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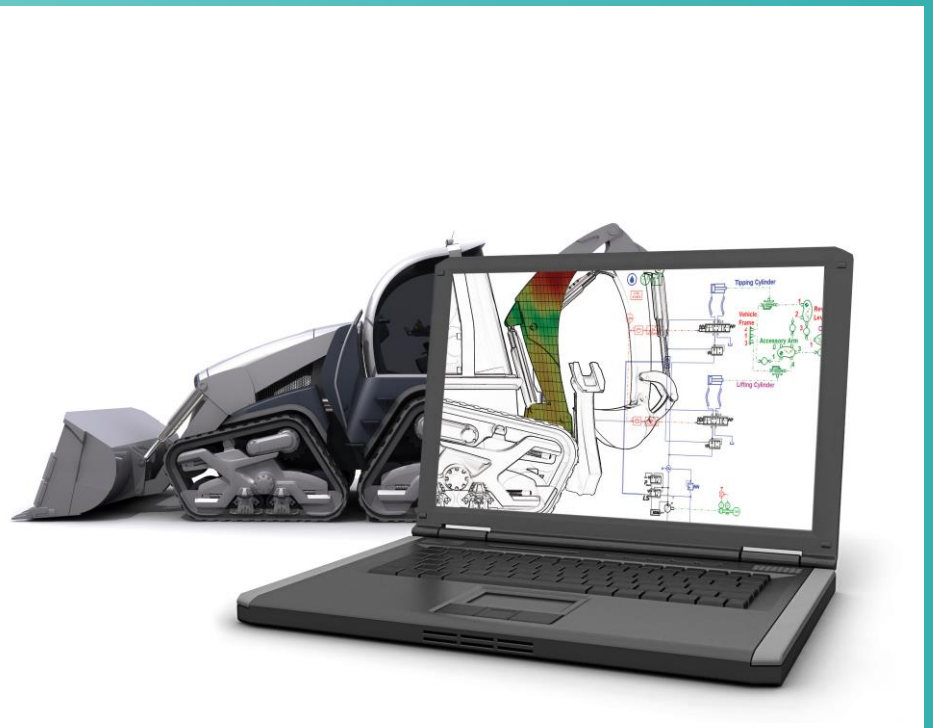
Introduction to Mechatronic System Simulation

Hannu Mäkinen / Ideal GRP

Agenda



- What is a system? Few examples
- What is Mechatronic System Simulation?
- Concept and positioning
- Simcenter technology with Simcenter Amesim
- Examples of typical applications
- Solutions for all industries
- Simcenter Amesim Student Edition

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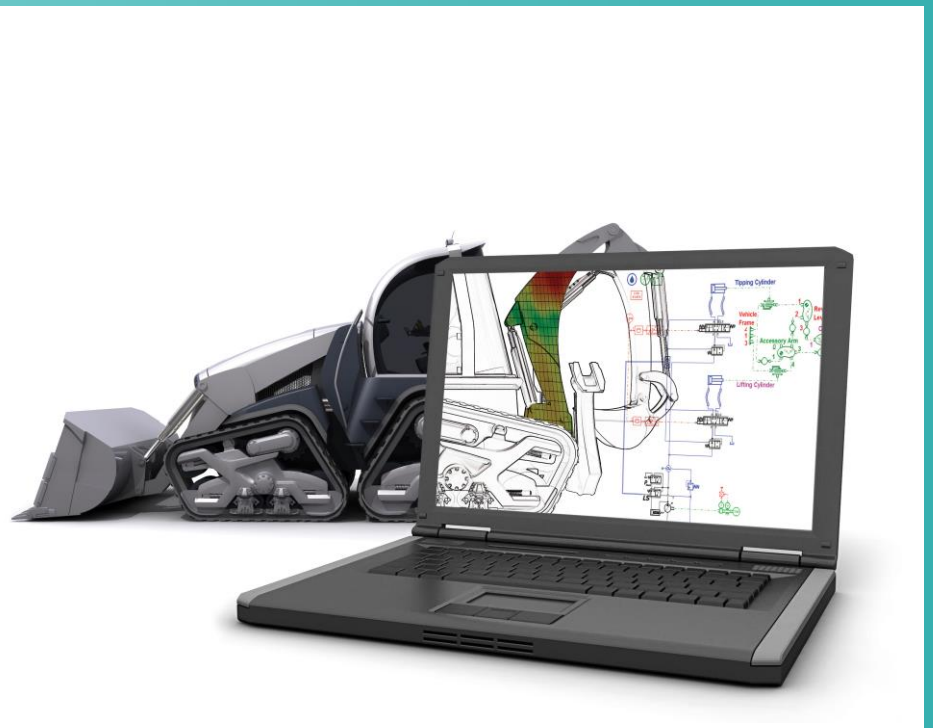

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What is a system?

A **group** of
multi-domain | multi-physics
components
interacting together

What is a system? Examples

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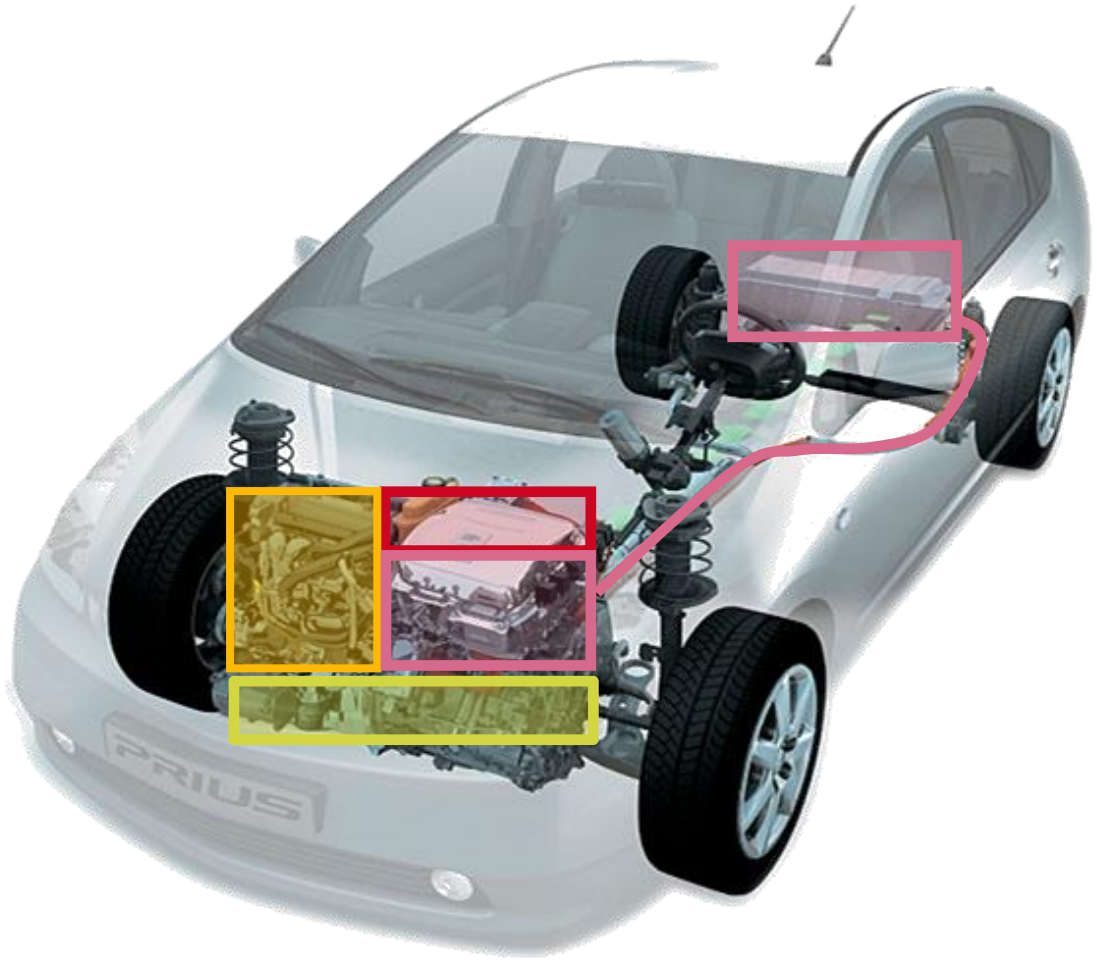
Hybrid vehicle

- Control
- Electric
- Hydraulic / Pneumatic
- Mechanic
- Thermal



What is a system? Examples

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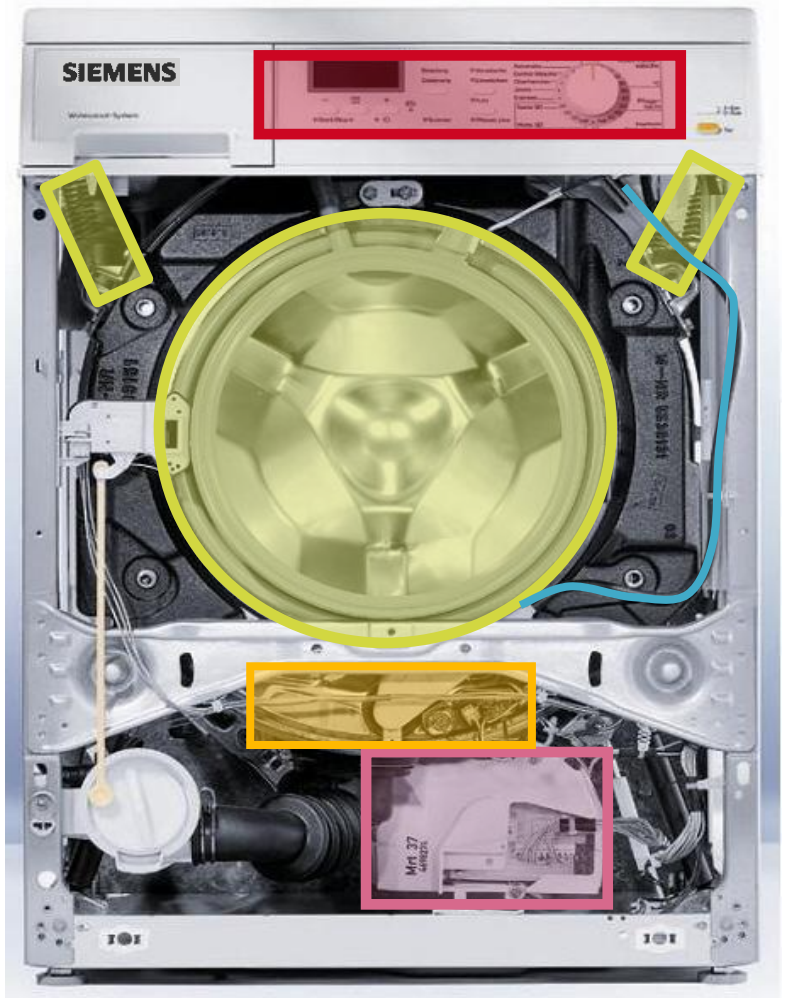
Washing machine

- Control
- Electric
- Hydraulic / Pneumatic
- Mechanic
- Thermal



What is a system? Examples

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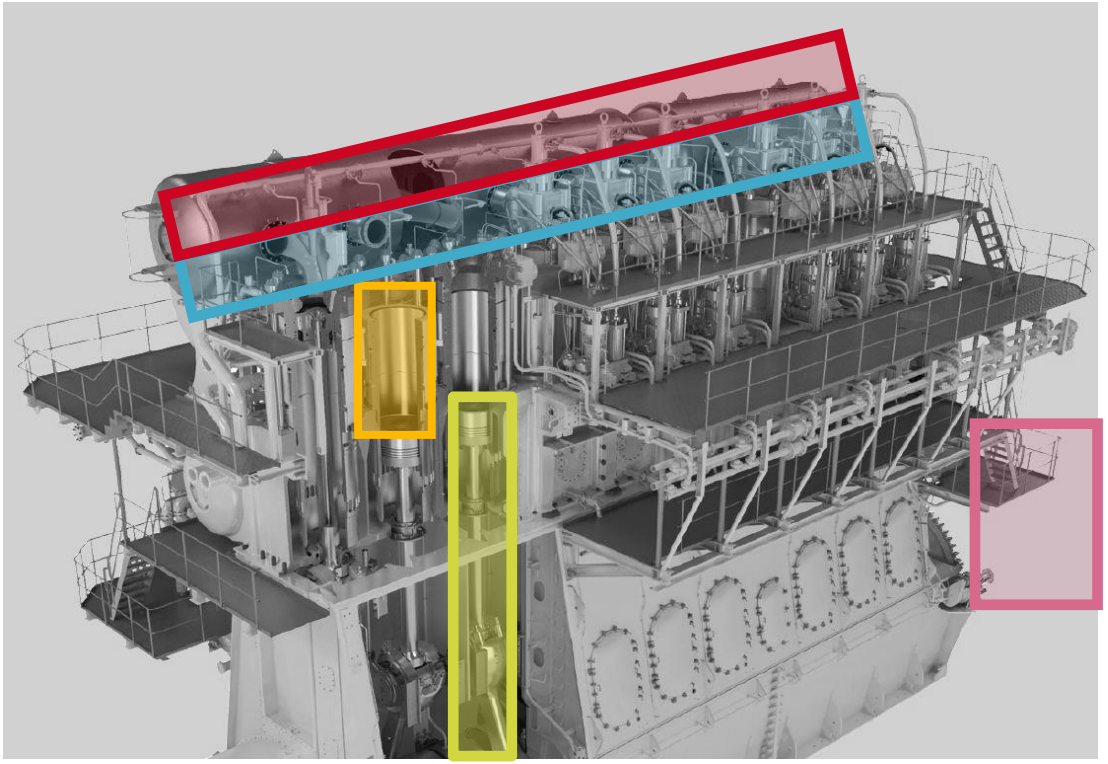
IC engine

