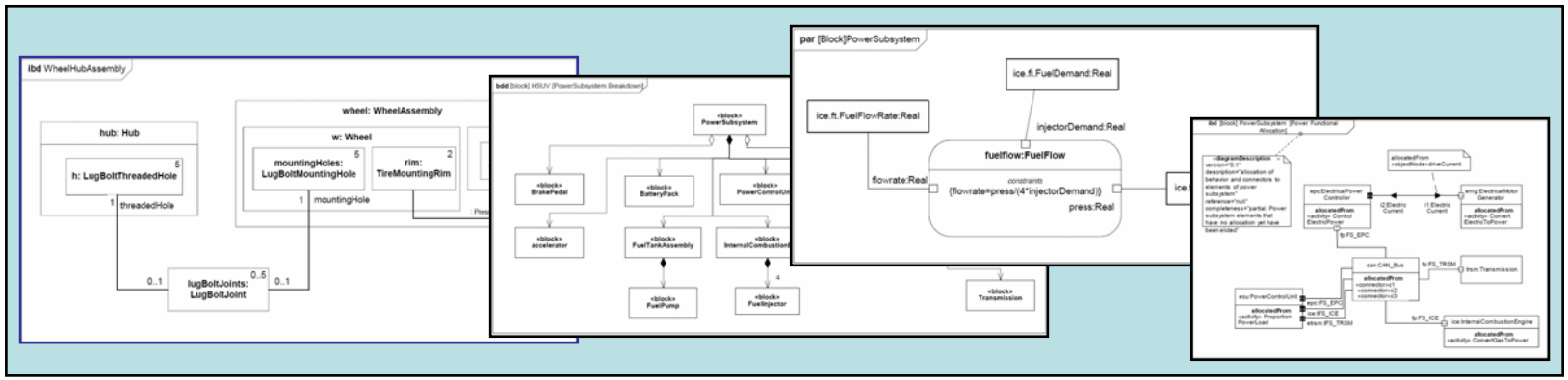
Structure



generates

publish/subscribe

System.java
- Attributes
- Constraints
- Methods

Event.java

Requirement.java

validated

TestCase.java

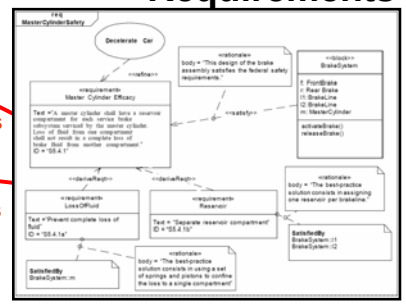
generates

uses

1

*

Requirements

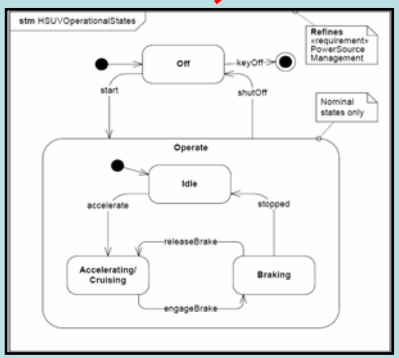


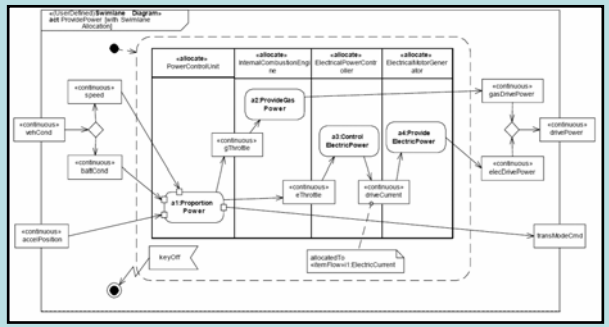
Behavior

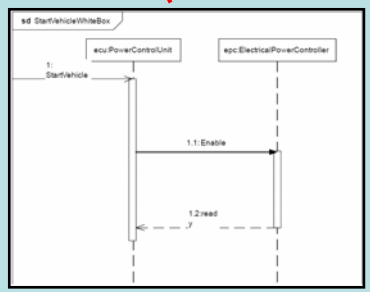
StateMachine.java

Activity.java

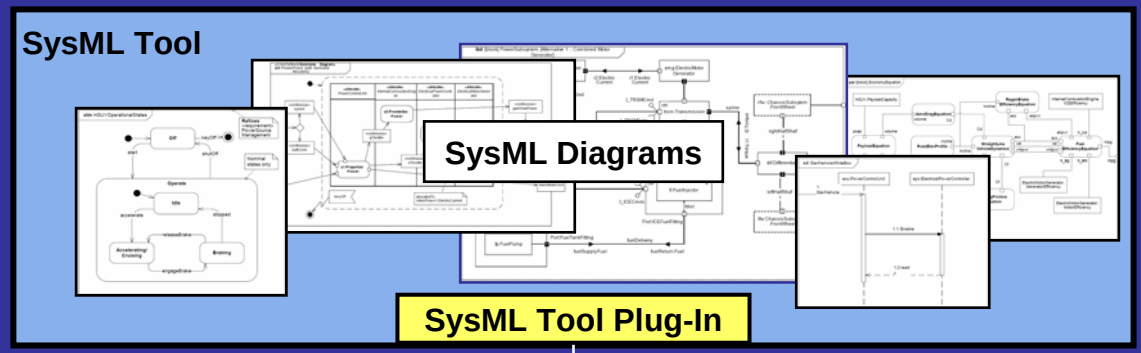
Sequence.java







Integration with SysML Systems



generate

Componentized, meta-solving framework

Java Classes

uses

Execution Client

extend

COB Framework

API/Base Classes

COB Services

Graph Management

Persistence

Versioning Control

Tool Access

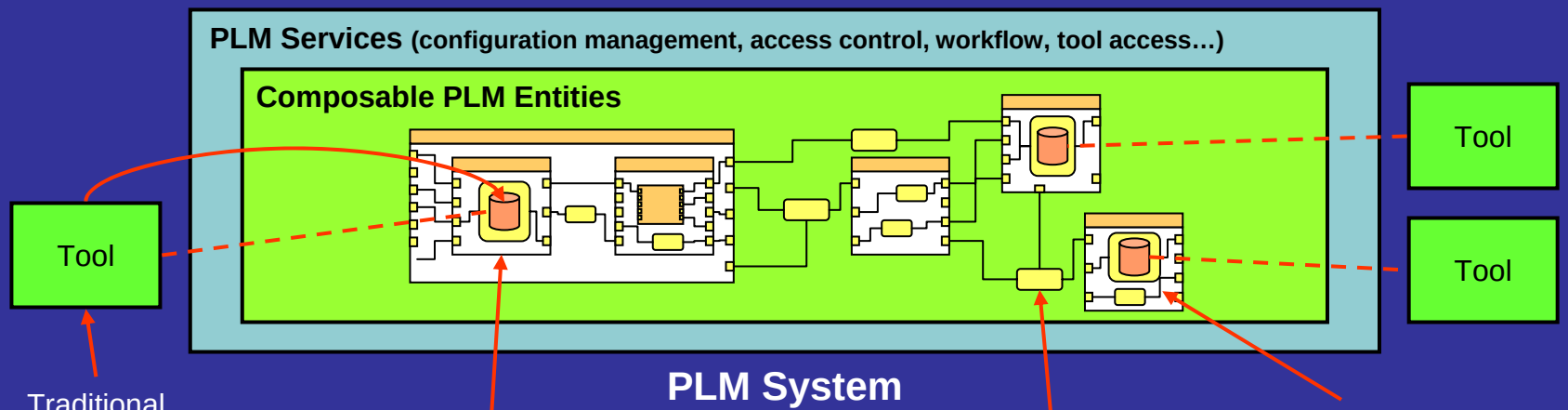
Connector

Connector

Tool

Tool

Integration With PLM Systems



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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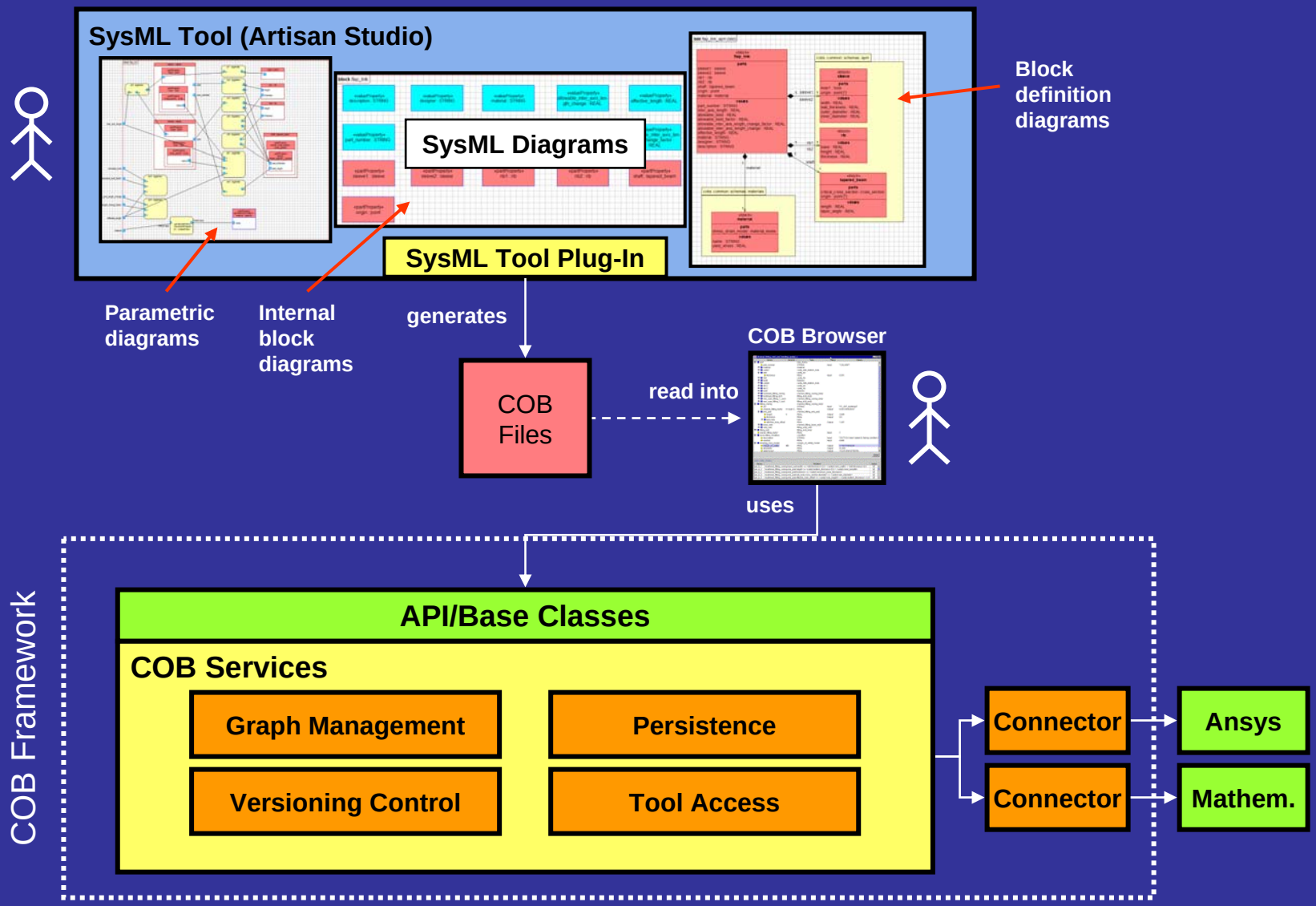
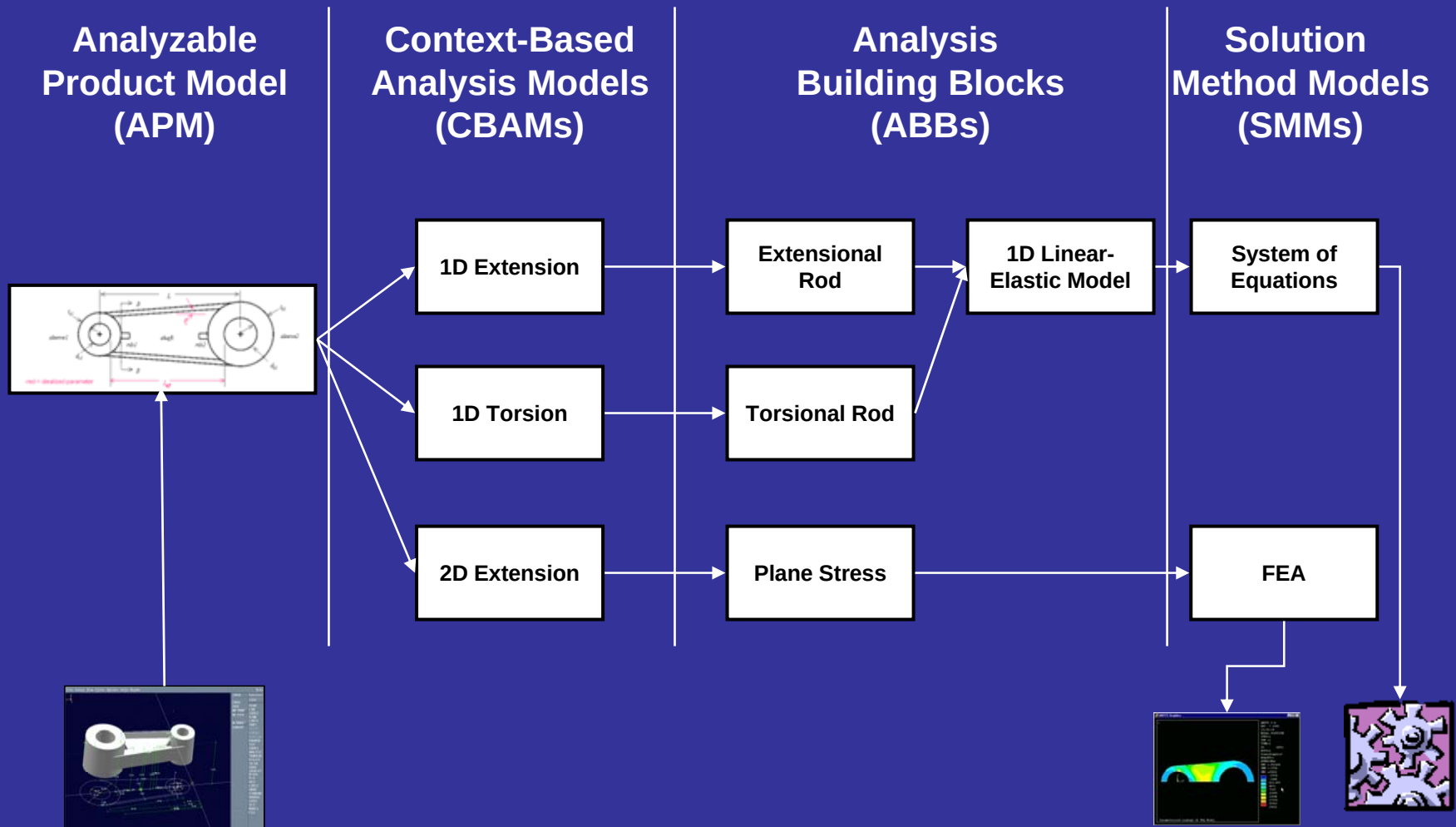
Prototype SysML Tool Integration