- Control
- Electric
- Hydraulic / Pneumatic
- Mechanic
- Thermal



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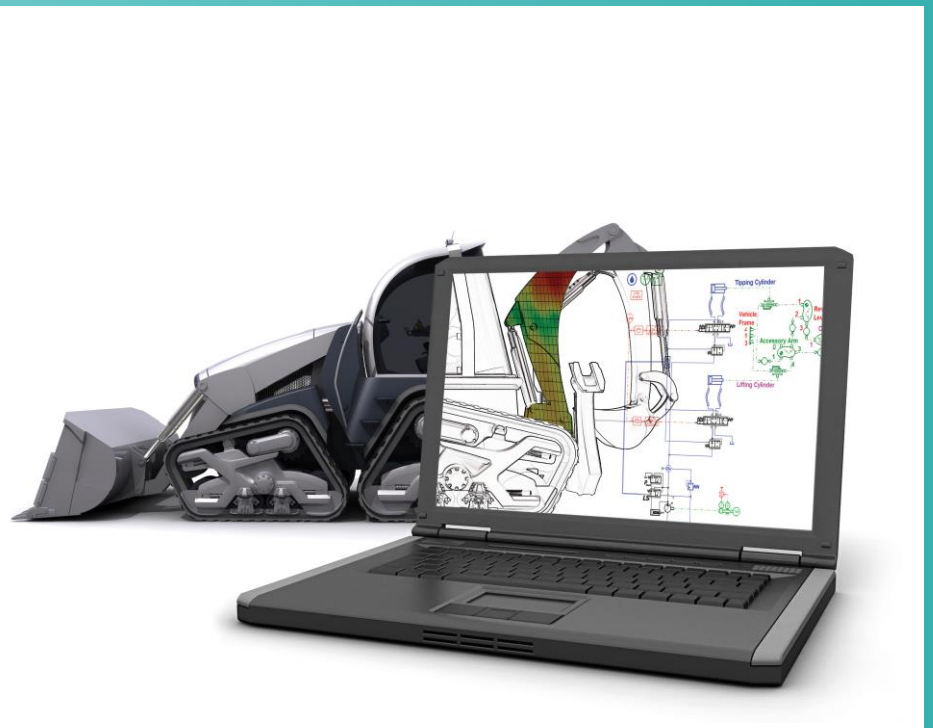

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“Mechatronics” definition

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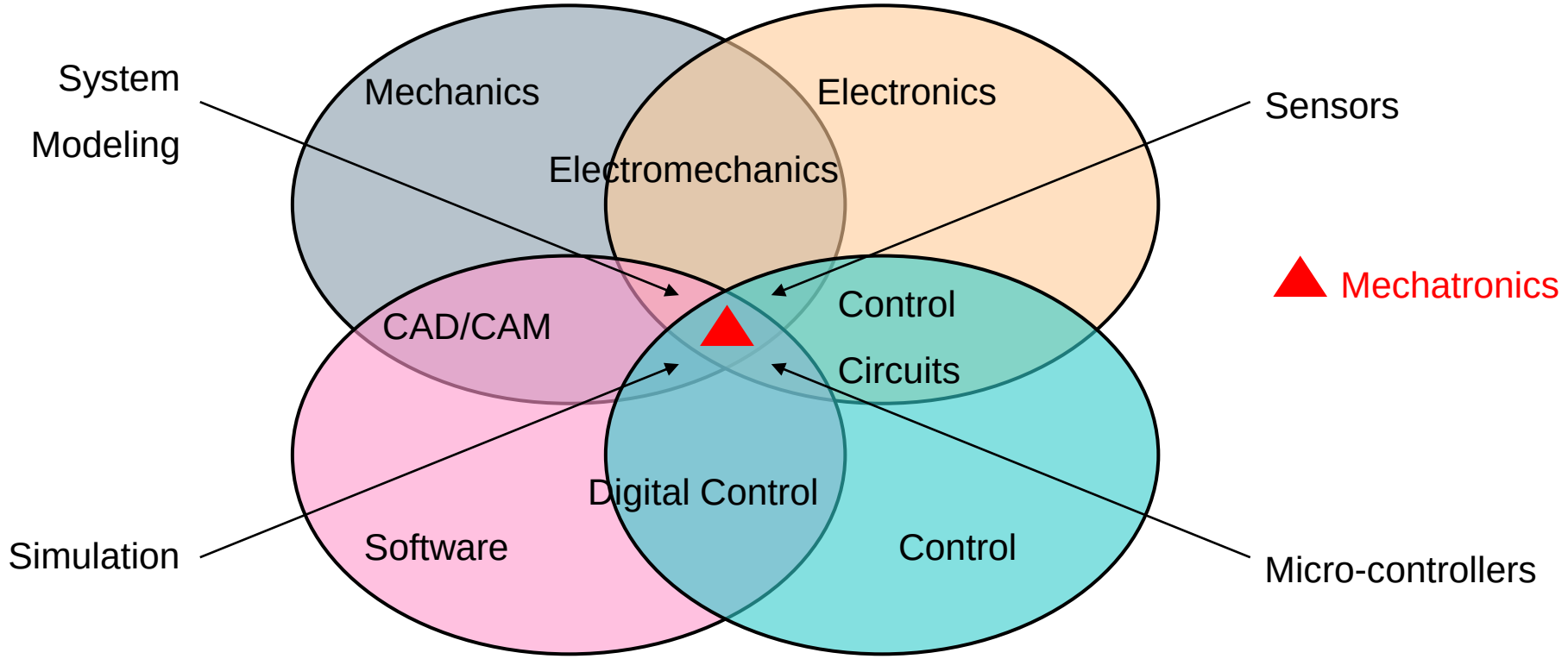
“The synergistic combination of mechanical, electronic, control and software engineering” (Wikipedia)



What is Mechatronic System Simulation?

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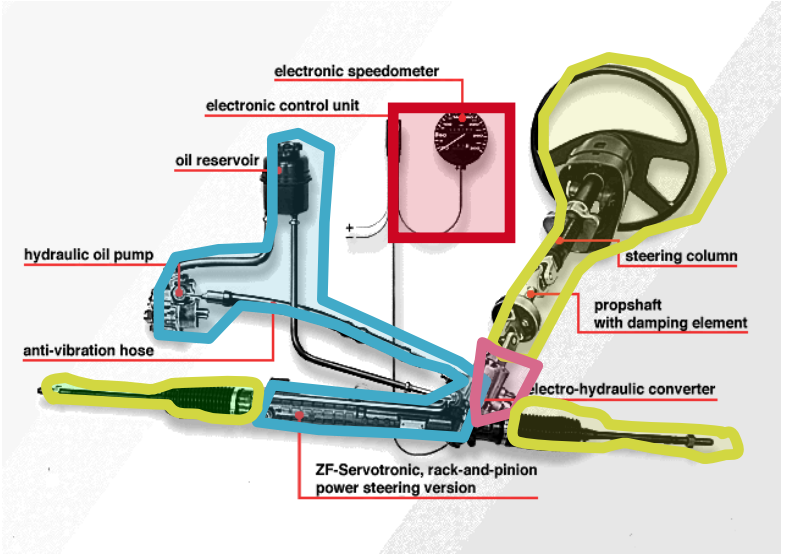
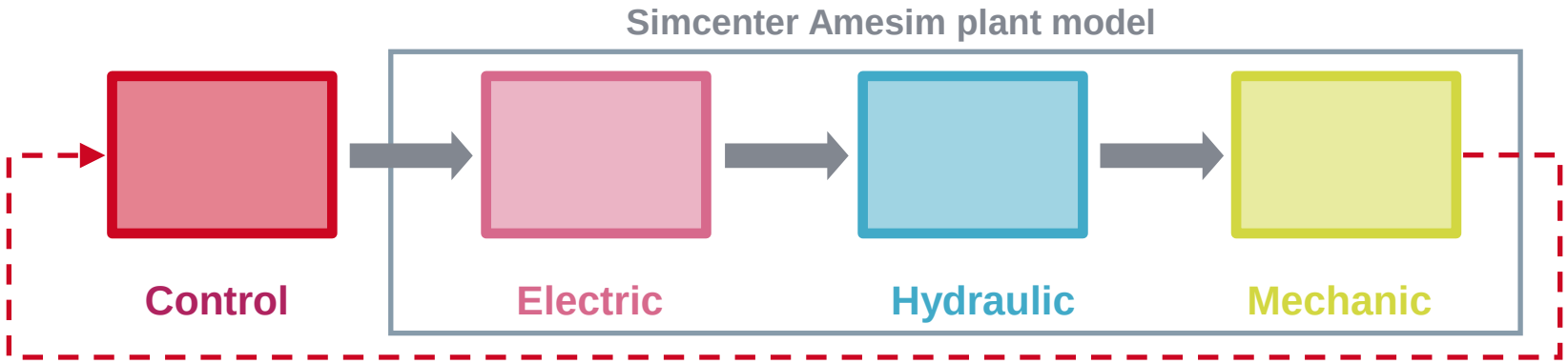
Classical design issues :

- Is the electric motor powerful enough?
- What is the time response of the system?
- What maximum pressure can be reached?
- Is there any risk of vibration?
- How to optimize the control design?



Key words :

- **Multiphysics** with **power exchange**
- Dynamic system (function of **time**)
- Physical system model = **plant model**



Abstraction level – Equations – Representation

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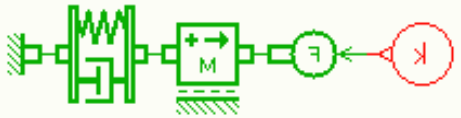
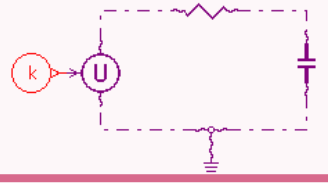
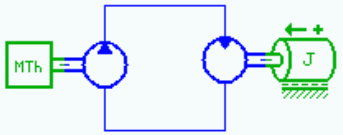
- Equations are usually written as **time dependent** with a focus on computing state derivative of variables to assess transient evolution
- Physical equations of component behavior are represented by ***readable objects (icons)***

	Equations level	**Physical icon representation**
Mechanics	$M * dx/dt^2 = F - Rdx/dt - Kx$ $s^2 + 2 \cdot z \cdot \omega_n \cdot s + \omega_n^2 = 0$	
Electric	$U = R * I$ $dU/dt = I/C$	
Hydraulics	$Q = displ * \Omega$ $T = displ * \Delta P$	

And many other physical domains…

Power flow and power conservation

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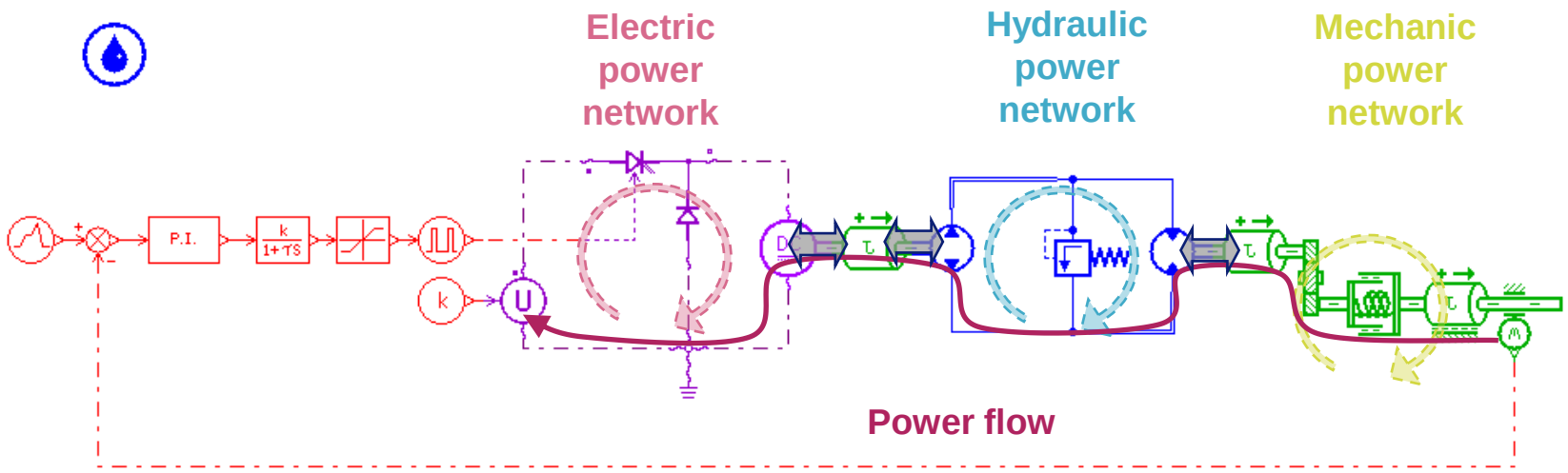
- System simulation is linked to the **power flow** and **power conservation** within a dynamical system
- Each power network can be modeled using different physics with **gates** between subsystem frontiers

- **control**
- **electric**
- **hydraulic**
- **mechanic**

Tension	U	*Current*	*I*
Pressure	P	*Flow rate*	*Q*
Torque	T	*RPM*	*Ω*



You are **manipulating equations**, not drawing a circuit!

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A concept

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It is an approach to modeling and analyzing **multi-domain systems**, and thus predicting their multi-disciplinary **performance**, by connecting validated analytical modeling blocks of electrical, hydraulic, pneumatic and mechanical **subsystems** into a comprehensive and schematic **full-system model**.

One-dimensional computer-aided engineering (1D CAE), also referred to as **Mechatronic System Simulation**, is multi-domain systems simulation in combination with controls.

1D CAE helps you create a **concept design** of complex mechatronic systems, analyze their **transient** and **steady-state behavior**, and front-load **design decisions** when integrating **intelligent** systems into your product.