Demo: Airplane Wing Flap Link



Demo: Defining Flap Link Structure

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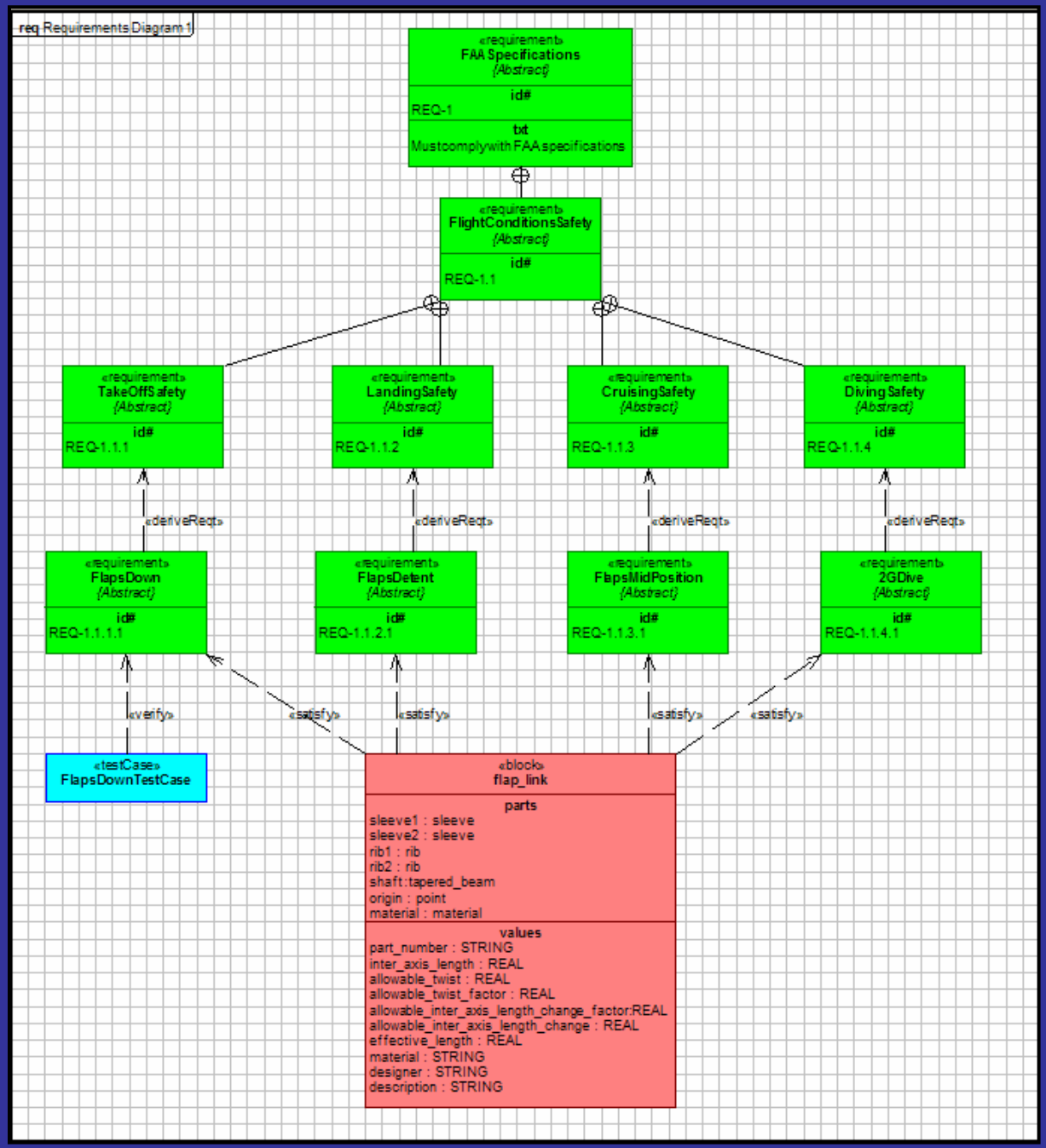
Demo: Requirements



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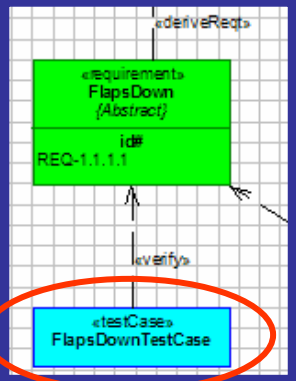
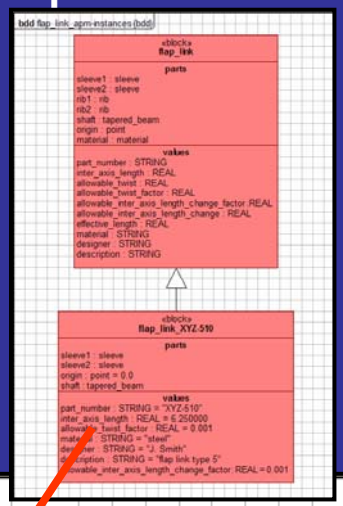
Demo: Verification Test Cases

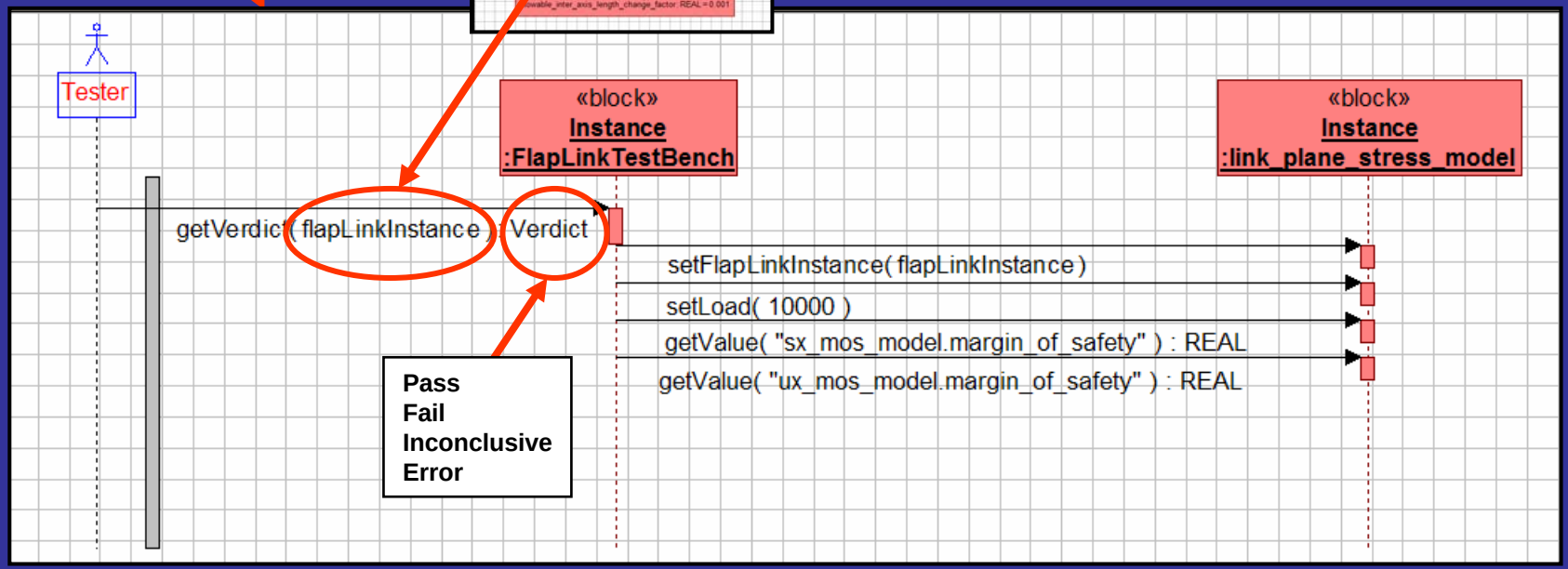
Test Case



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)

MIPS

- 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.

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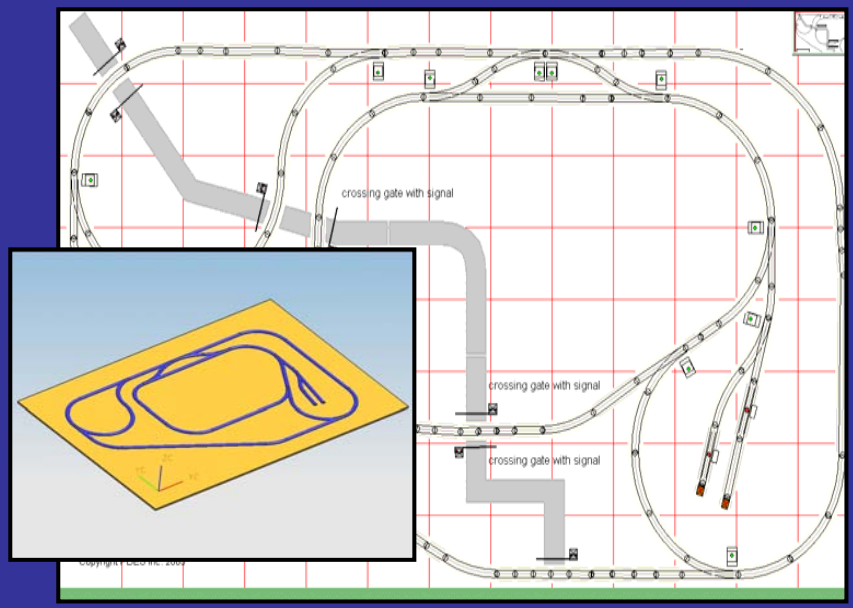
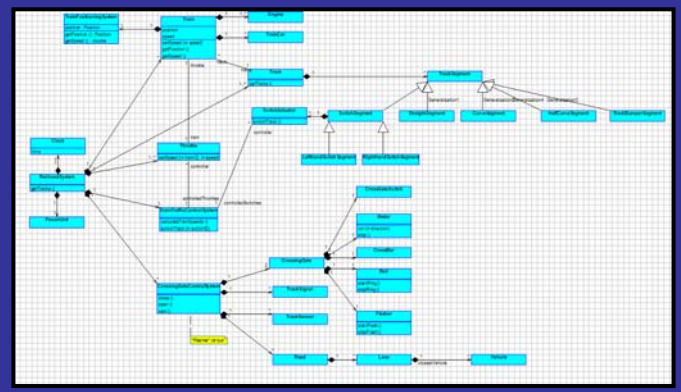
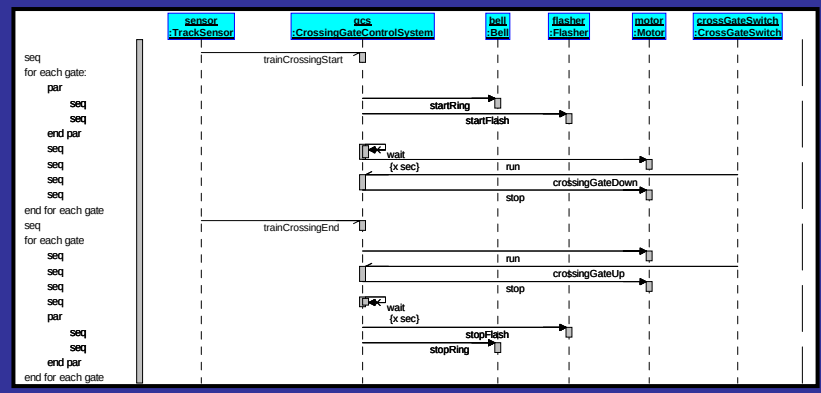
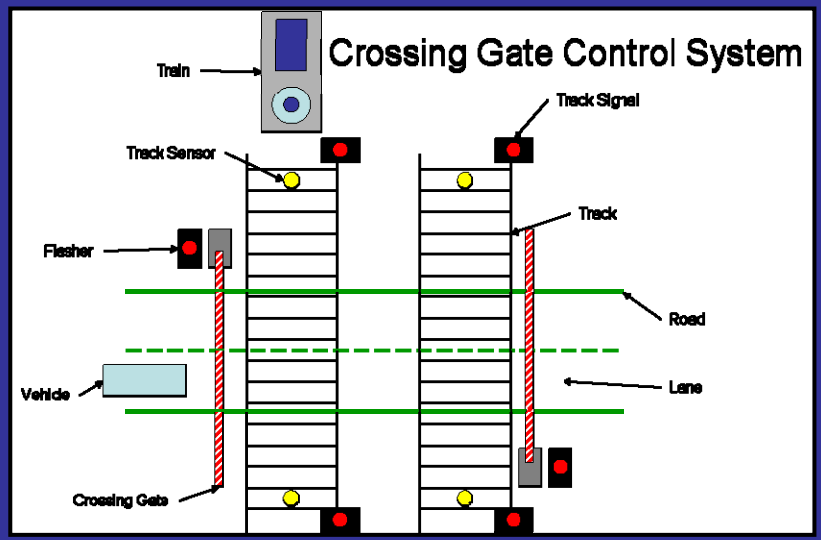
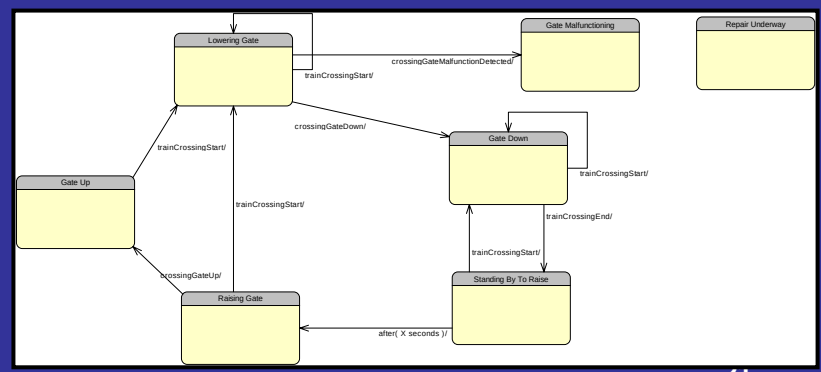
Mechatronics Interoperability Project for Systems