Example of transmission solutions

Modeling interactions between all transmission subsystems

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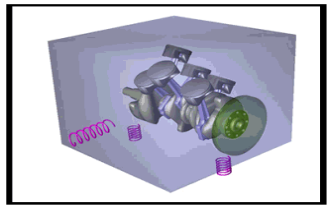
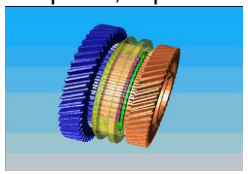
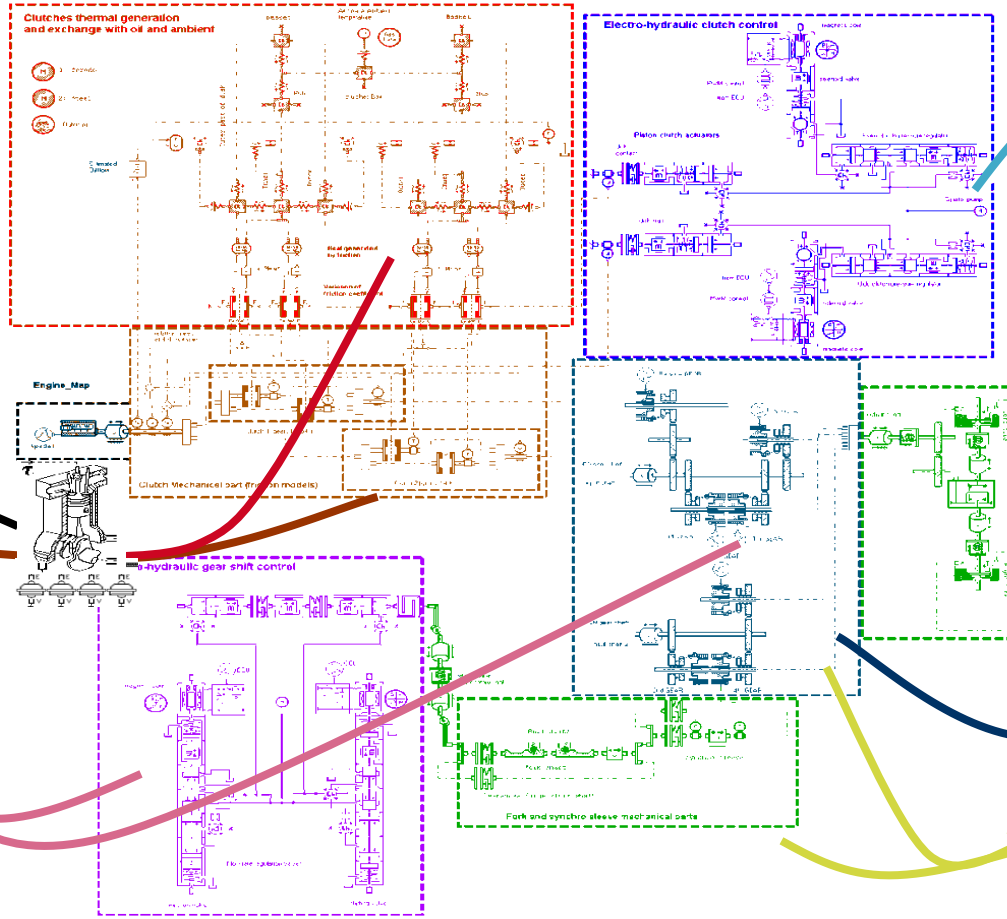


Engine
Crankshaft
Camshaft Vibrations
Torque oscillations

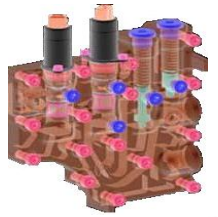
Clutch / DMF
Dry/Wet, Multidisk, dampers
Thermal aspects, slip control



Shift control
Synchronizers, 3D animations
Planetary gear trains
Gearshift control

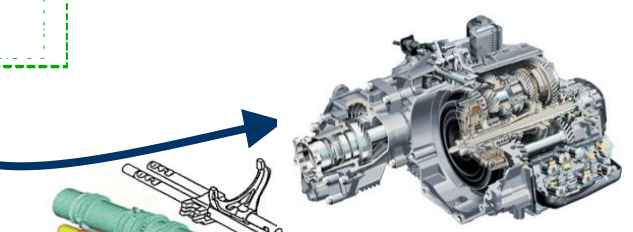


DCT model for Gear shift Comfort analysis (0-40Hz)



Actuation
Switch valves
Pressure regulation
Hydraulic/electric
Networks

Driveline
2D/3D modeling
U-joints, tires
ESP / ASR
Piloted differential



Transmission
Robotized / automatics
DCT/Hybrid
IVT/CVT

A concept

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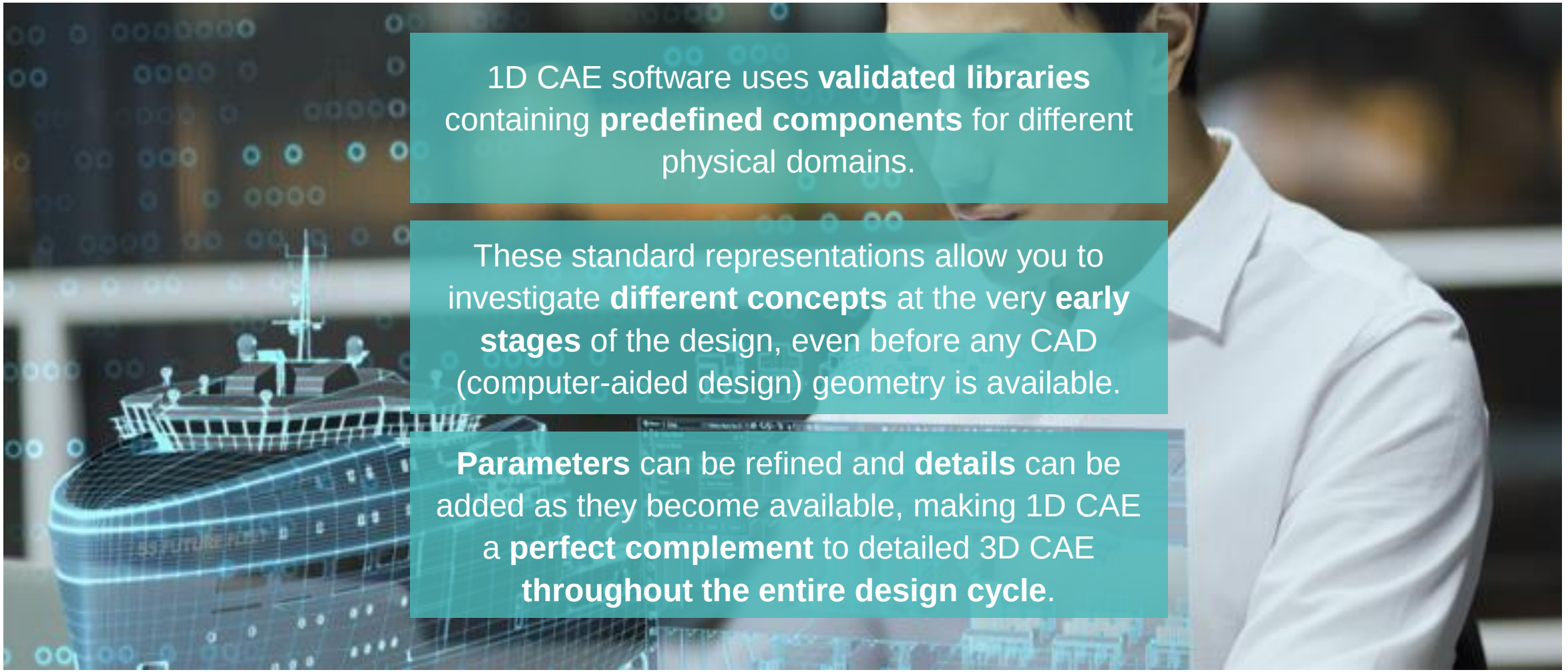

1D CAE software uses **validated libraries** containing **predefined components** for different physical domains.

These standard representations allow you to investigate **different concepts** at the very **early stages** of the design, even before any CAD (computer-aided design) geometry is available.

Parameters can be refined and **details** can be added as they become available, making 1D CAE a **perfect complement** to detailed 3D CAE **throughout the entire design cycle**.

Positioning in the CAE world

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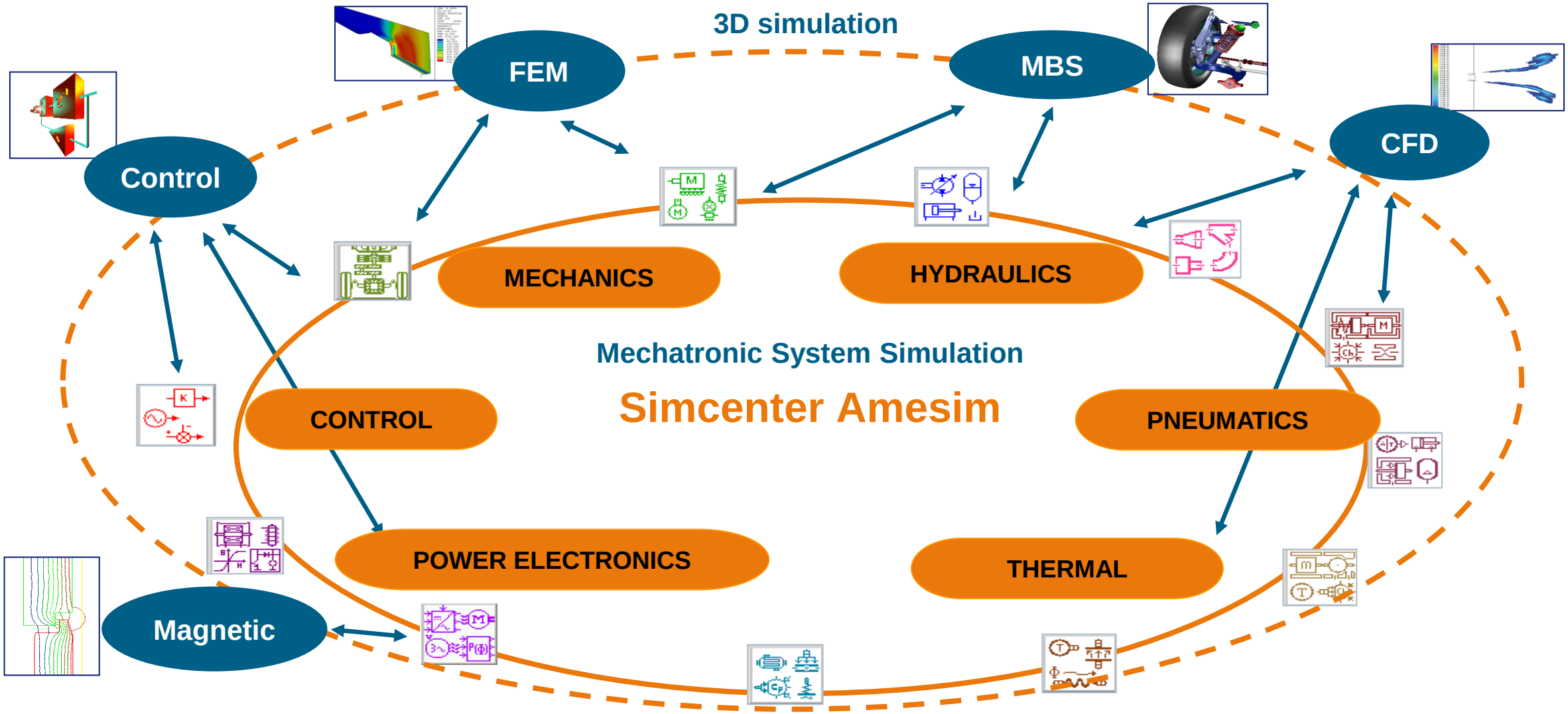

A concept

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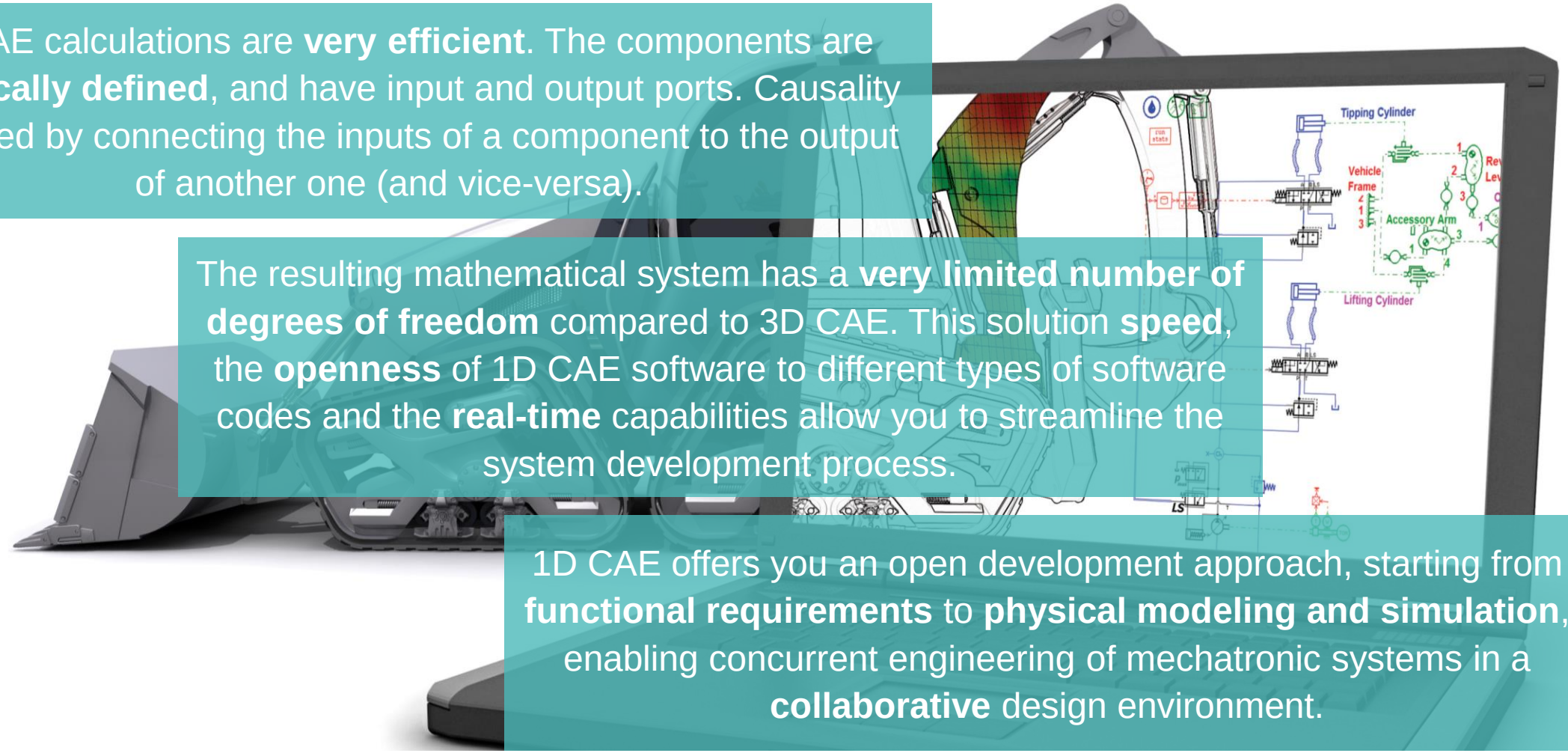
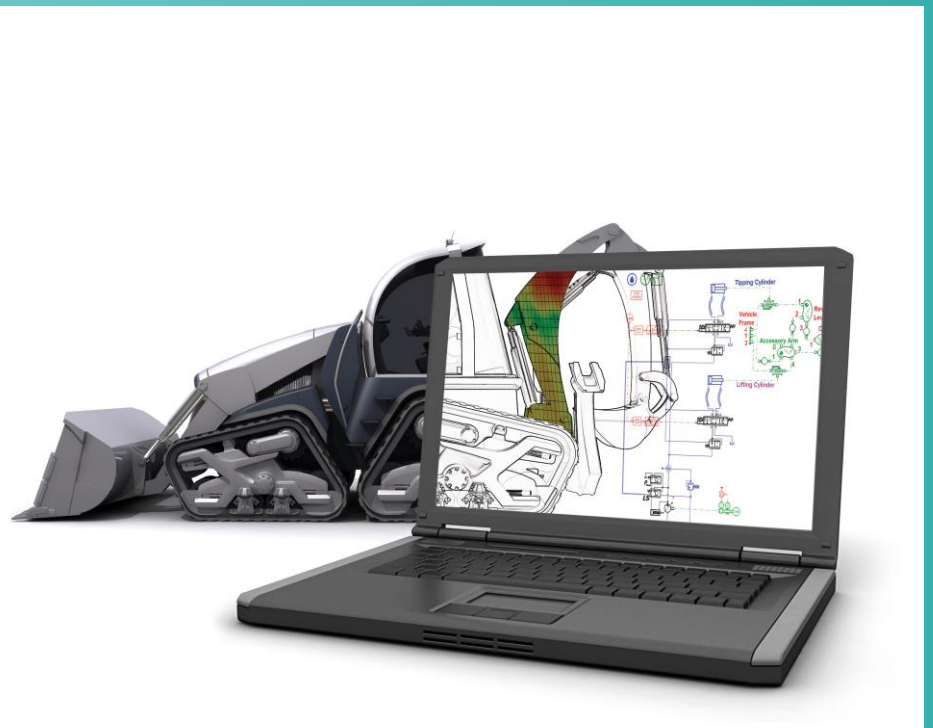
1D CAE calculations are **very efficient**. The components are **analytically defined**, and have input and output ports. Causality is created by connecting the inputs of a component to the output of another one (and vice-versa).



The resulting mathematical system has a **very limited number of degrees of freedom** compared to 3D CAE. This solution **speed**, the **openness** of 1D CAE software to different types of software codes and the **real-time** capabilities allow you to streamline the system development process.

1D CAE offers you an open development approach, starting from **functional requirements** to **physical modeling and simulation**, enabling concurrent engineering of mechatronic systems in a **collaborative** design environment.

Agenda



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Simcenter™ Portfolio for Predictive Engineering Analytics

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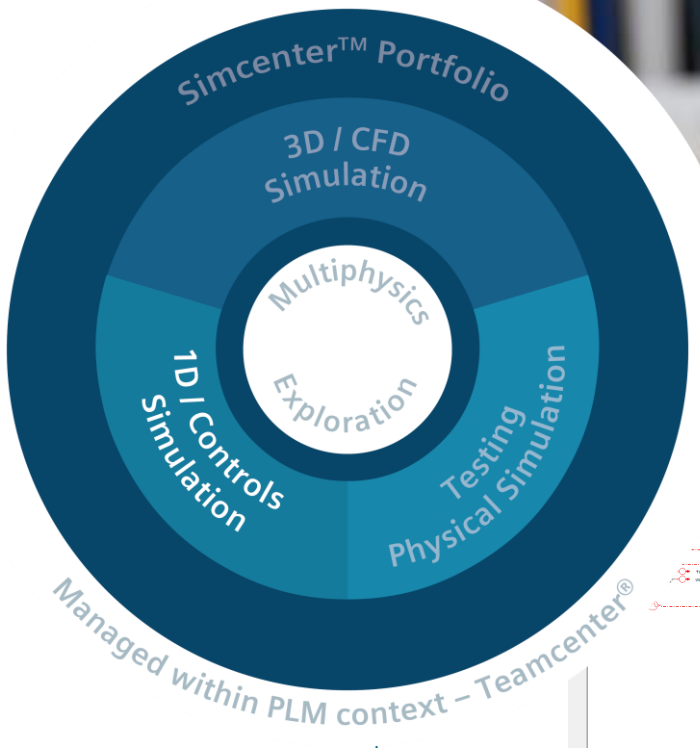
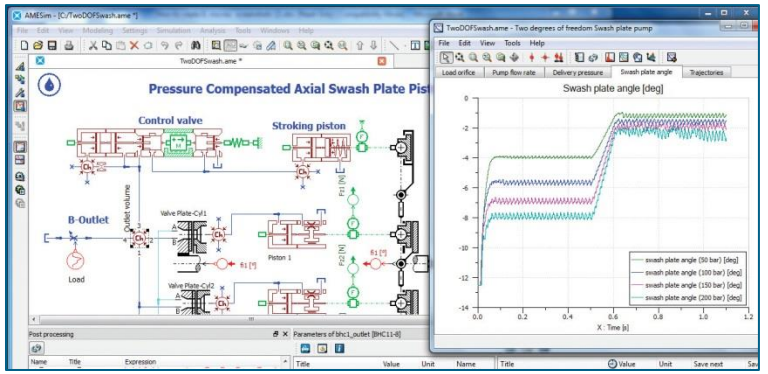
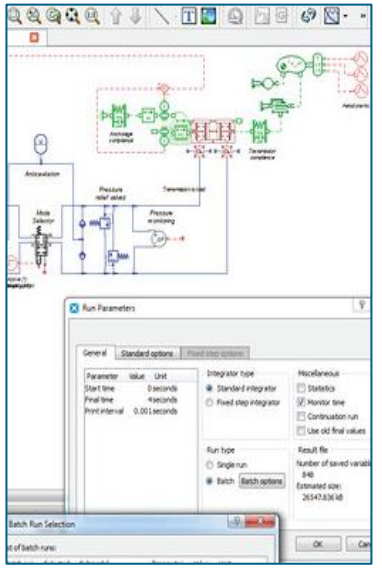
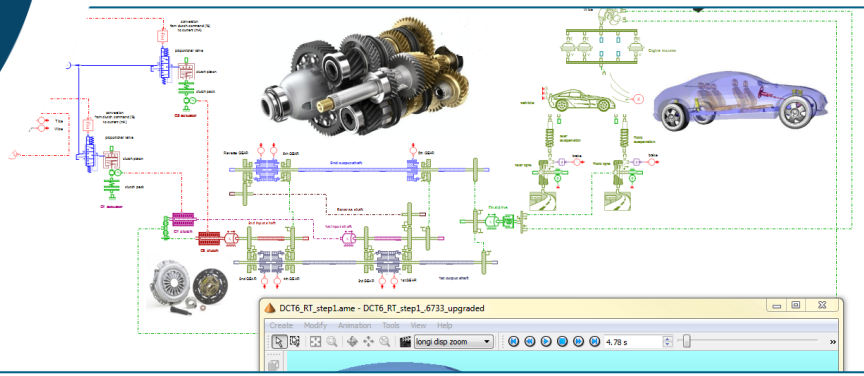
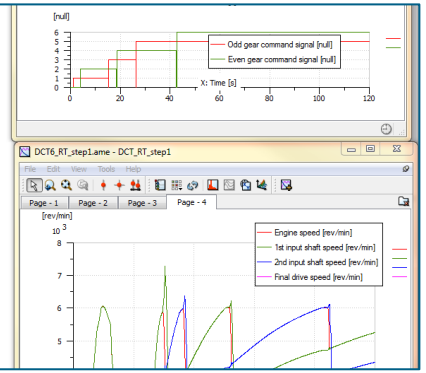


Simcenter Amesim









Collaboration & workflow

Simcenter™ Portfolio for Predictive Engineering Analytics
Simcenter Amesim and Simcenter System Synthesis

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Model-based system testing

Industry specific

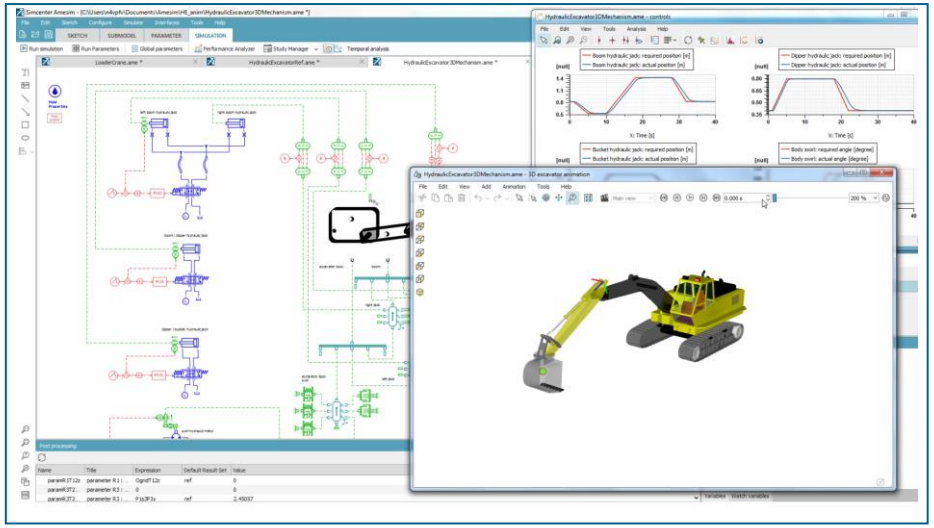
- Internal combustion
- After treatment
- Transmission
- Thermal systems
- Vehicle dynamics
- Electrical systems
- Pumps and compressors
- Electrohydraulic valves
- Fluid actuation systems
- Heat exchangers
- Heat pumps / refrigerators

Pre-design

Systems sizing and integration

Performance balancing

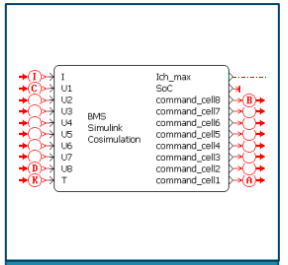
Controls validation



Scalable simulation

Connecting "mechanical" – "controls"

Model reduction for real-time

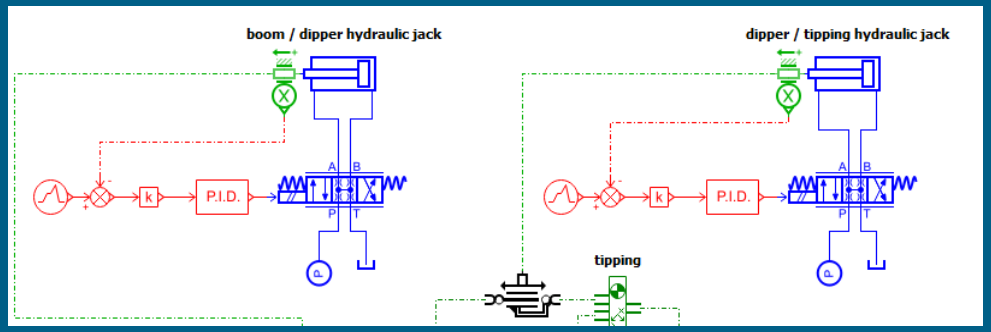


Co-simulation

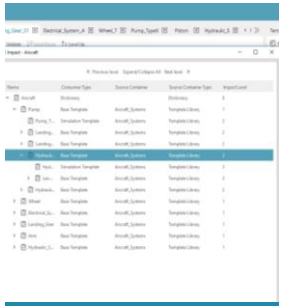
Open and customizable

>48 libraries

>6,500 multi-physics models



Hydraulics
Pneumatics
Thermal
Electrical
Mechanical
Signals



System architecture management

Simcenter™ for Predictive Engineering Analytics
Enabling "Closed Loop" System Driven Product Development

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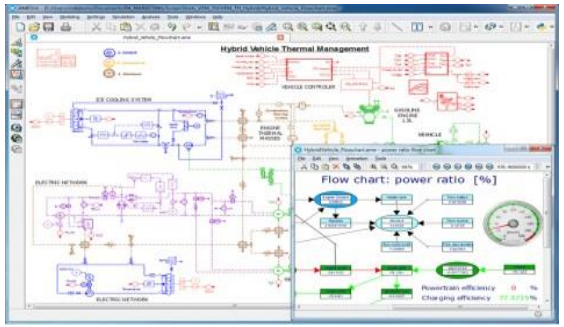
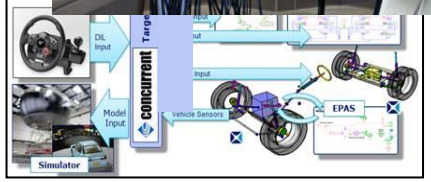
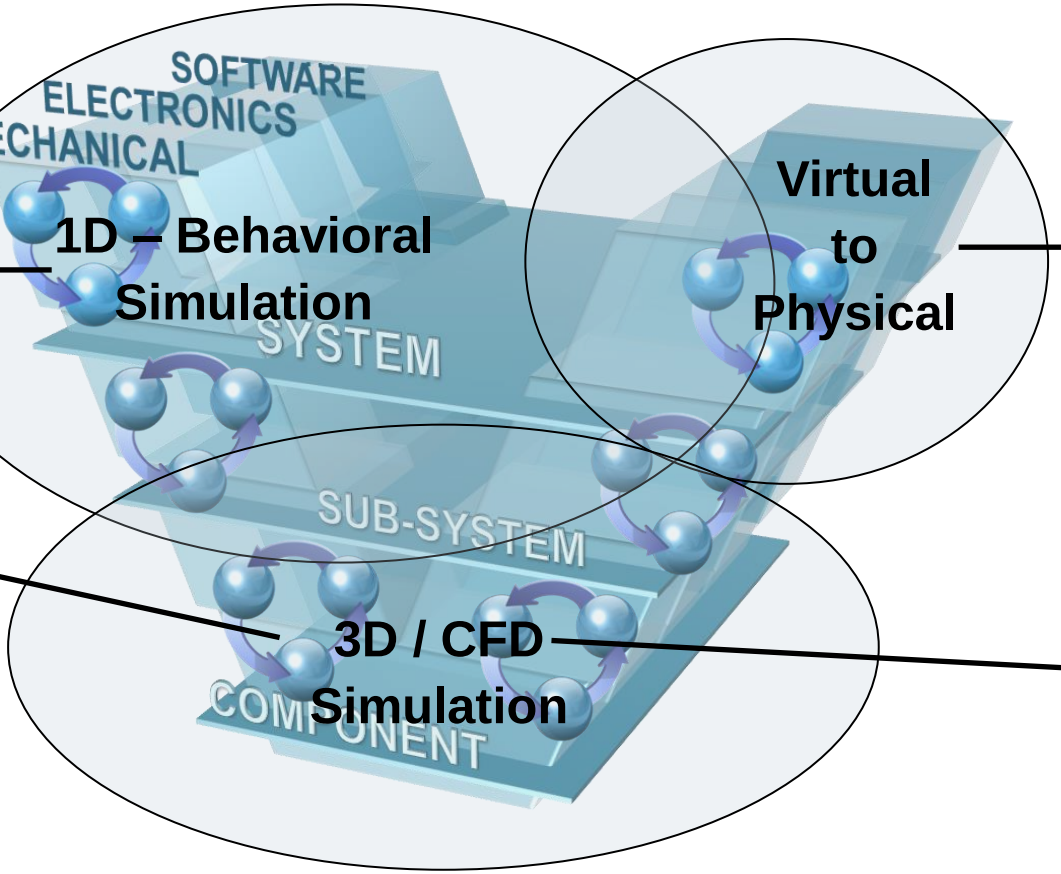
Simcenter Amesim