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MIPS

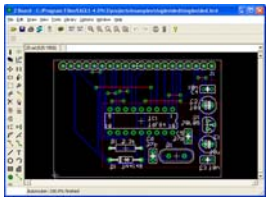
MIPS Project Testbed

ECAD

IDA-STEP AP210

GIT XaiTools PWA-B

Eagle

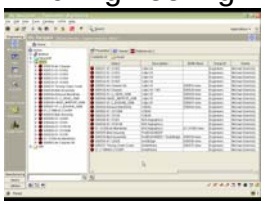


Mentor

Collaboration Environments

TcCommunity

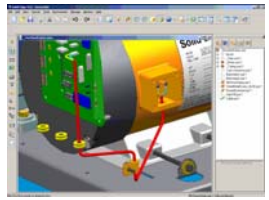
TcEngineering



Plone SOLUTIONS

MCAD

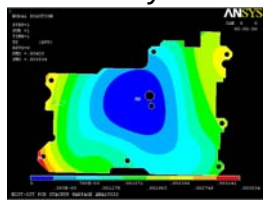
NX/SolidEdge



Solvers

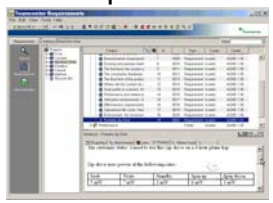
Mathematica

Ansys

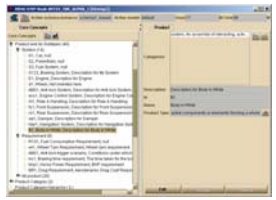


Requirements Management

TcRequirements

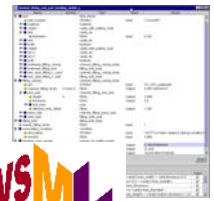


IDA-STEP AP233



Enabling Technologies

GIT COB Framework



SysML SYSTEMS MODELING LANGUAGE

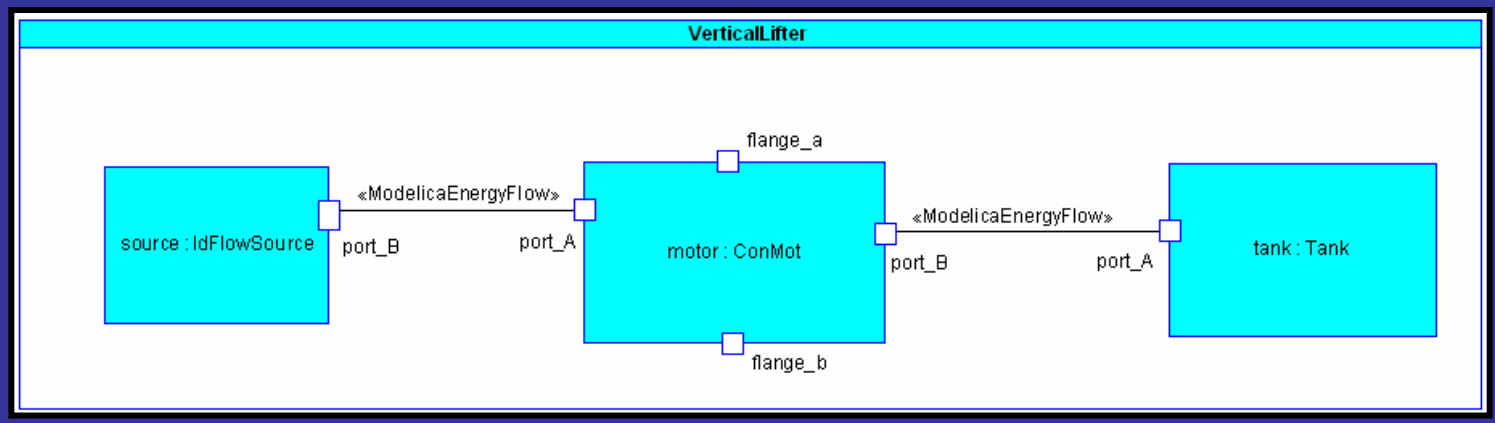
STEP AP233/AP210

ISO

FiPER

JSDAI

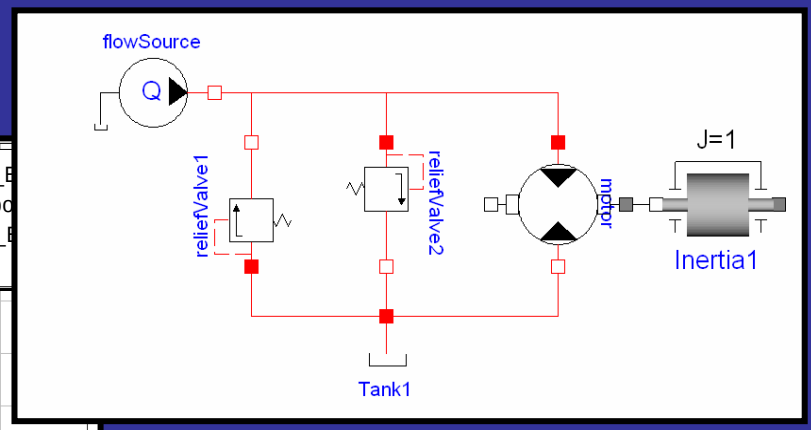
SysML-based Reference Models for Fluid Power Components