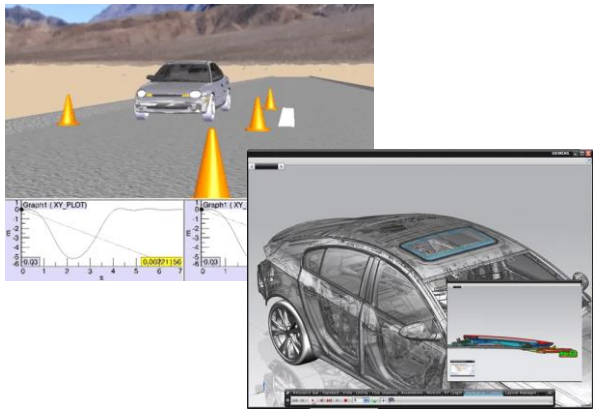
Simcenter Test.Lab



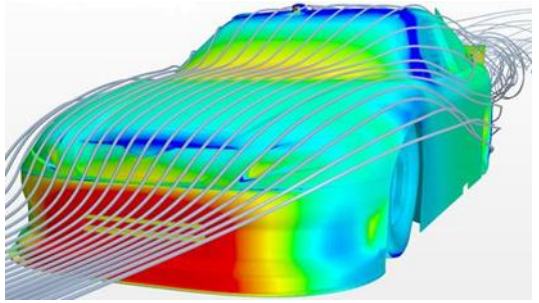
Real-Time Simulation
MIL-SIL-HIL



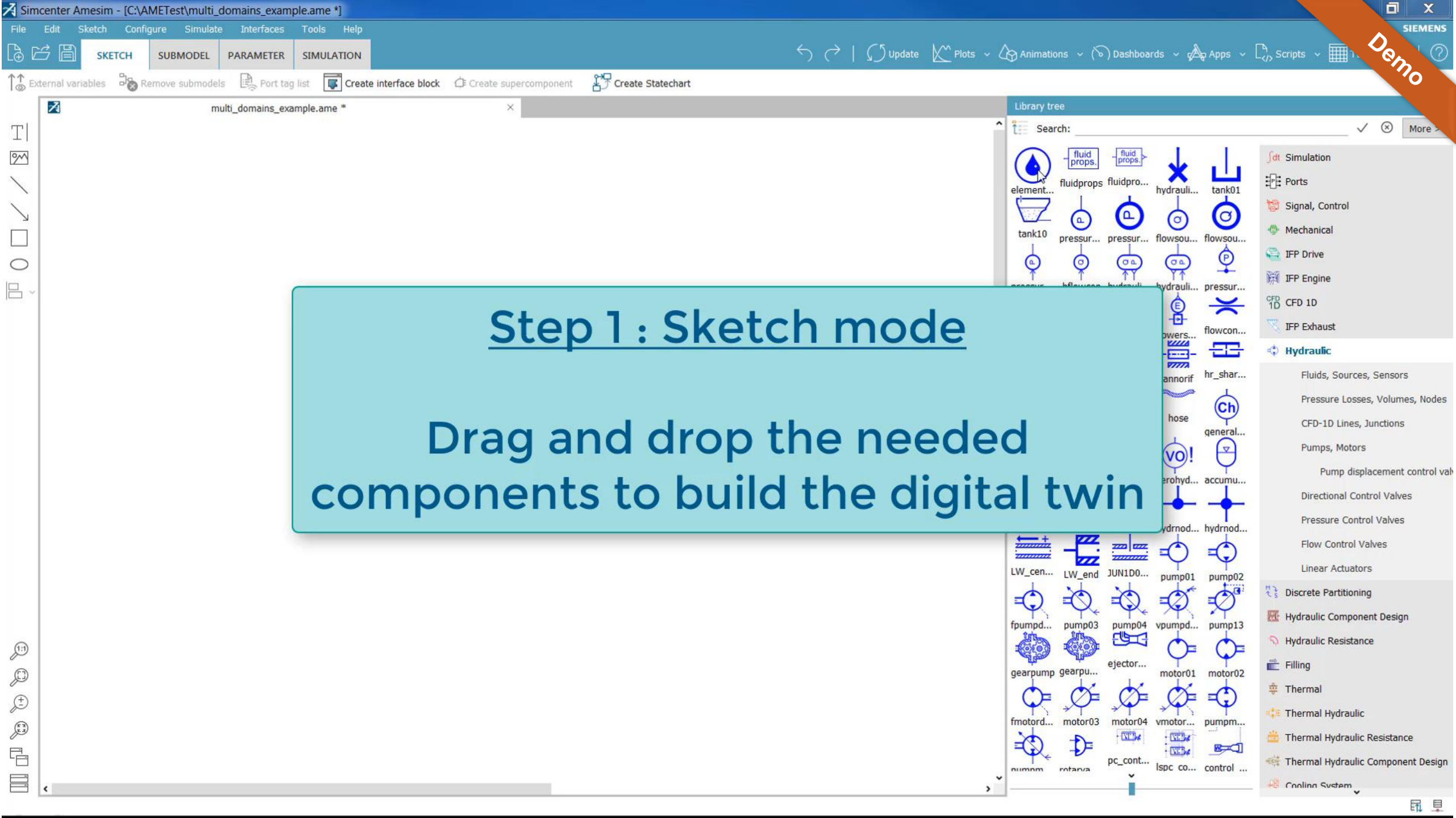
Simcenter 3D
Simcenter Nastran



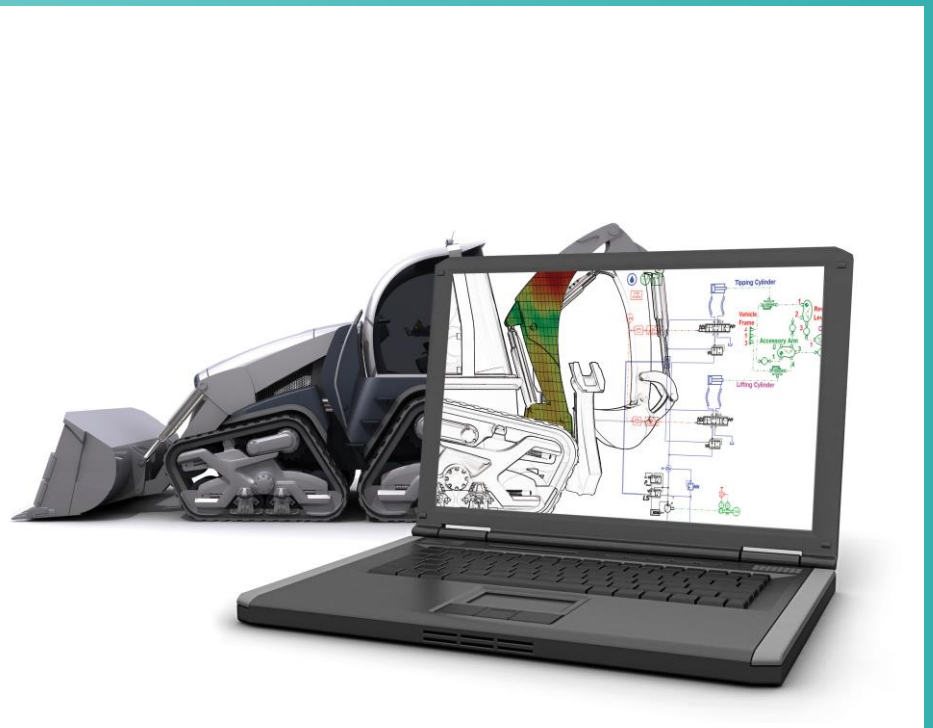
Simcenter STAR-CCM+



Scalable 1D - 3D Simulation


Simcenter Amesim - [C:\AMETest\multi_domains_example.ame *]
File Edit Sketch Configure Simulate Interfaces Tools Help
SIEMENS
SKETCH SUBMODEL PARAMETER SIMULATION
Update Plots Animations Dashboards Apps Scripts
External variables Remove submodels Port tag list Create interface block Create supercomponent Create Statechart
Demo
multi_domains_example.ame *
Library tree
Search:
More
Simulation
Ports
Signal, Control
Mechanical
IFP Drive
IFP Engine
CFD 1D
IFP Exhaust
Hydraulic
Fluids, Sources, Sensors
Pressure Losses, Volumes, Nodes
CFD-1D Lines, Junctions
Pumps, Motors
Pump displacement control valv
Directional Control Valves
Pressure Control Valves
Flow Control Valves
Linear Actuators
Discrete Partitioning
Hydraulic Component Design
Hydraulic Resistance
Filling
Thermal
Thermal Hydraulic
Thermal Hydraulic Resistance
Thermal Hydraulic Component Design
Cooling System
Step 1 : Sketch mode
Drag and drop the needed components to build the digital twin

Agenda



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Examples of typical applications

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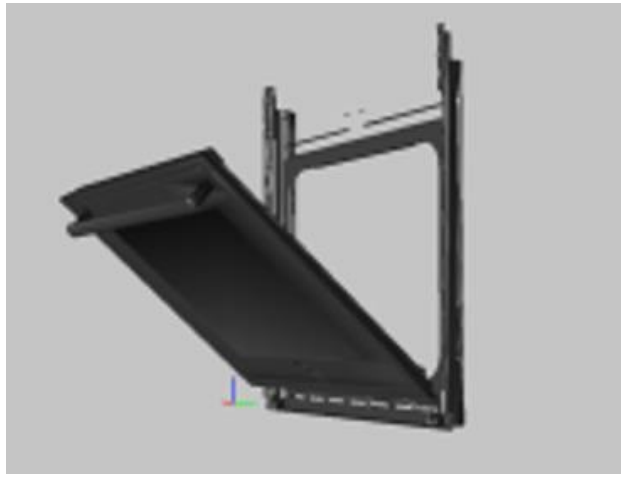
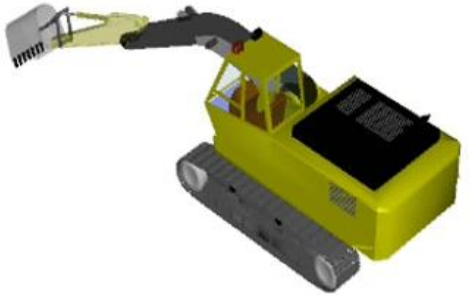
① Optimization of an oven hinge mechanism



② Hybridization of an excavator



Example 1: Optimization of an oven hinge mechanism

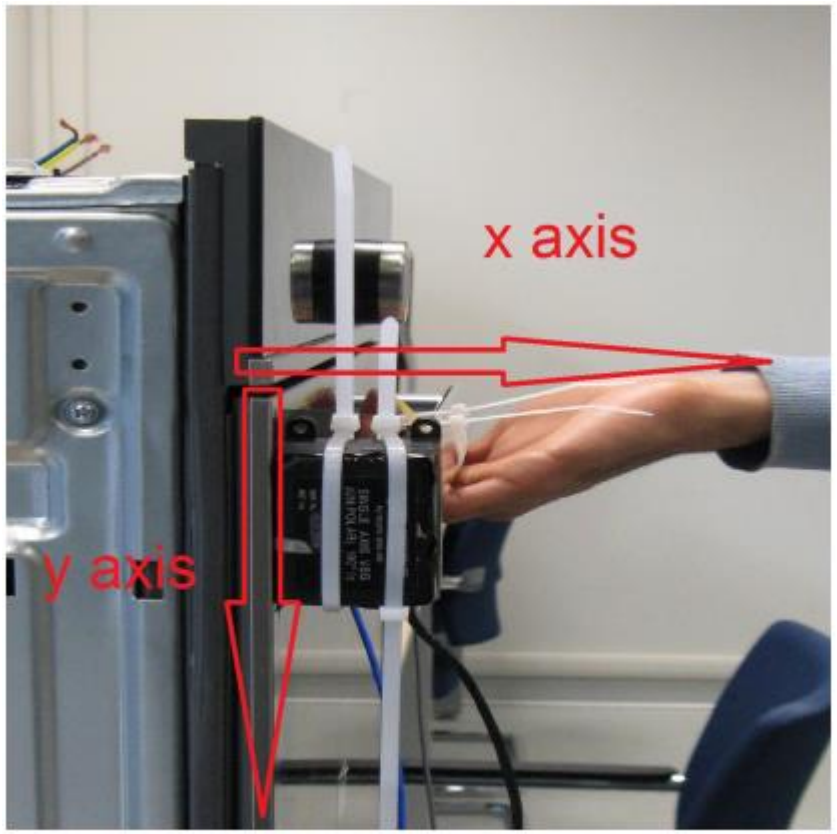
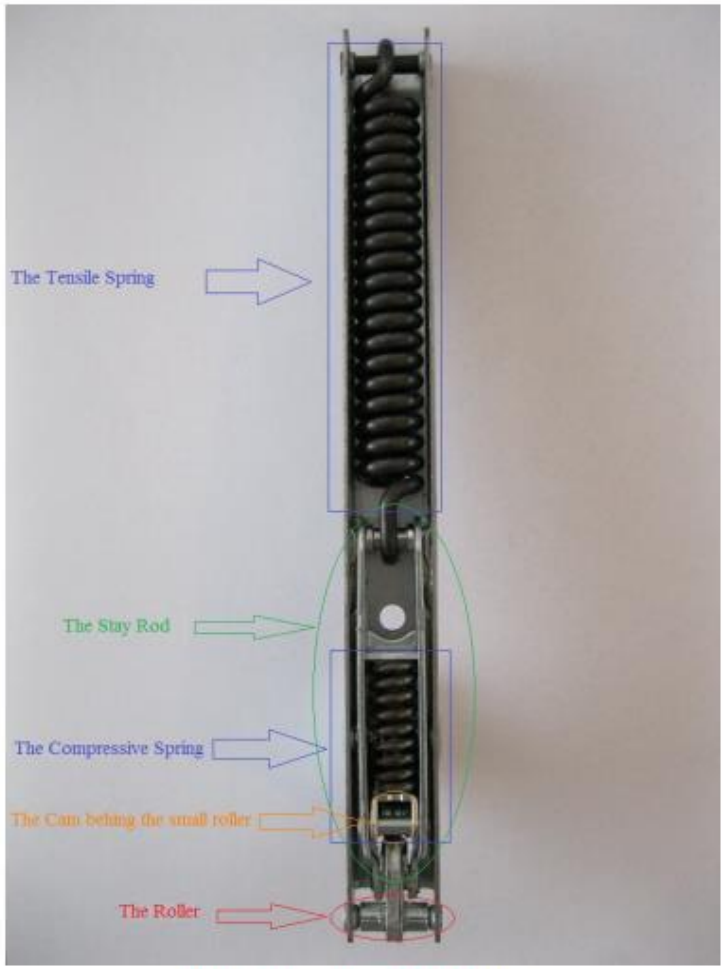