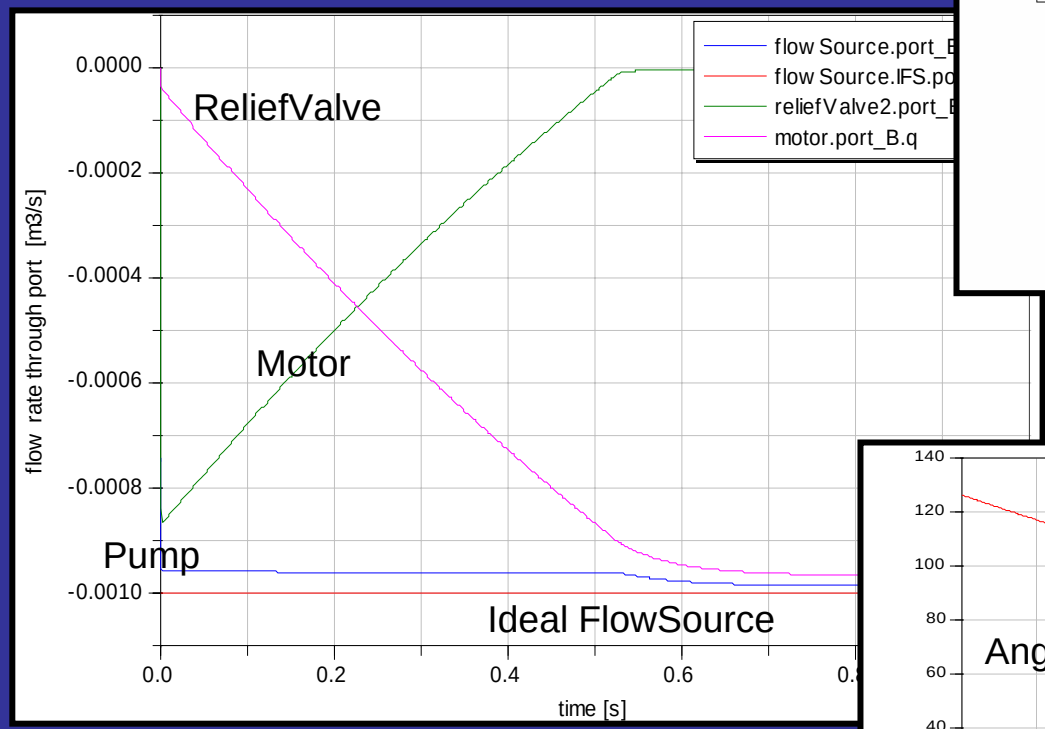


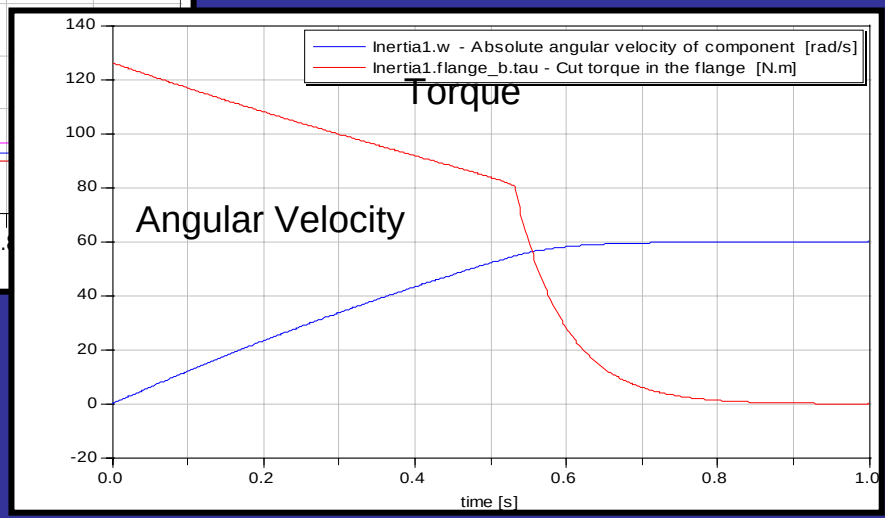
Automatically-Generated Modelica Model

```
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

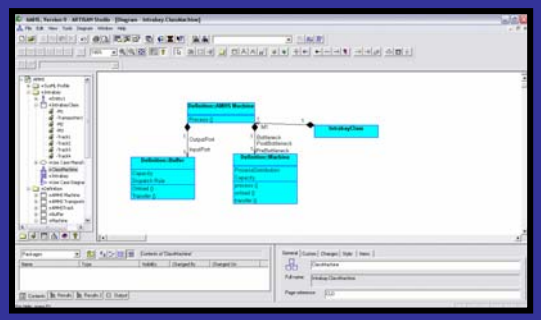




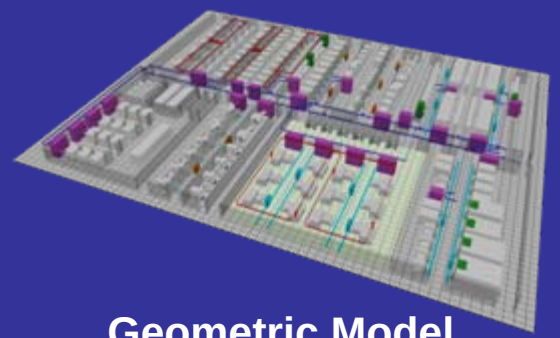


Wafer Fabrication Factory Simulation

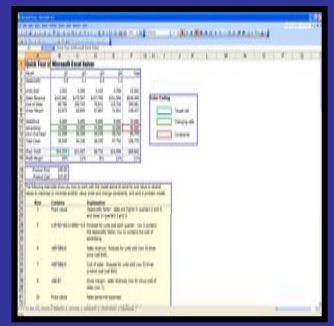
Wafer Fabrication Factory



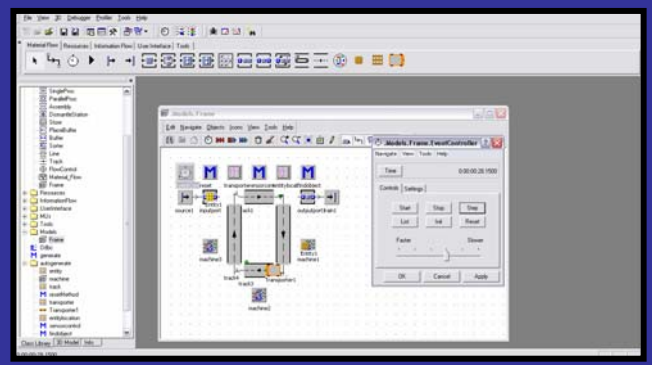
Logic Model (SysML)



Geometric Model (CAD)



Other Models



Simulation Model (eM-Plant)

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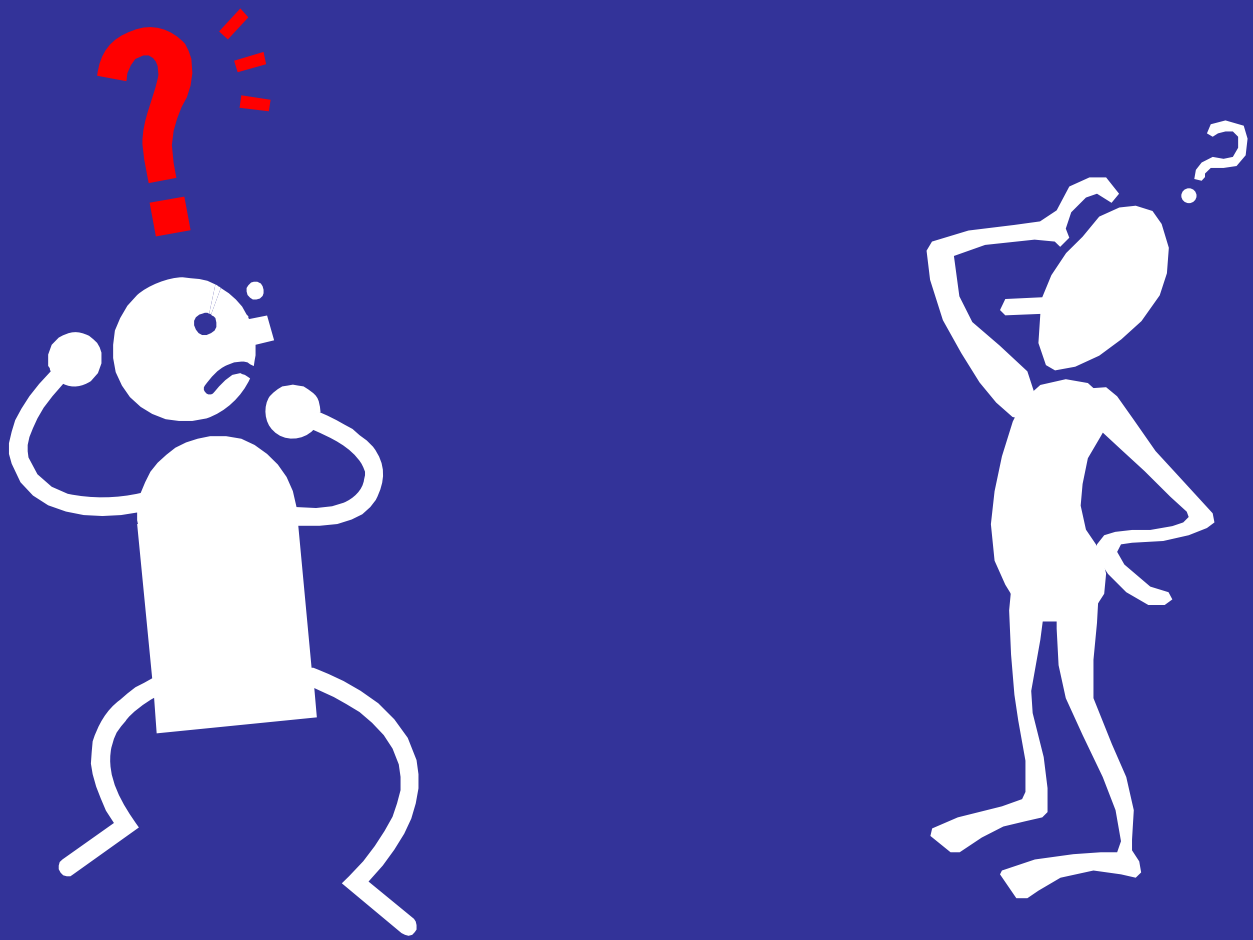
Questions or Reactions?



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Thank you!

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http://www.pslm.gatech.edu

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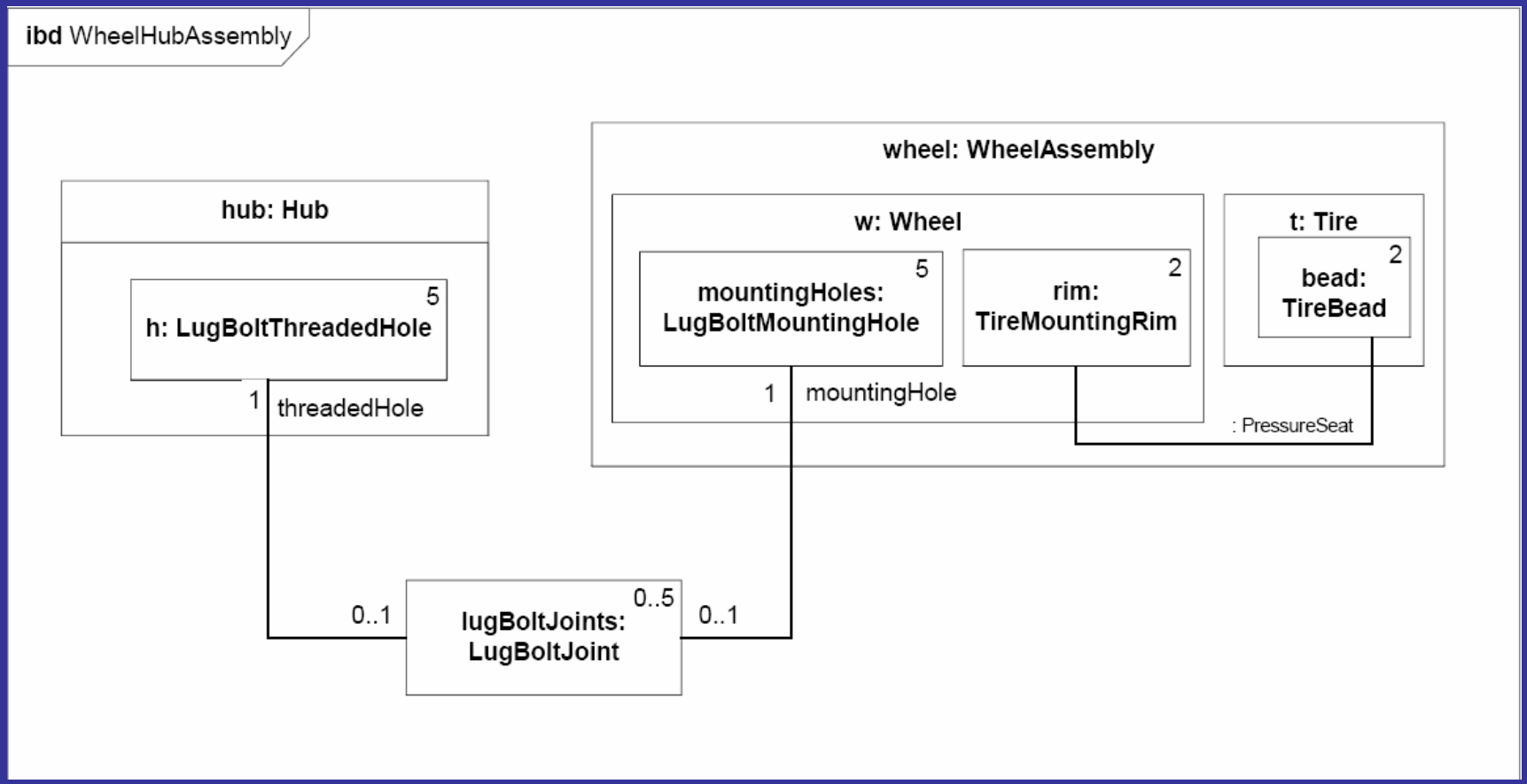
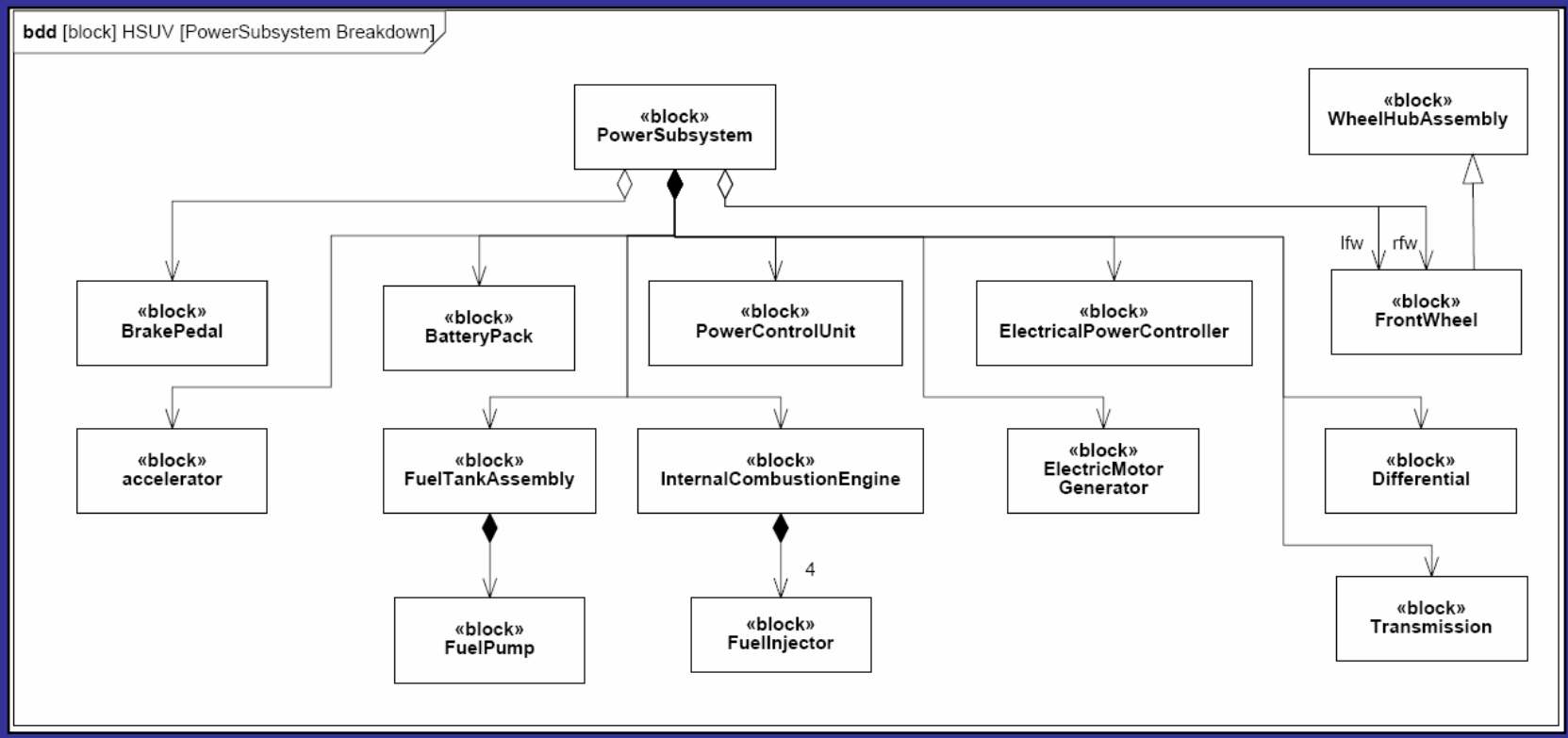
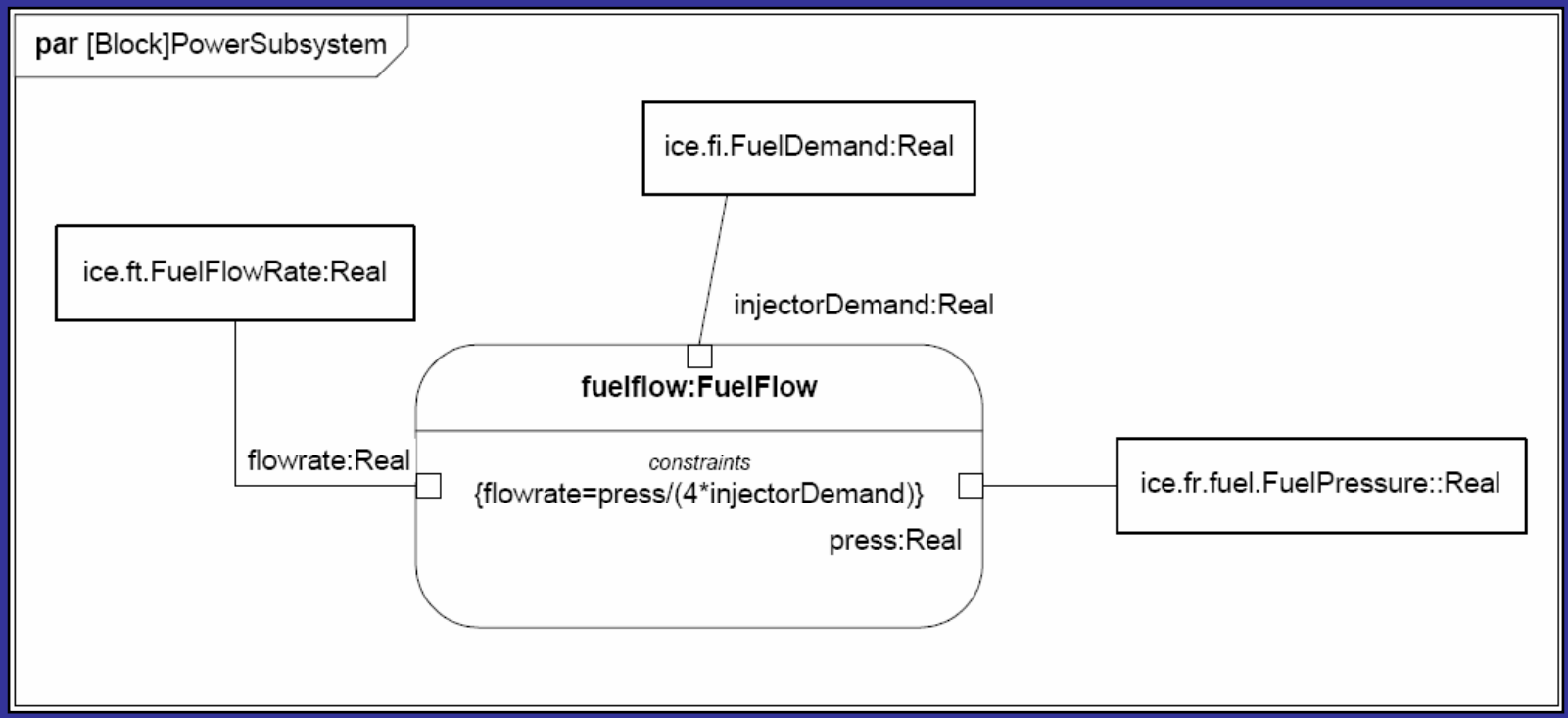
Hyperlinked Slides


ibd WheelHubAssembly
hub: Hub
h: LugBoltThreadedHole
5
1
threadedHole
wheel: WheelAssembly
w: Wheel
mountingHoles:
LugBoltMountingHole
5
rim:
TireMountingRim
2
1
mountingHole
t: Tire
bead:
TireBead
2
: PressureSeat
0..1
lugBoltJoints:
LugBoltJoint
0..5
0..1


bdd [block] HSUV [PowerSubsystem Breakdown]
«block» PowerSubsystem
«block» WheelHubAssembly
lfw
rfw
«block» BrakePedal
«block» BatteryPack
«block» PowerControlUnit
«block» ElectricalPowerController
«block» FrontWheel
«block» accelerator
«block» FuelTankAssembly
«block» InternalCombustionEngine
«block» ElectricMotor Generator
«block» Differential
4
«block» FuelPump
«block» FuelInjector
«block» Transmission


par [Block]PowerSubsystem
ice.fi.FuelDemand:Real
ice.ft.FuelFlowRate:Real
injectorDemand:Real
fuelflow:FuelFlow
flowrate:Real
constraints
{flowrate=press/(4*injectorDemand)}
press:Real
ice.fr.fuel.FuelPressure::Real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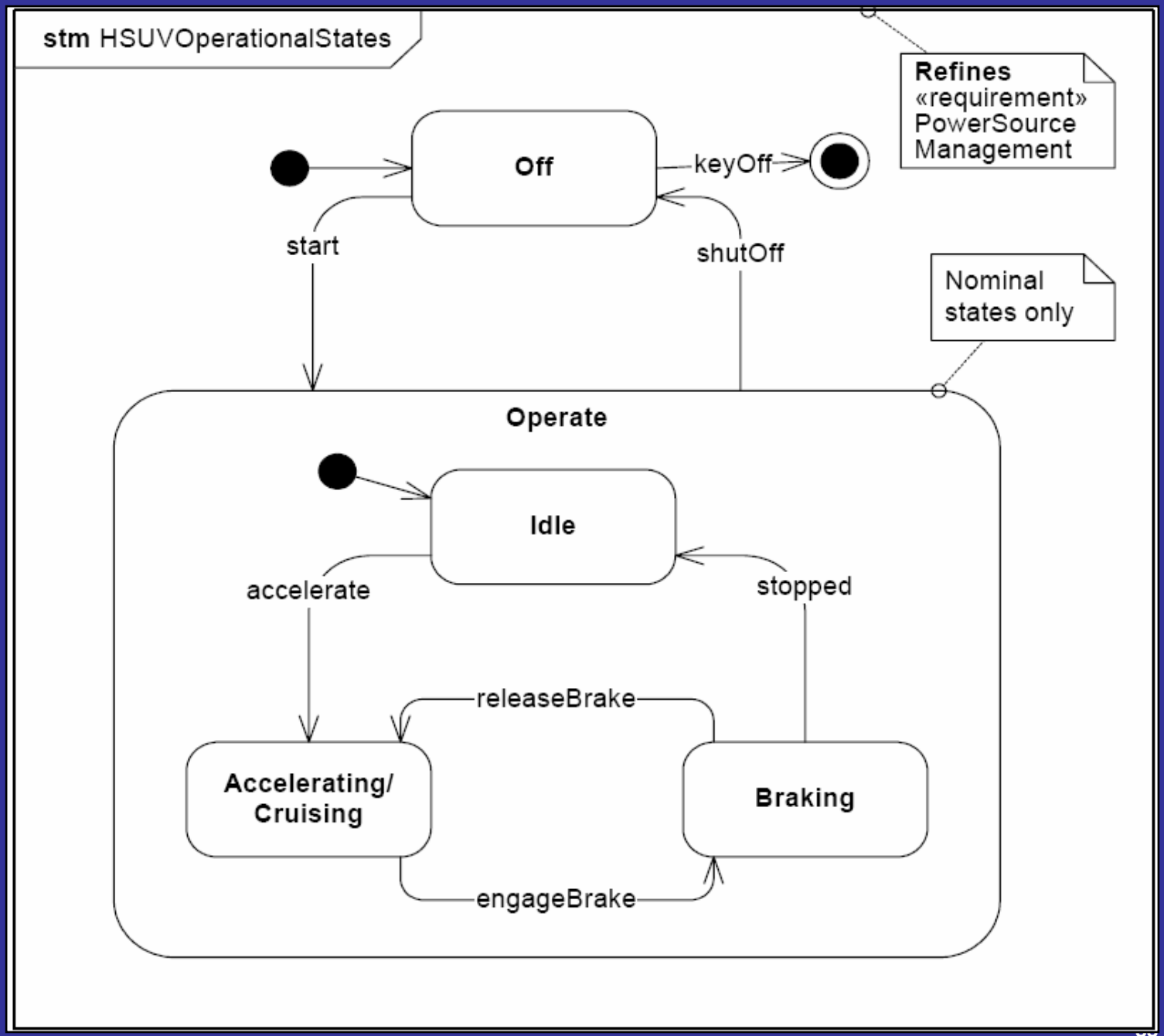
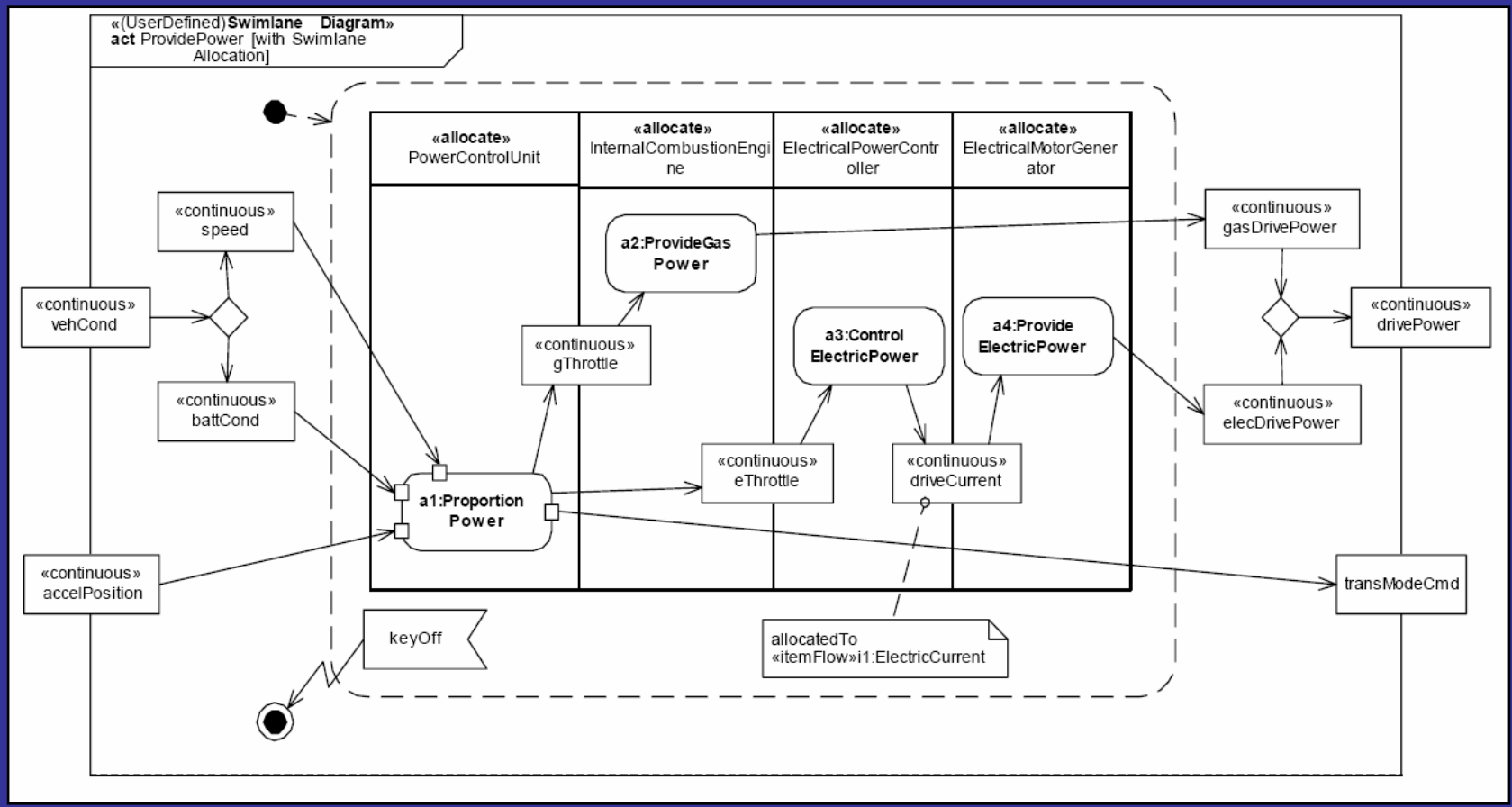