FIGURE 2.17: Force directions



(b) Corresponding part in real hinge

References :

Politecnico di Milano / Master Thesis : Simulation and Optimization of an oven hinge mechanism through Simcenter-AMESim

Example 1: Optimization of an oven hinge mechanism

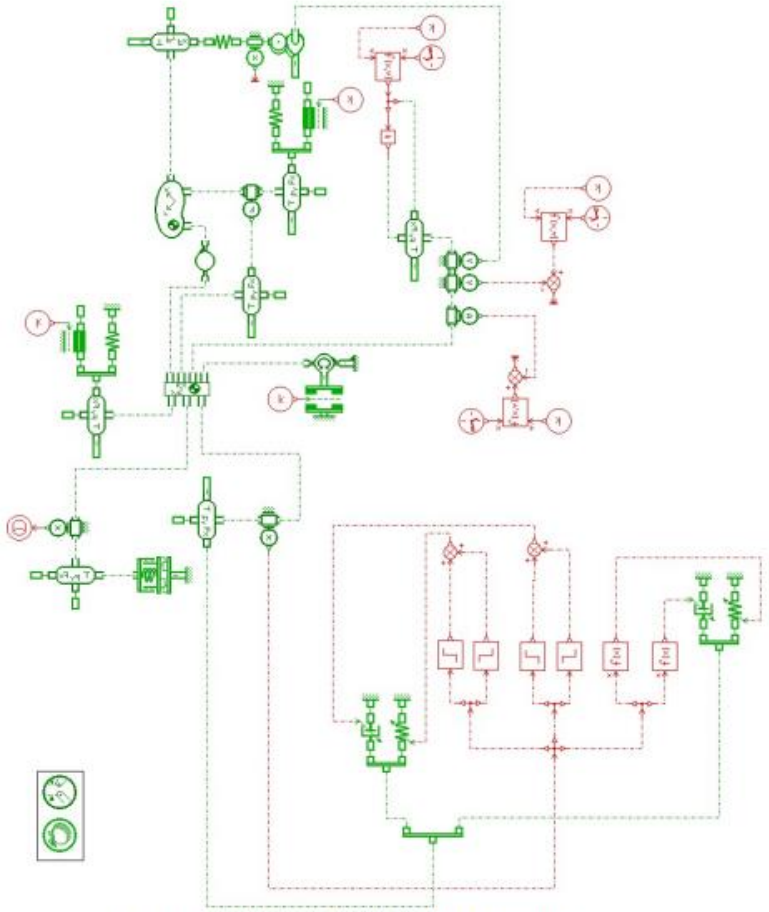
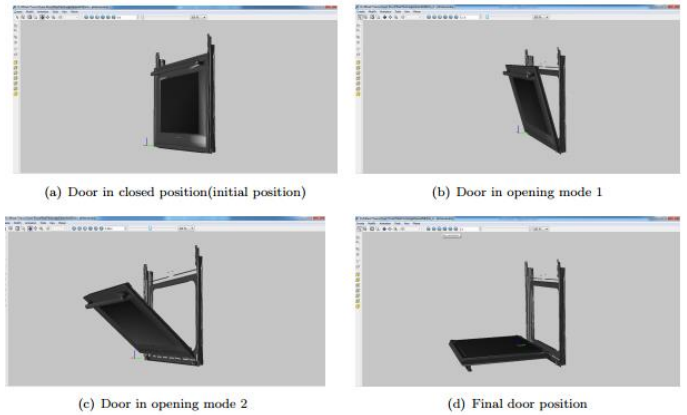


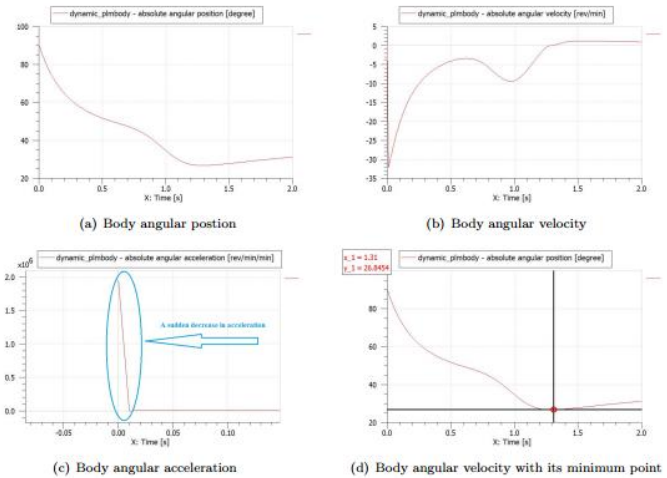
FIGURE 2.13: Opening-closing mechanism of the door of the oven



(a) Door in closed position(initial position) (b) Door in opening mode 1

(c) Door in opening mode 2 (d) Final door position

FIGURE 2.32: Animation of the opening-closing mechanism of the door of the oven with Large opening



(a) Body angular postion (b) Body angular velocity

(c) Body angular acceleration (d) Body angular velocity with its minimum point

FIGURE 2.34: Graph for position, velocity and acceleration of the main body

Example 2: hybridization of an excavator
Fuel economy estimation

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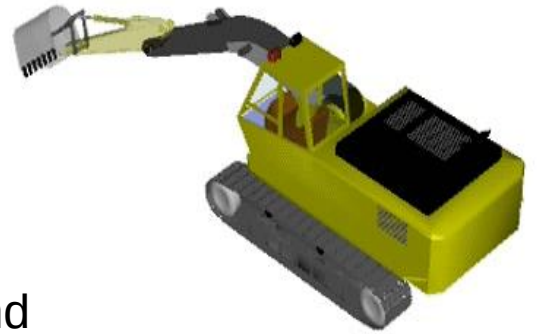
Objectives
- Reduce the operational cost of the equipment by improving the fuel economy and productivity
- Recover the energy lost:
  - During the swing braking maneuvers
  - When the boom is falling down



Solution
- Develop energy recovery systems, including hydraulic pump/motors, valves and accumulators on the swing function and on the boom actuation
- Estimate fuel economy and the productivity using a complete equipment simulator

Example 2: hybridization of an excavator
Conventional system

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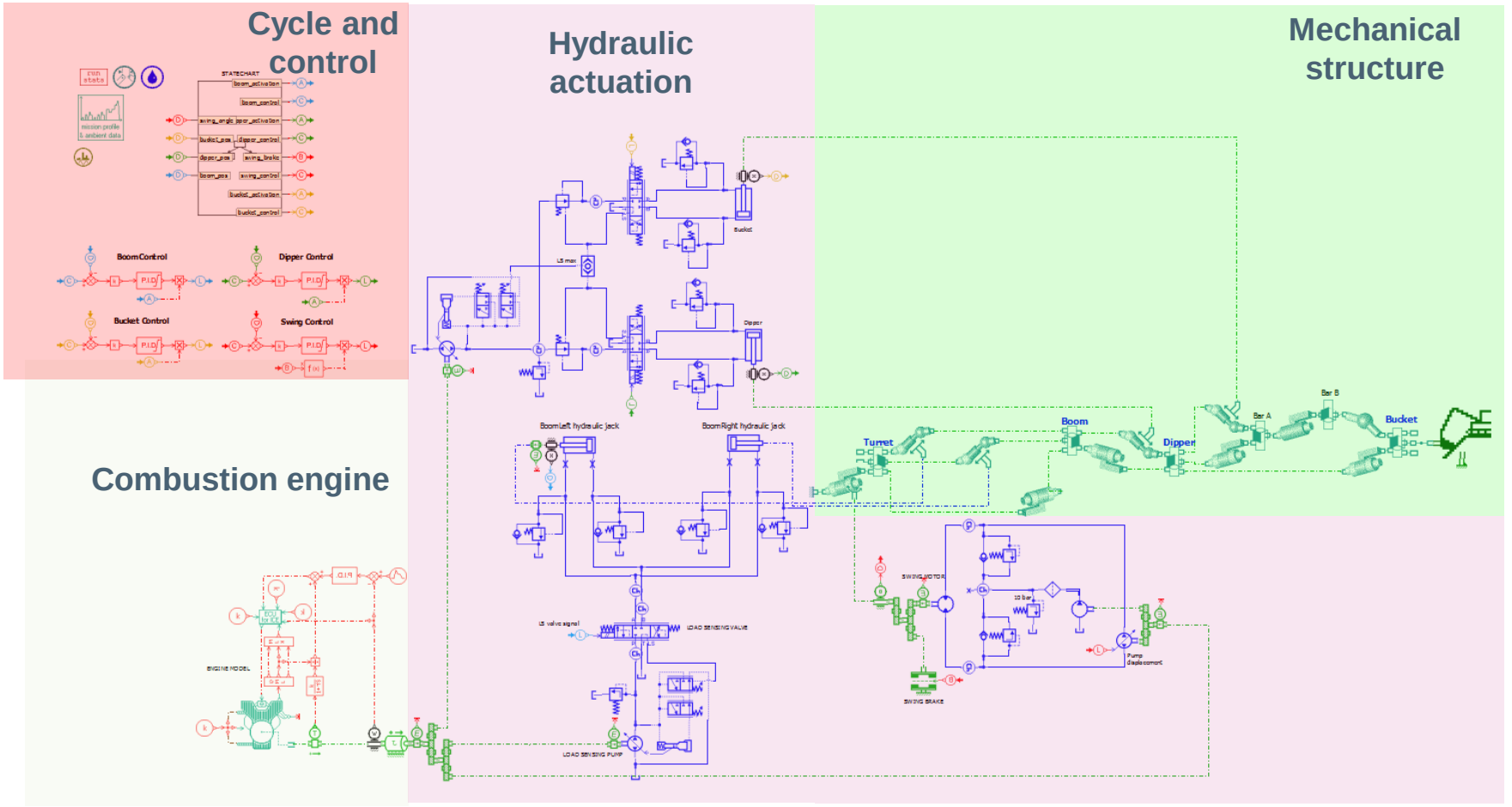

Example 2: hybridization of an excavator
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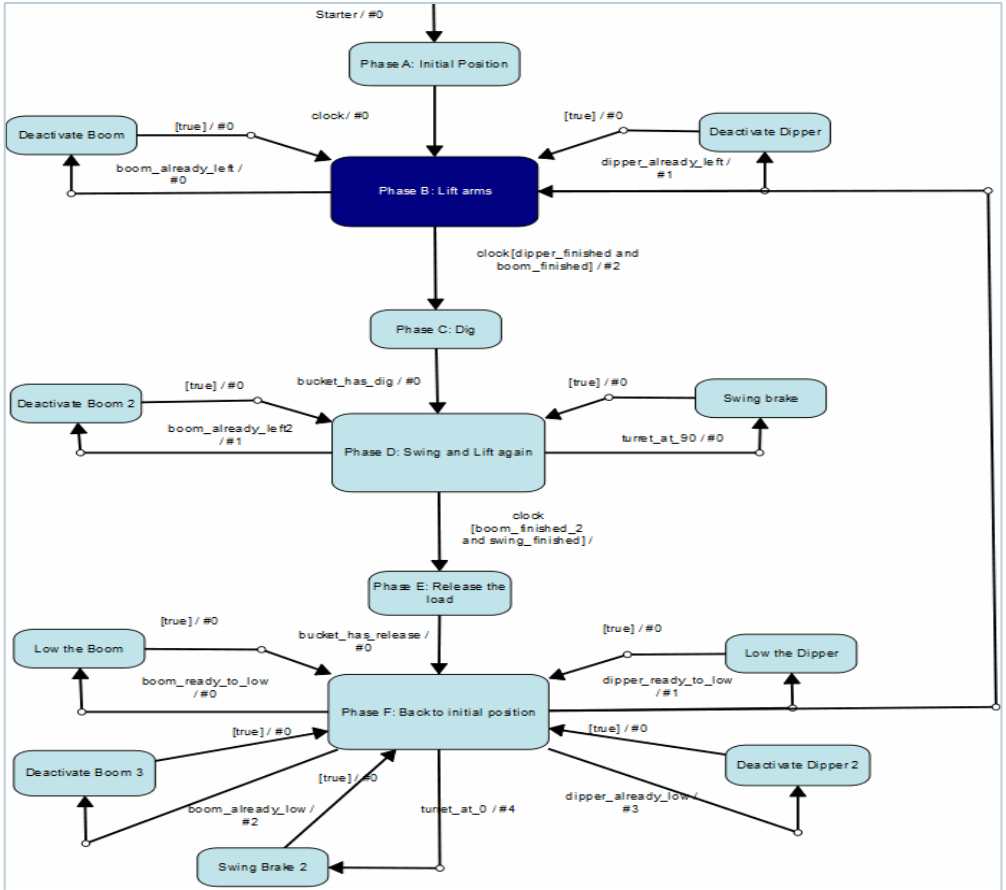
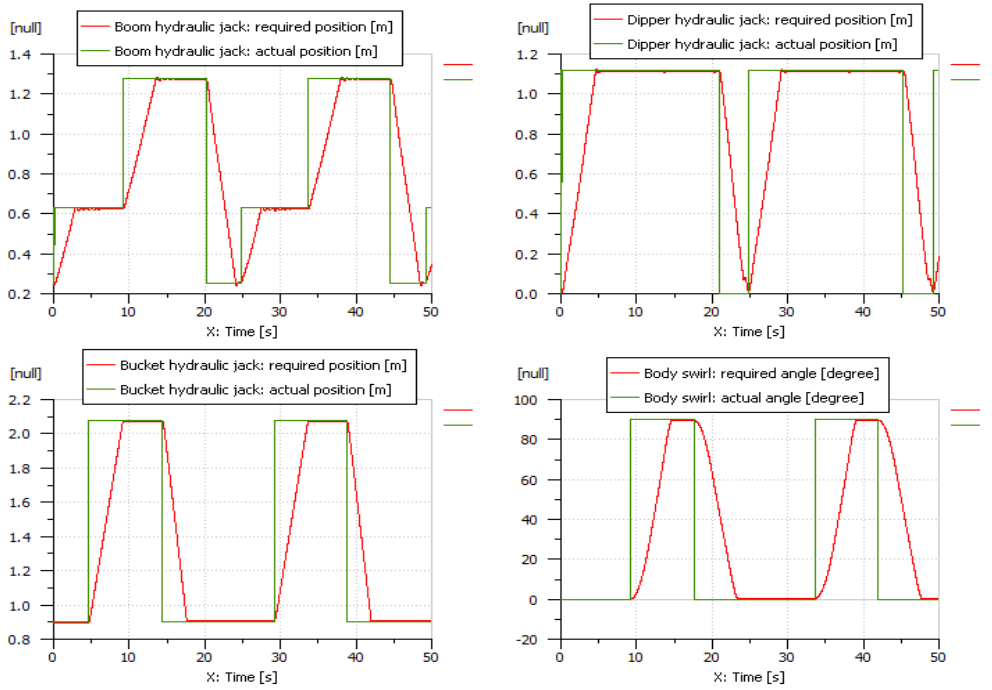
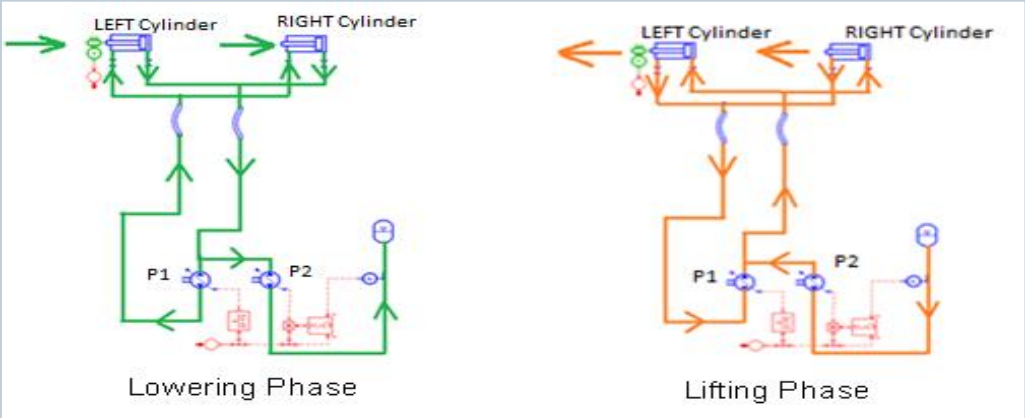


JCMAS:H020 cycle within the statechart environment

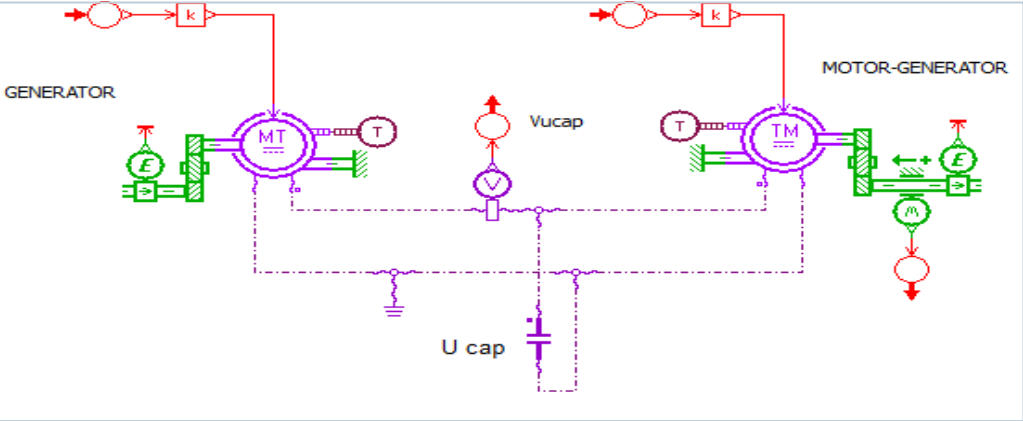


Hydraulic cylinder displacements and animation

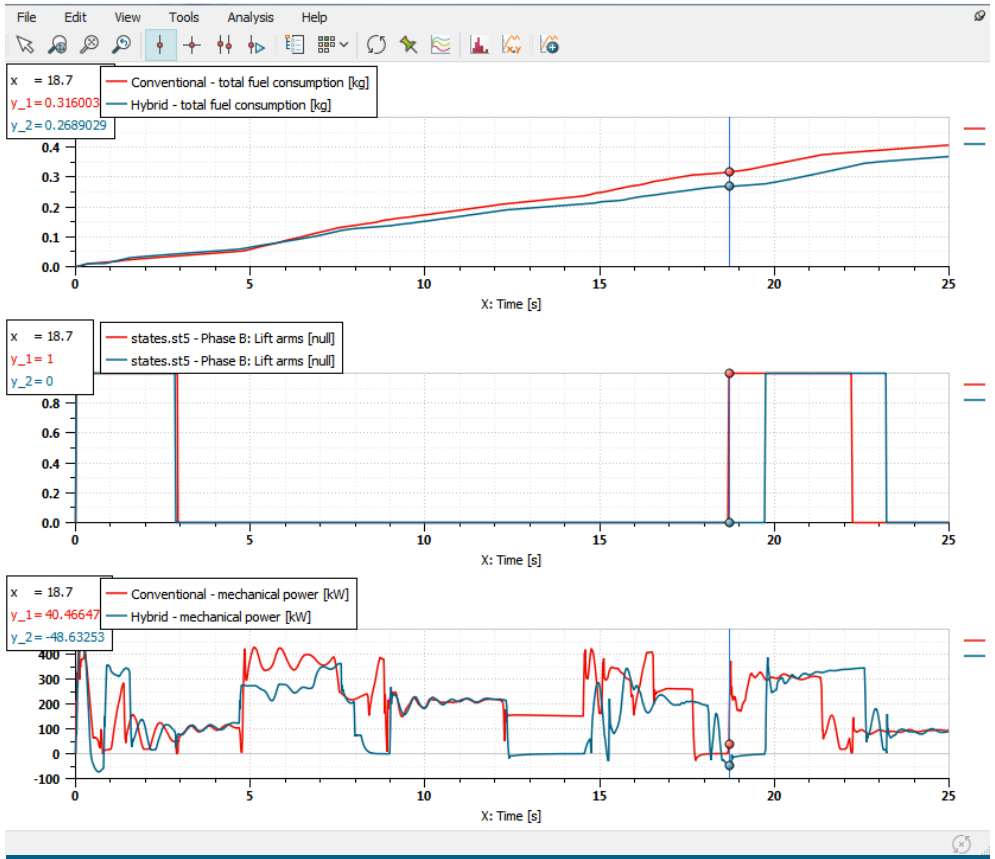
Example 2: hybridization of an excavator
Energy recovery systems



Flow path for the boom energy recovery system (hydraulic)

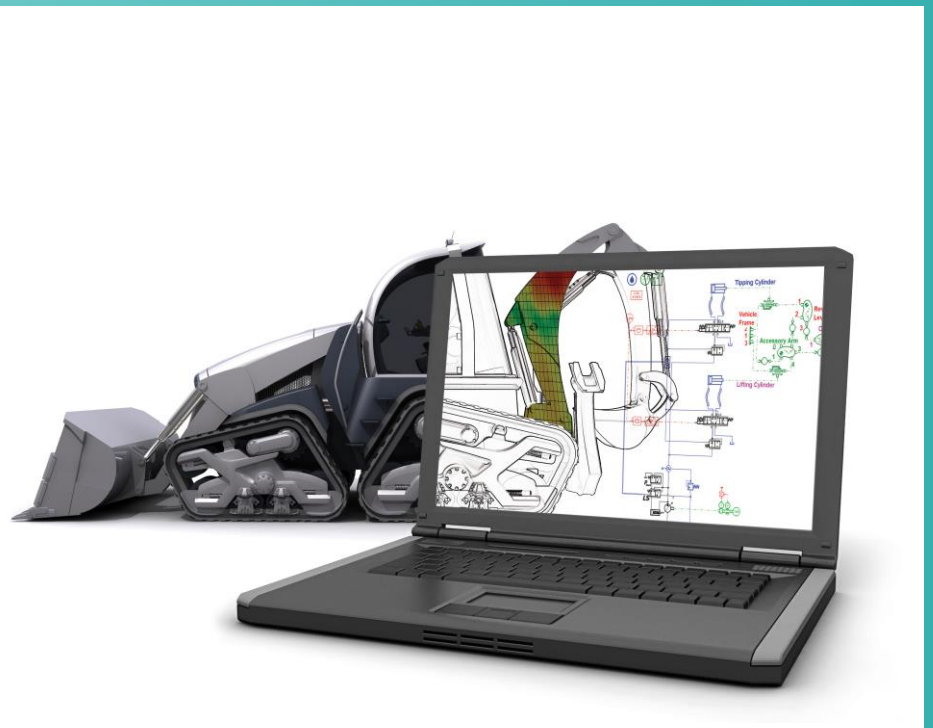


Swing energy recovery system (electrical)



Impact of energy recovery systems on fuel consumption and power peak

Agenda



- What is a system? Few examples
- What is Mechatronic System Simulation?
- Concept and positioning
- Simcenter technology with Simcenter Amesim
- Examples of typical applications
- **Solutions for all industries**
- Simcenter Amesim Student Edition

Simcenter Mechatronic System Simulation solutions

Bringing innovative product designs faster to market

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Automotive & Transportation

Aerospace & Defense

Heavy Equipment

Industrial Machinery

Marine & Shipbuilding

Energy

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Ingenuity for life

Assess the global vehicle **dynamic performance** in terms of **fuel economy**, **drivability** and **safety** at the early design stages

Applications

- Powertrain performance and controls optimization
- Chassis subsystems design and integration
- Vehicle integration and attributes balancing

Simcenter system simulation solutions

Well Established & Proven, for example in Automotive

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Auto OEMs

Suppliers

Aerospace and Defense

SIEMENS
Ingenuity for life

Build **safer, reliable aircrafts** while shortening the time-to-market by enabling real **integration** of physical systems together with their **controls**

Applications

- Virtual Integrated Aircraft
- Landing gear and flight controls
- Fuel systems, engine equipment
- Environmental controls systems

Simcenter system simulation solutions

Well Established & Proven, for example in Aerospace

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Airplane

Helicopter

Propulsion

Space

System supplier

Component supplier

Heavy Equipment

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Balance and optimize the **global performance** of the systems while satisfying **operating costs** reduction and **environmental regulations**

Applications

- Architecture performance evaluation
- Energy management optimization
- Systems sizing

Industrial Machinery

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Balance **machines' performance** and **energy-consumption** by predicting the multidisciplinary behavior of intelligent systems

Applications

- Fluid-powered systems design
- Mechanical systems optimization
- Electrical and electromechanical actuation

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Optimizing ship designs for NOx and CO2 reduction while keeping overall **costs** – innovation and operation – as low as possible

Applications

- Internal combustion engine optimization
- Electric & hybrid drivetrain performance evaluation
- Electric and hydraulic component design