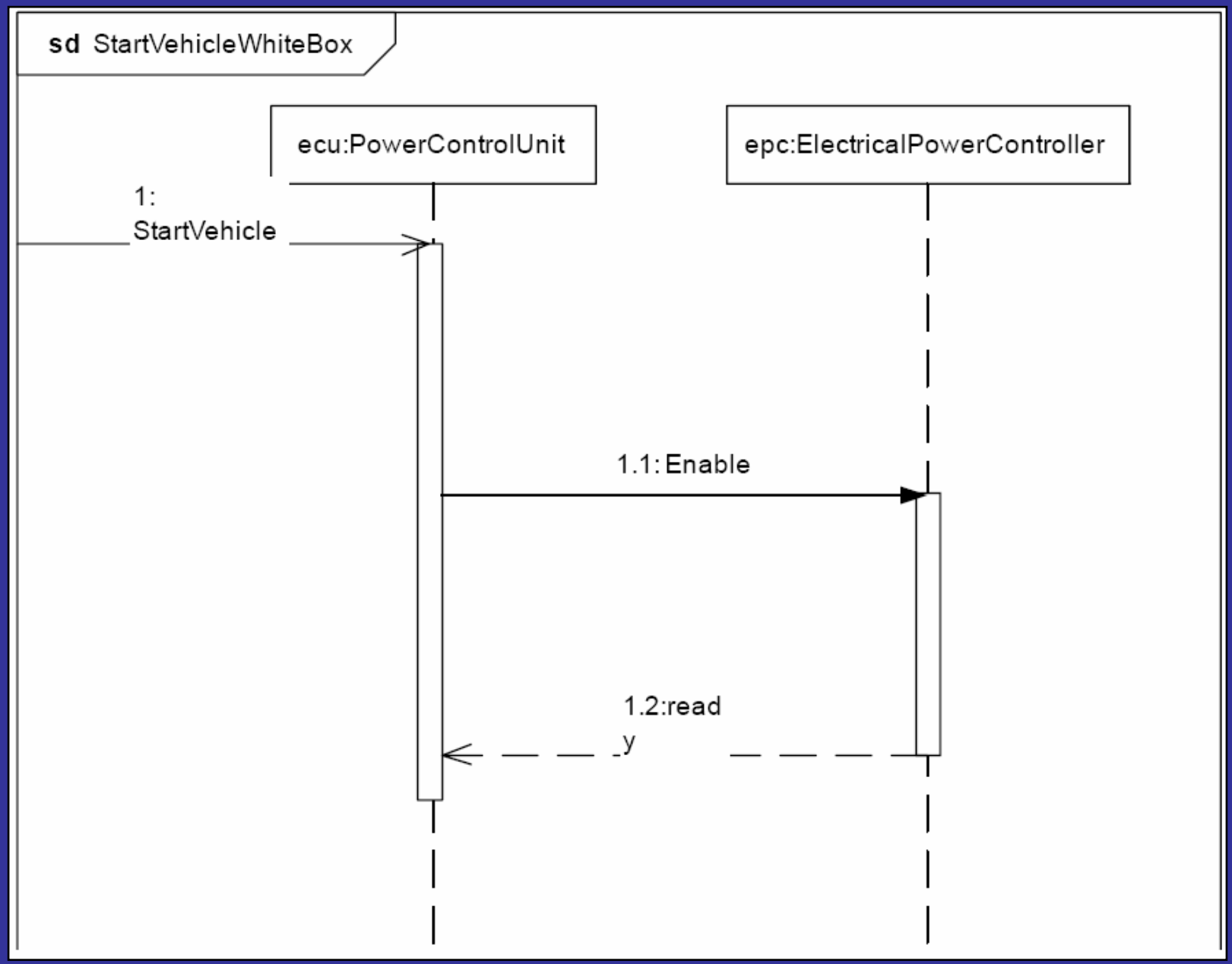
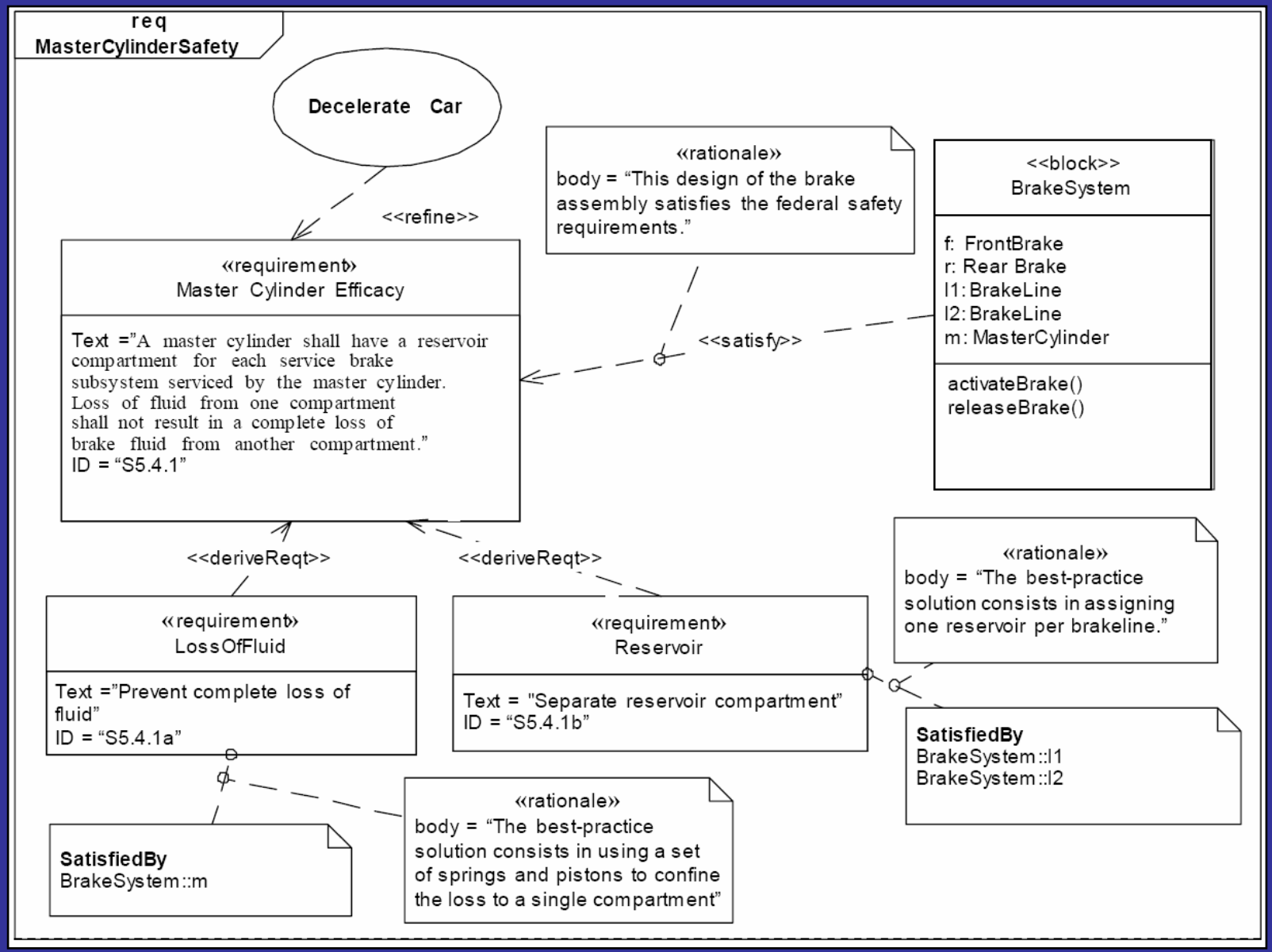
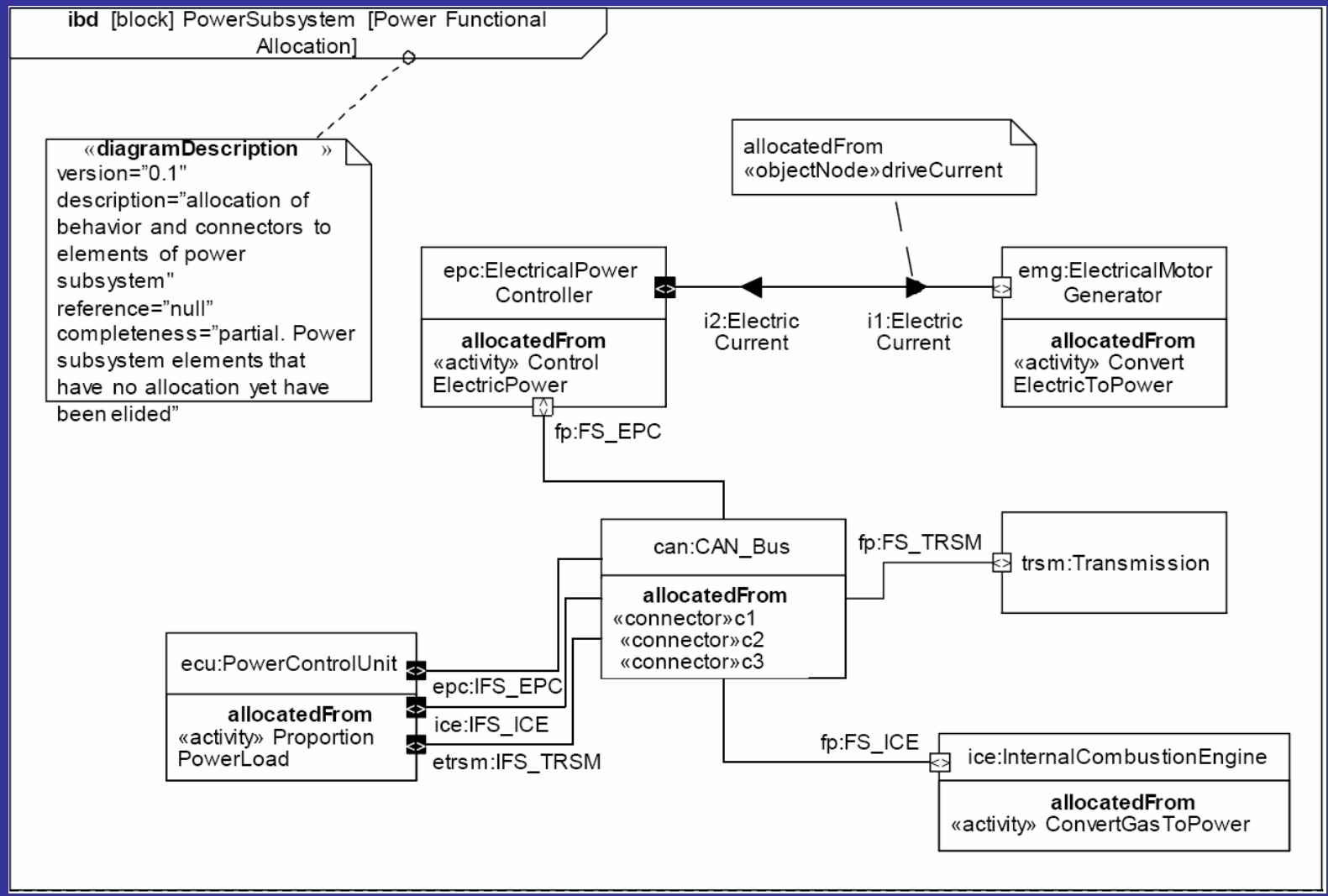
RESEARCH
CENTER


stm HSUVOperationalStates
Refines
«requirement»
PowerSource
Management
Off
keyOff
start
shutOff
Nominal
states only
Operate
Idle
accelerate
stopped
releaseBrake
Accelerating/
Cruising
Braking
engageBrake


«(UserDefined)Swimlane Diagram»
act ProvidePower [with Swimlane Allocation]
«allocate» PowerControlUnit
«allocate» InternalCombustionEngine
«allocate» ElectricalPowerController
«allocate» ElectricalMotorGenerator
«continuous» speed
«continuous» vehCond
«continuous» battCond
«continuous» accelPosition
a1:Proportion Power
a2:ProvideGas Power
a3:Control ElectricPower
a4:Provide ElectricPower
«continuous» gThrottle
«continuous» eThrottle
«continuous» driveCurrent
«continuous» gasDrivePower
«continuous» drivePower
«continuous» elecDrivePower
transModeCmd
keyOff
allocatedTo
«itemFlow»i1:ElectricCurrent


sd StartVehicleWhiteBox
ecu:PowerControlUnit
epc:ElectricalPowerController
1:
StartVehicle
1.1: Enable
1.2:read
y


req
MasterCylinderSafety
Decelerate Car
<<refine>>
«rationale»
body = "This design of the brake assembly satisfies the federal safety requirements."
<<block>>
BrakeSystem
f: FrontBrake
r: Rear Brake
l1: BrakeLine
l2: BrakeLine
m: MasterCylinder
activateBrake()
releaseBrake()
«requirement»
Master Cylinder Efficacy
Text ="A master cylinder shall have a reservoir compartment for each service brake subsystem serviced 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"
<<satisfy>>
<<deriveReqt>>
<<deriveReqt>>
«requirement»
LossOfFluid
Text ="Prevent complete loss of fluid"
ID = "S5.4.1a"
«requirement»
Reservoir
Text = "Separate reservoir compartment"
ID = "S5.4.1b"
«rationale»
body = "The best-practice solution consists in assigning one reservoir per brakeline."
SatisfiedBy
BrakeSystem::l1
BrakeSystem::l2
SatisfiedBy
BrakeSystem::m
«rationale»