Simcenter system simulation solutions

Well Established & Proven, for example apart from Auto and Aero

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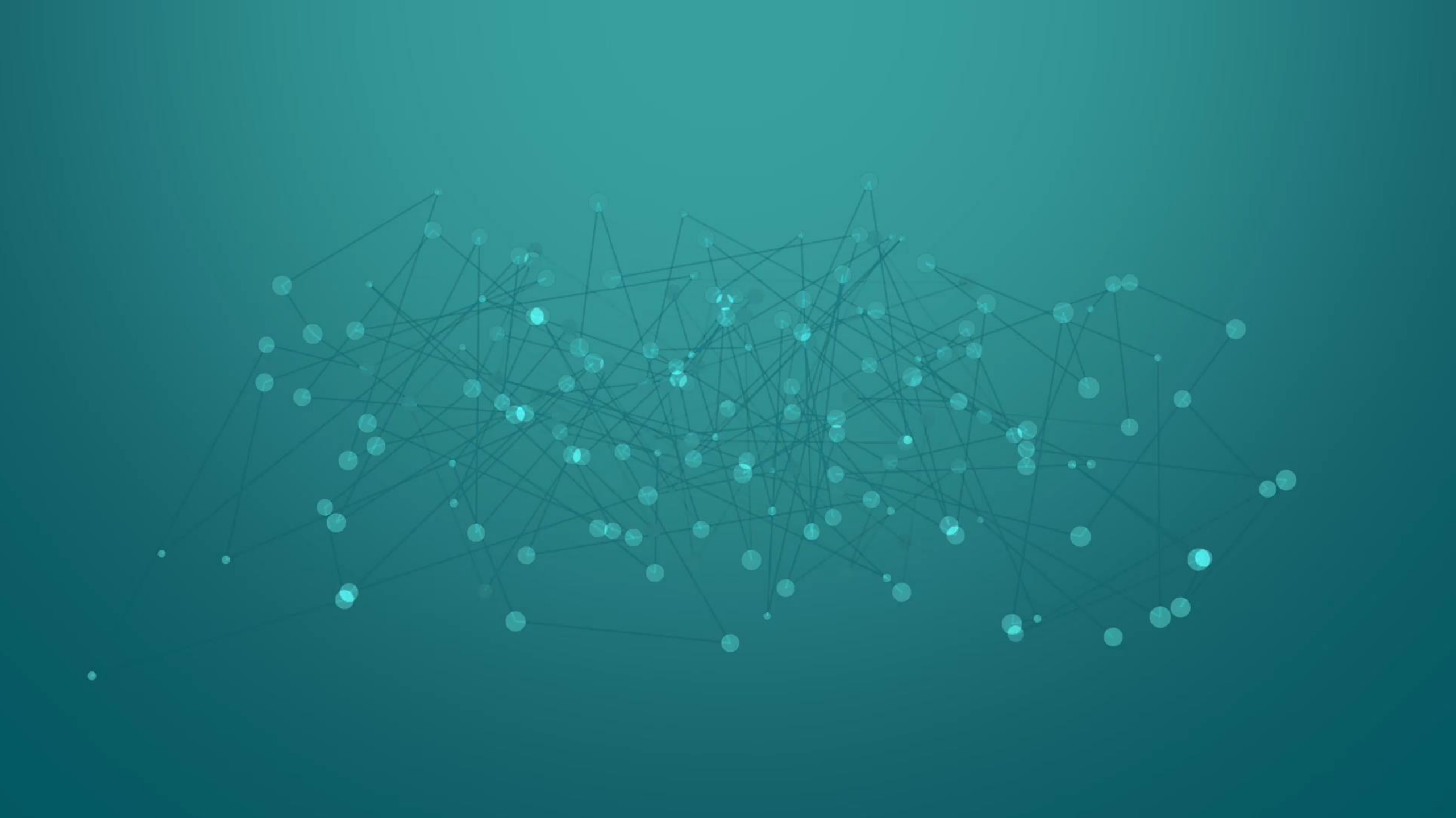
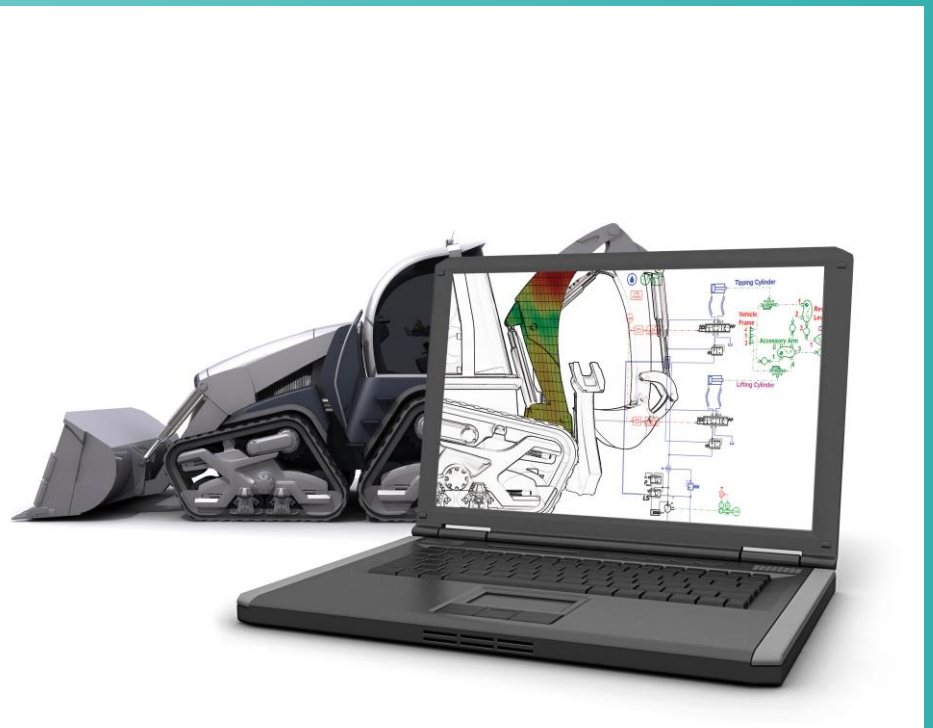
Agricultural machinery, trains, shipbuilding, mechanical industry, elevators, energy, motorbike, large engines…



Agenda



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Simcenter Amesim
Students talking about it

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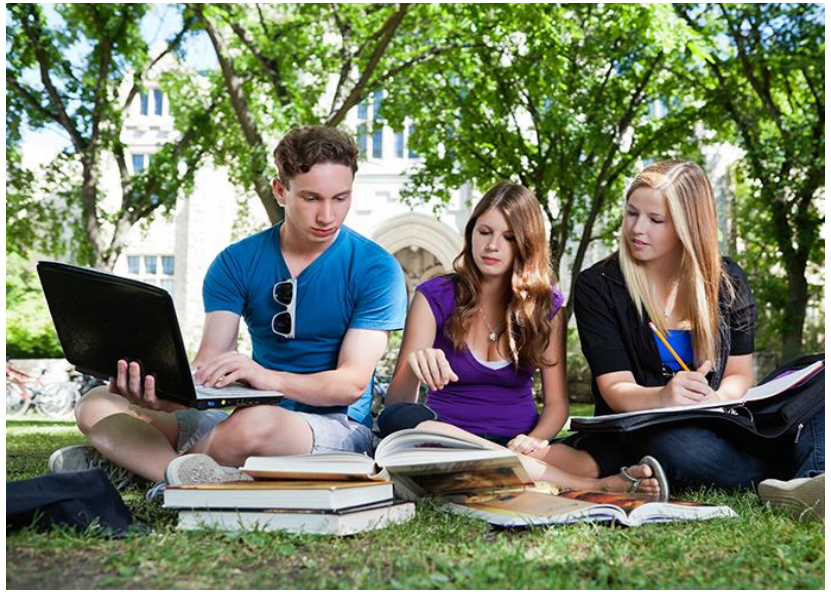
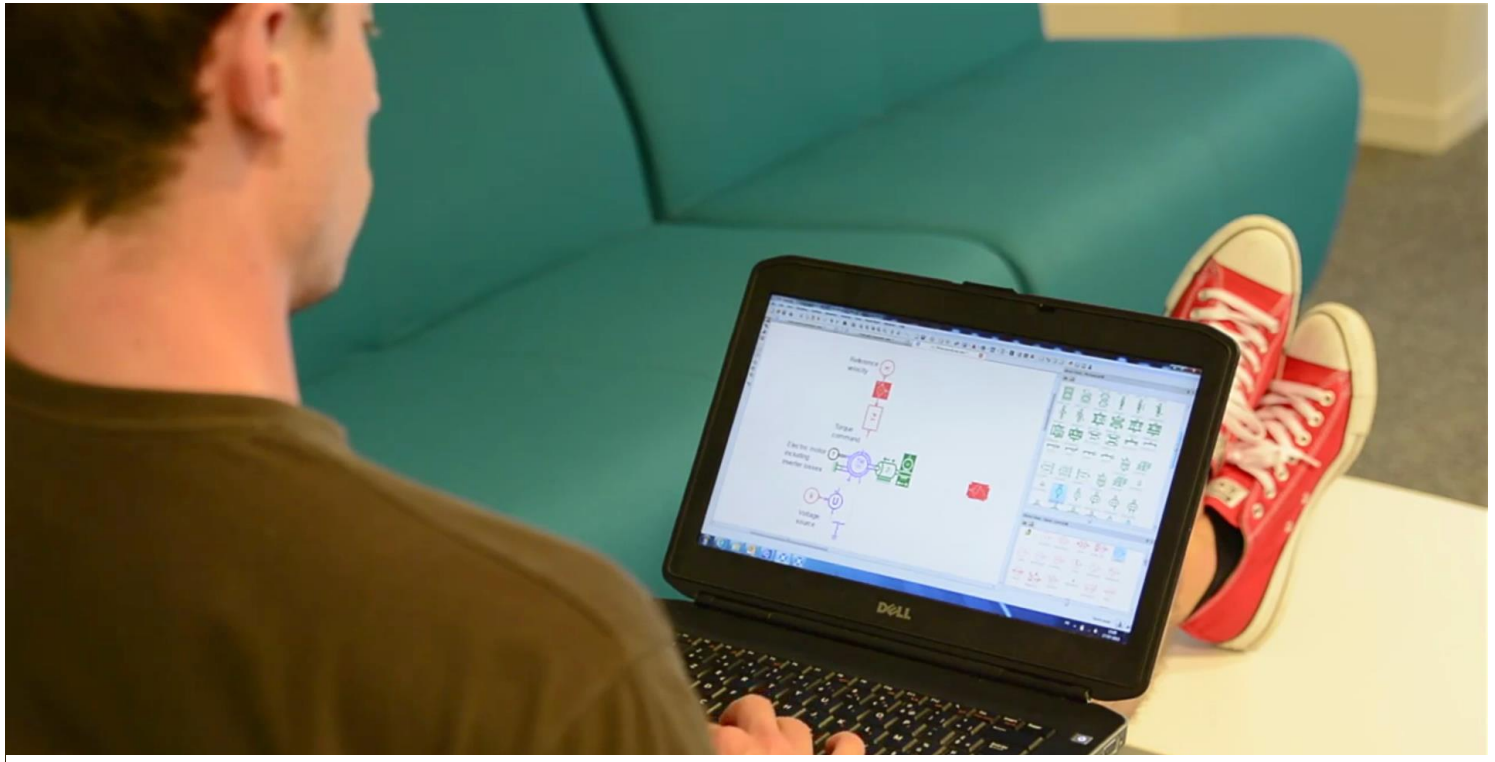
Ingenuity for life



- Intuitive, easy-to-use interface
- Modeled multi-domain systems with different levels of complexity
- Seamlessly analyzed simulation results



"Simcenter Amesim is a powerful tool not only for any engineering project but also for student learning."

Bernardo Sidou, Federal University of Rio Grande do Sul

Simcenter Amesim Student Edition
Benefits for students

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- Seamless system simulation experience – **for free**
- **No limit** on size of the model
- **Industry-leading** system simulation **technology**
- Capability to put **theory** into **practice** thanks to Simcenter Amesim **physical libraries:** Mechanical, hydraulic, pneumatic, thermal, electrics, signal
- Set of **analysis tools**: linear analysis, batch runs, power and energy calculations, 2D-animation
- **Scripting** capabilities: Matlab, Python, Visual Basic Application

Simcenter Amesim Student Edition

Get started freely with system simulation

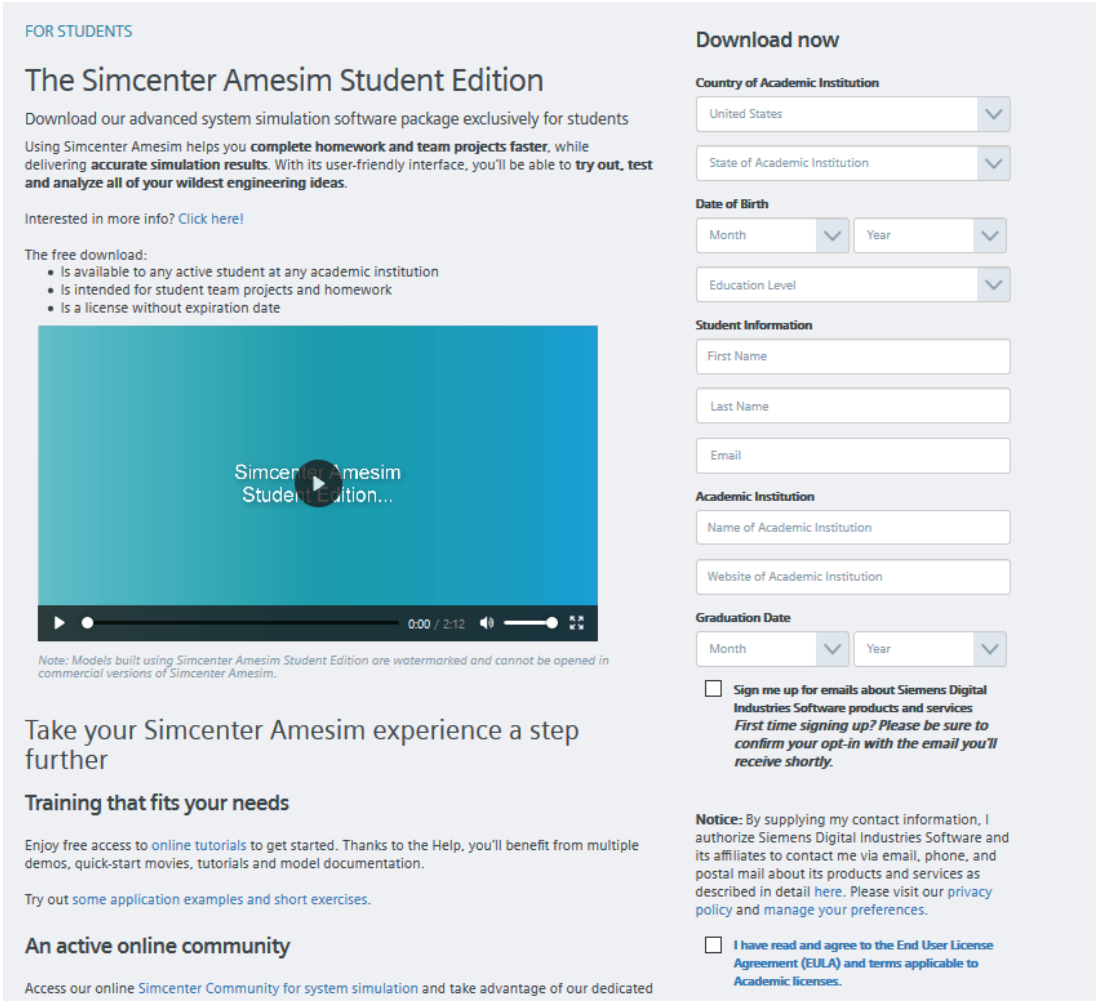
1 - Download the software (free perpetual license):

https://www.plm.automation.siemens.com/plmapp/education/simcenter/en_us/free-software/student

2 - Get started with modeling with videos, demos, tutorials, model documentations

3 - Ask questions and share ideas with students, educators and experts:

Simcenter community



Thank you!

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Realize innovation.