body = "The best-practice solution consists in using a set of springs and pistons to confine the loss to a single compartment"


ibd [block] PowerSubsystem [Power Functional Allocation]
«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"
allocatedFrom «objectNode»driveCurrent
epc:ElectricalPower Controller
allocatedFrom «activity» Control ElectricPower
i2:Electric Current
i1:Electric Current
emg:ElectricalMotor Generator
allocatedFrom «activity» Convert ElectricToPower
fp:FS_EPC
can:CAN_Bus
allocatedFrom «connector»c1 «connector»c2 «connector»c3
fp:FS_TRSM
trsm:Transmission
ecu:PowerControlUnit
allocatedFrom «activity» Proportion PowerLoad
epc:IFS_EPC
ice:IFS_ICE
etrsm:IFS_TRSM
fp:FS_ICE
ice:InternalCombustionEngine
allocatedFrom «activity» ConvertGasToPower

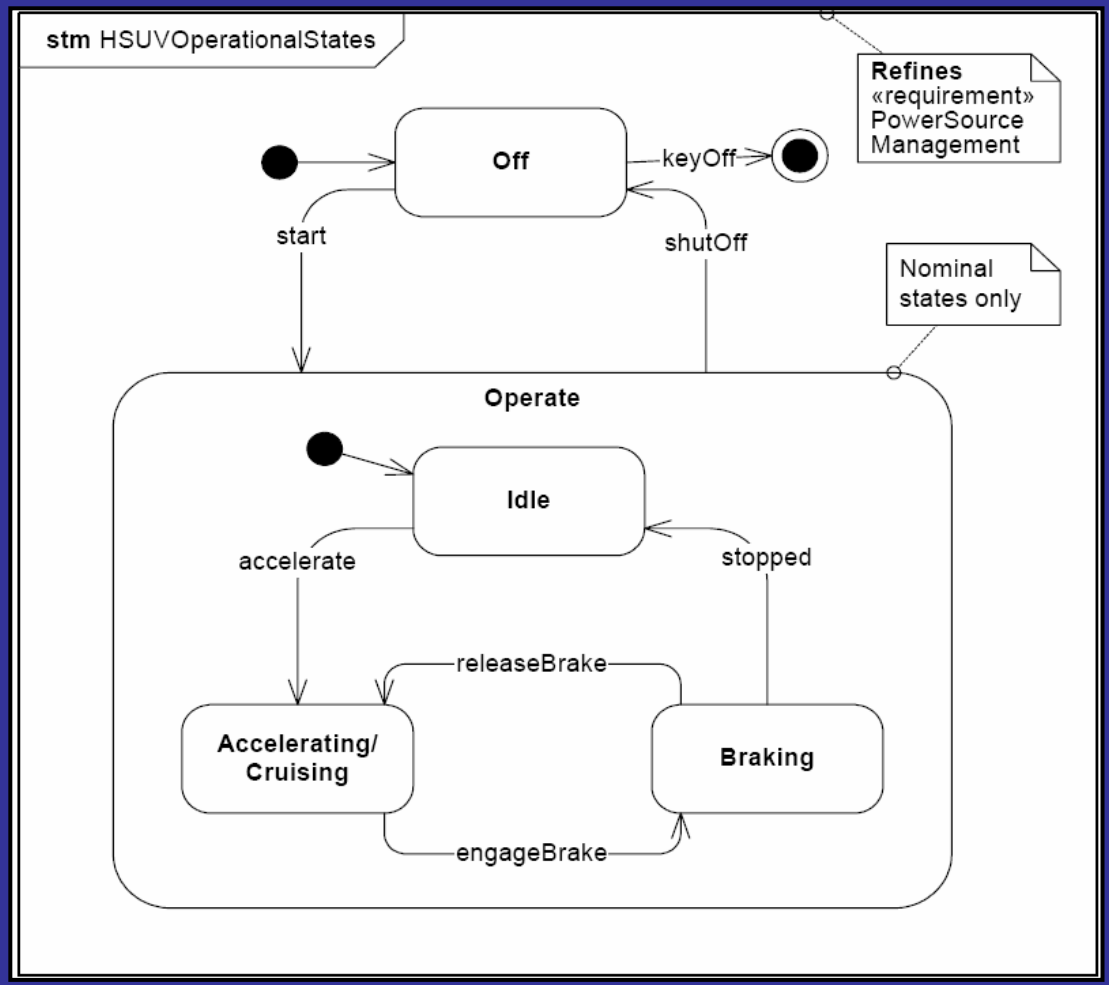
link_extensional_model

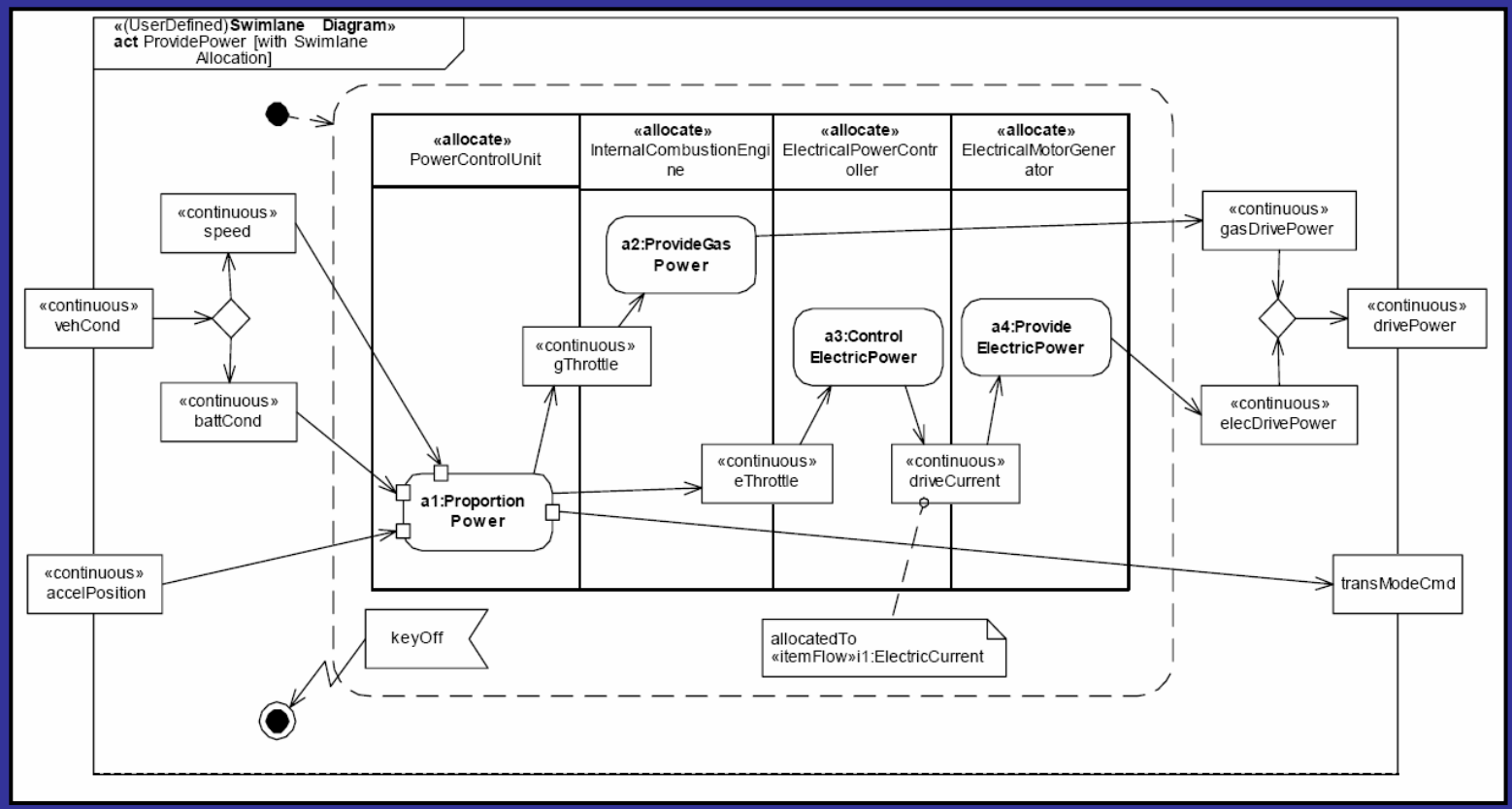
Name	Symbol	Type	Input	Values
root		link_extensional_model		
link		flap_link		
description		STRING	Input	"flap link type 5"
designer		STRING	Input	"J. Smith"
origin		coordinate		
material		material		
part_number		STRING	Input	"XYZ-510"
inter_axis_length	L_a	REAL	Input	6.25
effective_length	L_{eff}	REAL	Output	5
sleeve1		sleeve		
sleeve2		sleeve		
shaft		tapered_beam		
rib1		rib		
rib2		rib		
allowable_twist		REAL	Output	0.005
allowable_twist_factor		REAL	Input	0.001
allowable_inter_axis_leng	C_φ	REAL	Input	0.001
allowable_inter_axis_leng	C<sub>ΔLa...	REAL	Output	0.005
associated_condition		condition		
description		STRING	Input	"flaps mid position"
reaction		REAL	Input	10,000
stress_mos_model		margin_of_safety_model		
margin_of_safety	MS	REAL	Output	1.025
allowable		REAL	Output	18,000
determined		REAL	Output	8,888.888888888889
deformation_model		extensional_rod_isothermal		
undeformed_length		REAL	Output	5
area		REAL	Output	1.125
material_model		one_D_linear_elastic_model_...		
force		REAL	Output	10,000
length		REAL	Output	5.001481481481

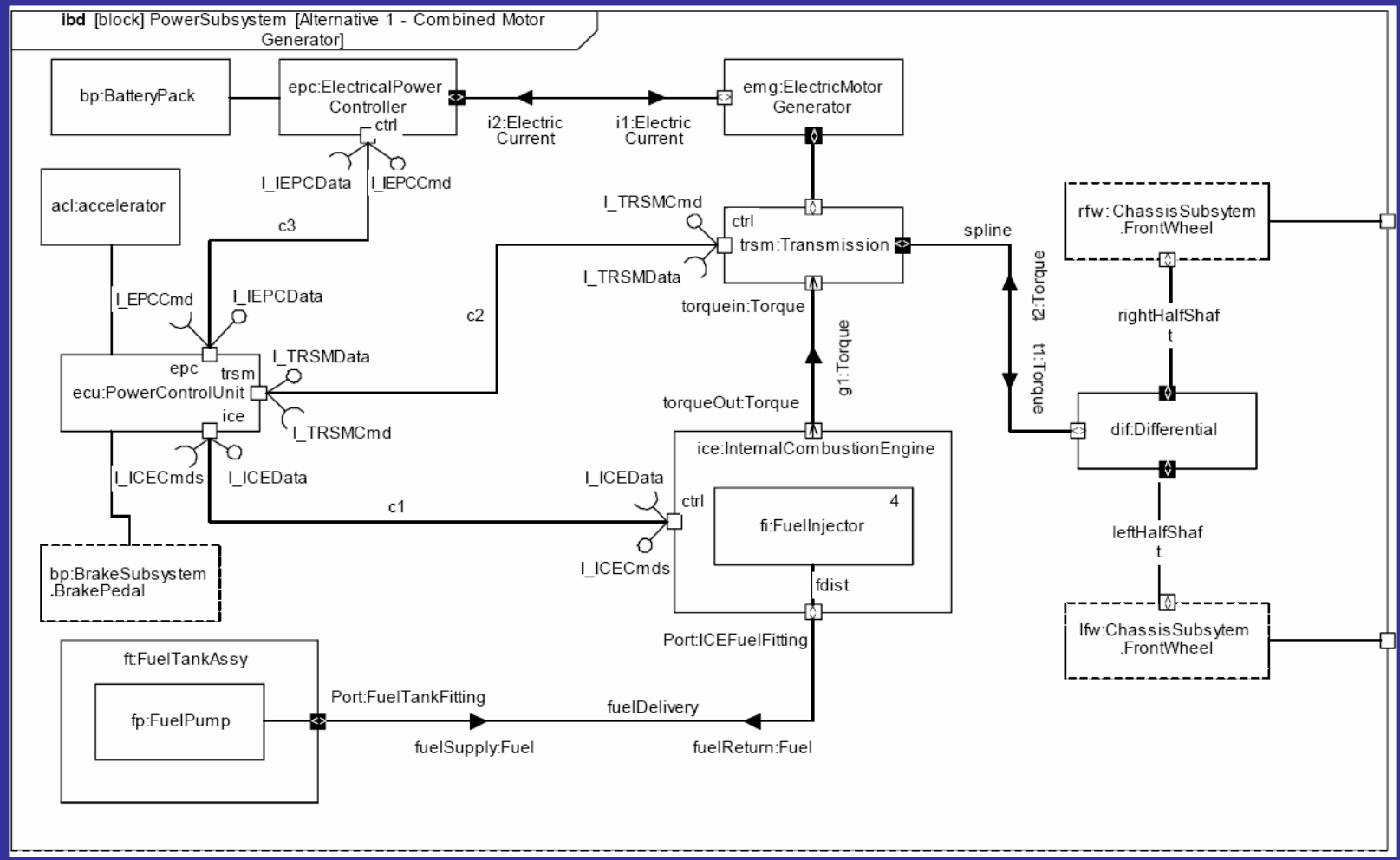
Solve

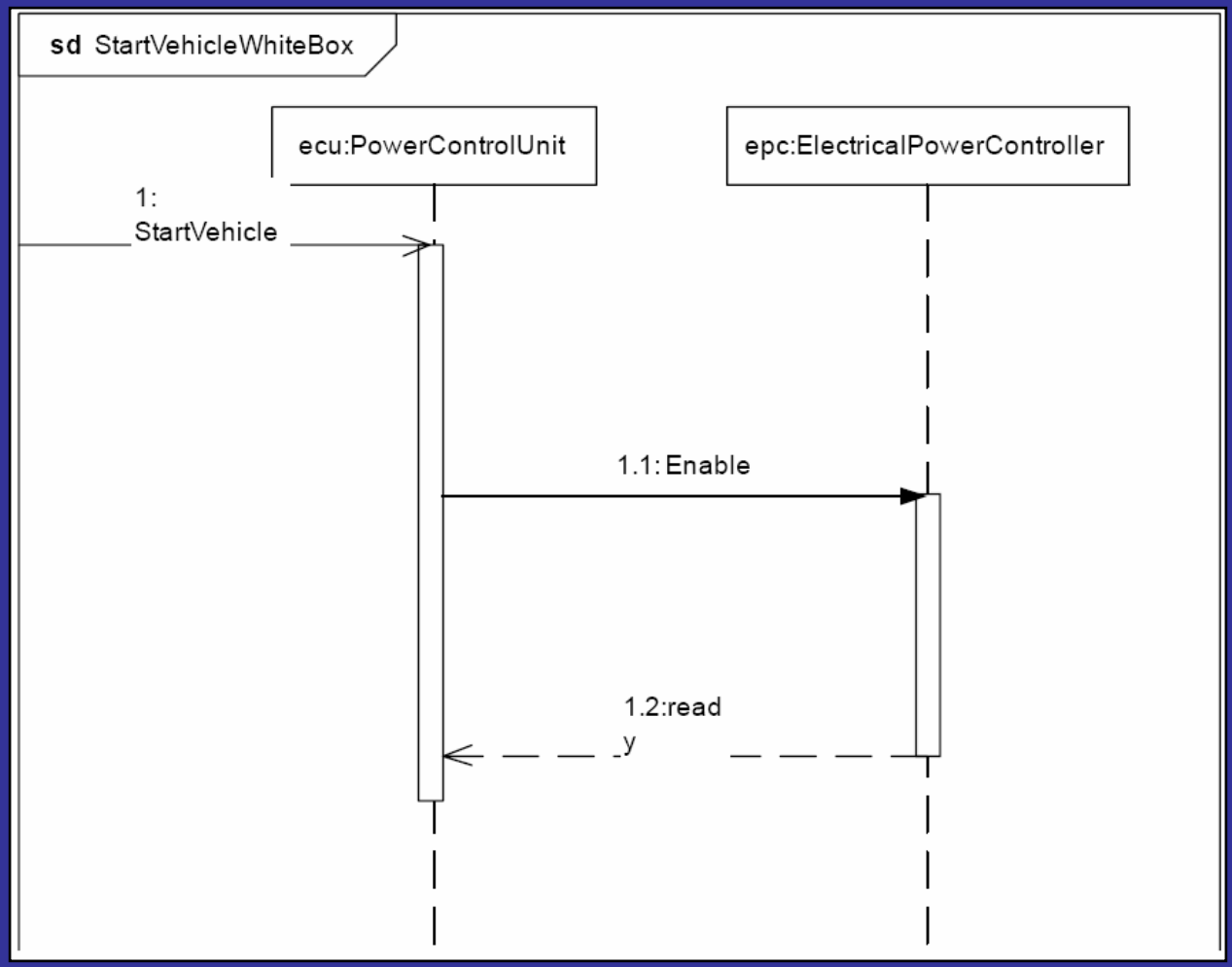
root (link_extensional_model)

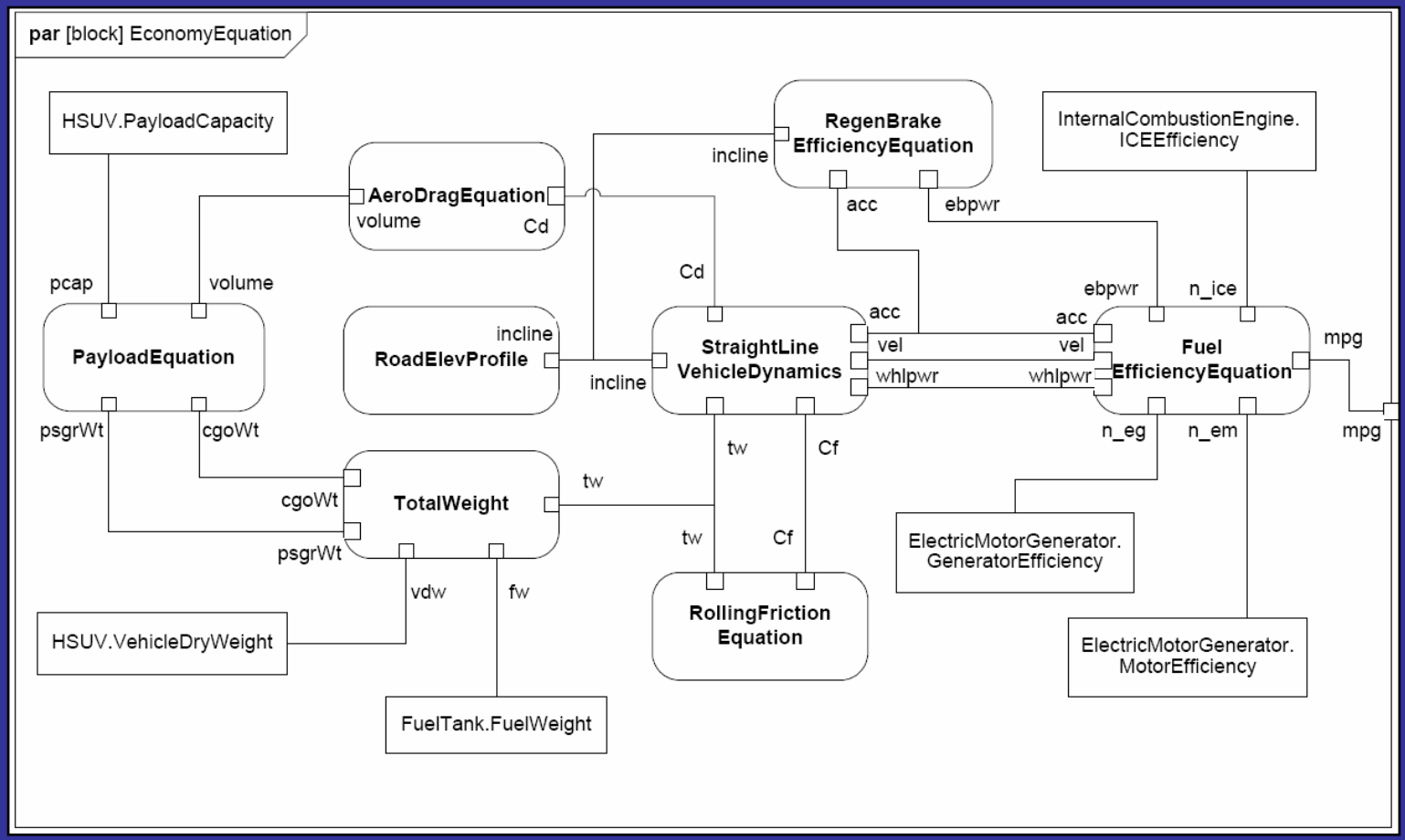
Name	Local	Oneway	Relation	Active	C...
al1	Y		<deformation_model.undeformed_length> == <link.effective_length>	☑	<l...
al2	Y		<deformation_model.area> == <link.shaft.critical_cross_section.basic.area>	☑	<l...
al3	Y		<deformation_model.material_model.youngs_modulus> == <link.material.stress_strain_model.linear_...	☑	<l...
al4	Y		<deformation_model.material_model.name> == <link.material.name>	☑	<l...
al5	Y		<deformation_model.force> == <associated_condition.reaction>	☑	<l...
al6	Y		<stress_mos_model.allowable> == <link.material.yield_stress>	☑	<l...
al7	Y		<stress_mos_model.determined> == <deformation_model.material_model.stress>	☑	<l...

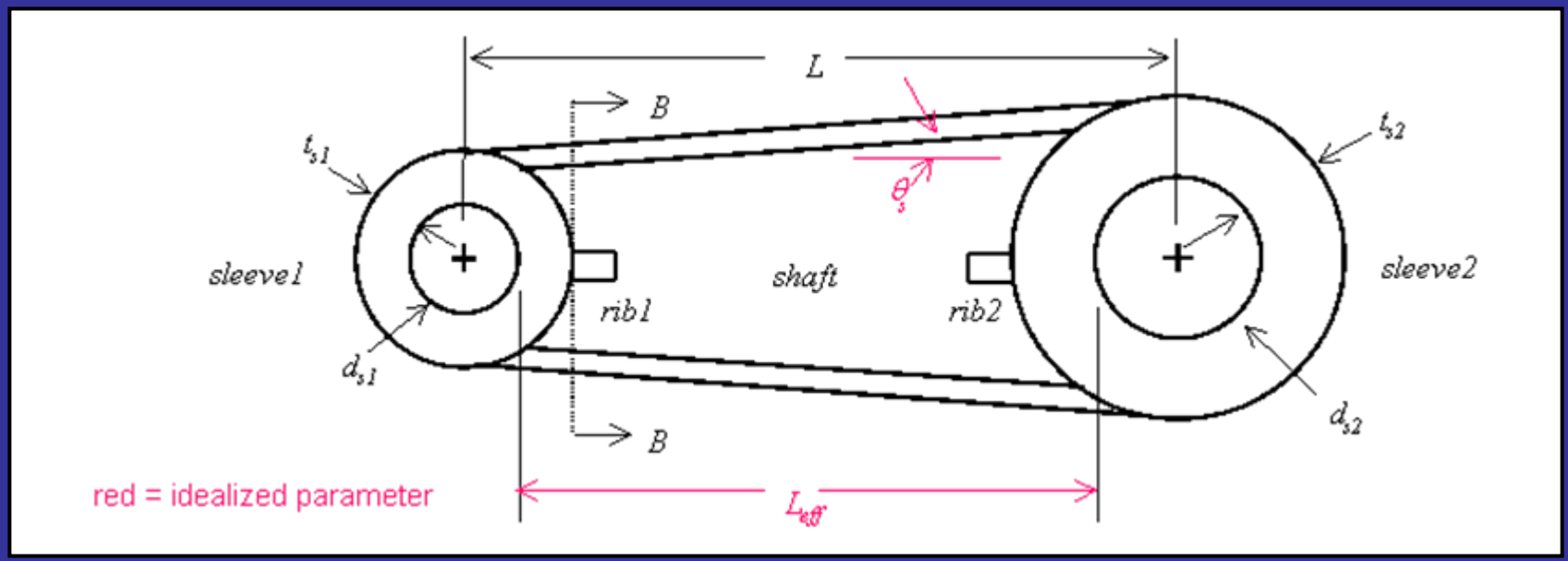

stm HSUVOperationalStates
Refines
«requirement»
PowerSource
Management
Off
keyOff
start
shutOff
Nominal
states only
Operate
Idle
accelerate
stopped
releaseBrake
Accelerating/
Cruising
Braking
engageBrake

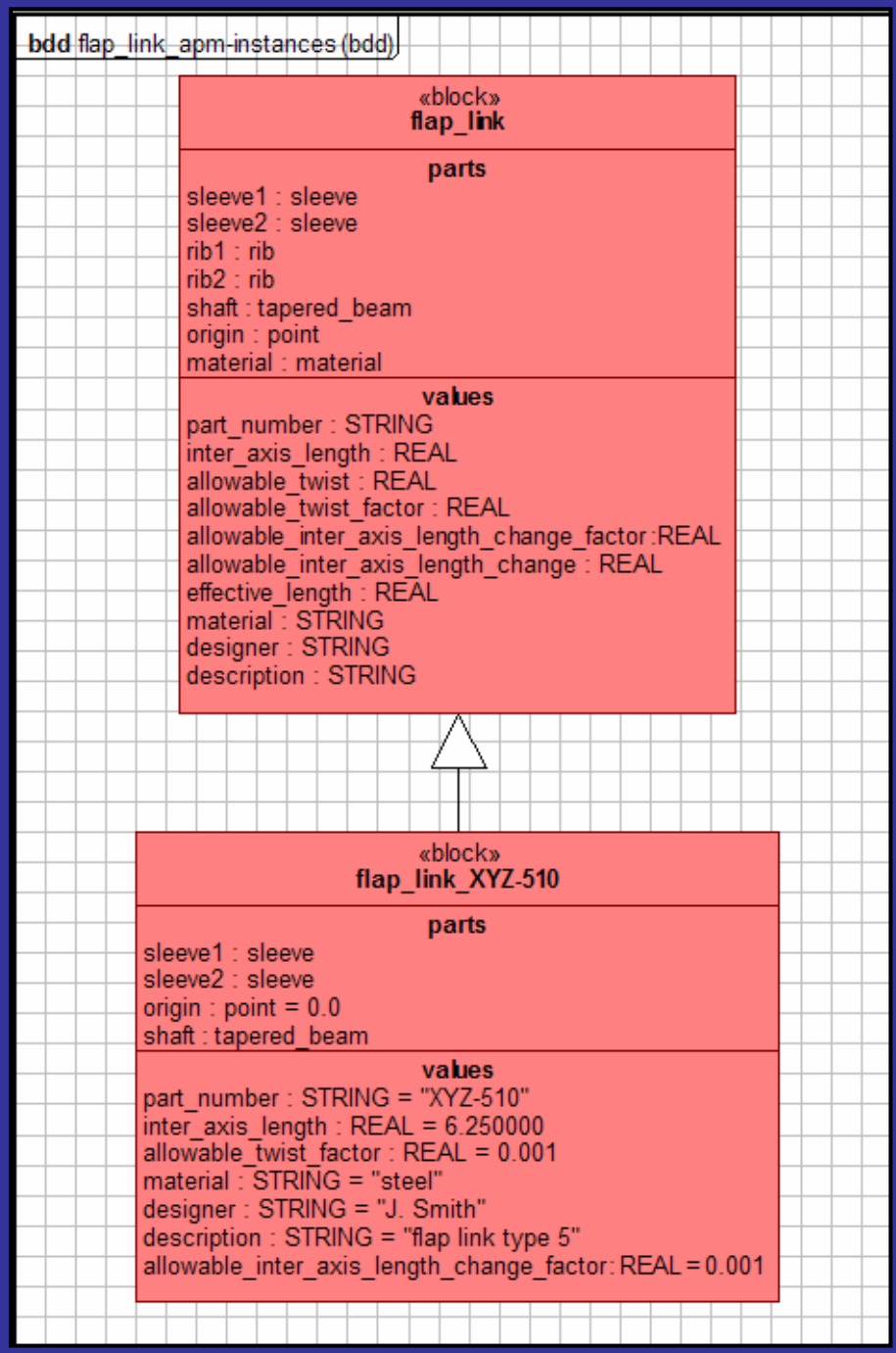

«(UserDefined)Swimlane Diagram»
act ProvidePower [with Swimlane Allocation]
«allocate» PowerControlUnit
«allocate» InternalCombustionEngine
«allocate» ElectricalPowerController
«allocate» ElectricalMotorGenerator
«continuous» speed
«continuous» vehCond
«continuous» battCond
«continuous» accelPosition
a1:Proportion Power
a2:ProvideGas Power
«continuous» gThrottle
«continuous» eThrottle
a3:Control ElectricPower
«continuous» driveCurrent
a4:Provide ElectricPower
«continuous» gasDrivePower
«continuous» elecDrivePower
«continuous» drivePower
transModeCmd
keyOff
allocatedTo
«itemFlow»i1:ElectricCurrent


ibd [block] PowerSubsystem [Alternative 1 - Combined Motor Generator]
bp:BatteryPack
epc:ElectricalPower Controller
ctrl
i2:Electric Current
i1:Electric Current
emg:ElectricMotor Generator
I_IEPCData
I_IEPCCmd
acl:accelerator
c3
I_TRSMCmd
ctrl
trsm:Transmission
spline
rfw:ChassisSubsytem .FrontWheel
I_TRSMData
torquein:Torque
t2:Torque
t1:Torque
rightHalfShaf t
I_EPCCmd
I_IEPCData
c2
epc
trsm
I_TRSMData
ecu:PowerControlUnit
ice
I_TRSMCmd
torqueOut:Torque
g1:Torque
dif:Differential
ice:InternalCombustionEngine
I_ICECmds
I_ICEData
I_ICEData
c1
ctrl
4
fi:FuelInjector
leftHalfShaf t
bp:BrakeSubsystem .BrakePedal
I_ICECmds
fdist
lfw:ChassisSubsytem .FrontWheel
Port:ICEFuelFitting
ft:FuelTankAssy
fp:FuelPump
Port:FuelTankFitting
fuelDelivery
fuelSupply:Fuel
fuelReturn:Fuel


sd StartVehicleWhiteBox
ecu:PowerControlUnit
epc:ElectricalPowerController
1:
StartVehicle
1.1: Enable
1.2:read
y


par [block] EconomyEquation
HSUV.PayloadCapacity
AeroDragEquation
volume
Cd
RegenBrake EfficiencyEquation
incline
acc
ebpwr
InternalCombustionEngine. ICEEfficiency
pcap
volume
PayloadEquation
psgrWt
cgoWt
RoadElevProfile
incline
Cd
StraightLine VehicleDynamics
acc
vel
whlpwr
Fuel EfficiencyEquation
ebpwr
n_ice
acc
vel
whlpwr
mpg
mpg
n_eg
n_em
TotalWeight
cgoWt
psgrWt
tw
tw
Cf
tw
Cf
vdw
fw
HSUV.VehicleDryWeight
FuelTank.FuelWeight
RollingFriction Equation
ElectricMotorGenerator. GeneratorEfficiency
ElectricMotorGenerator. MotorEfficiency


L
B
t_{s1}
θ_s
t_{s2}
sleeve1
shaft
sleeve2
rib1
rib2
d_{s1}
d_{s2}
B
red = idealized parameter
L_{eff}


bdd flap_link_apm-instances (bdd)
«block»
flap_link
parts
sleeve1 : sleeve
sleeve2 : sleeve
rib1 : rib
rib2 : rib
shaft : tapered_beam
origin : point
material : material
values
part_number : STRING
inter_axis_length : REAL
allowable_twist : REAL
allowable_twist_factor : REAL
allowable_inter_axis_length_change_factor :REAL
allowable_inter_axis_length_change : REAL
effective_length : REAL
material : STRING
designer : STRING
description : STRING
«block»
flap_link_XYZ-510
parts
sleeve1 : sleeve
sleeve2 : sleeve
origin : point = 0.0
shaft : tapered_beam
values
part_number : STRING = "XYZ-510"
inter_axis_length : REAL = 6.250000
allowable_twist_factor : REAL = 0.001
material : STRING = "steel"
designer : STRING = "J. Smith"
description : STRING = "flap link type 5"
allowable_inter_axis_length_change_factor: REAL = 0.001