What is mechatronic system simulation?

Introduction to concepts

LMS Imagine.Lab Amesim™

A world leading platform for physical simulation of mechatronic systems

Table of content

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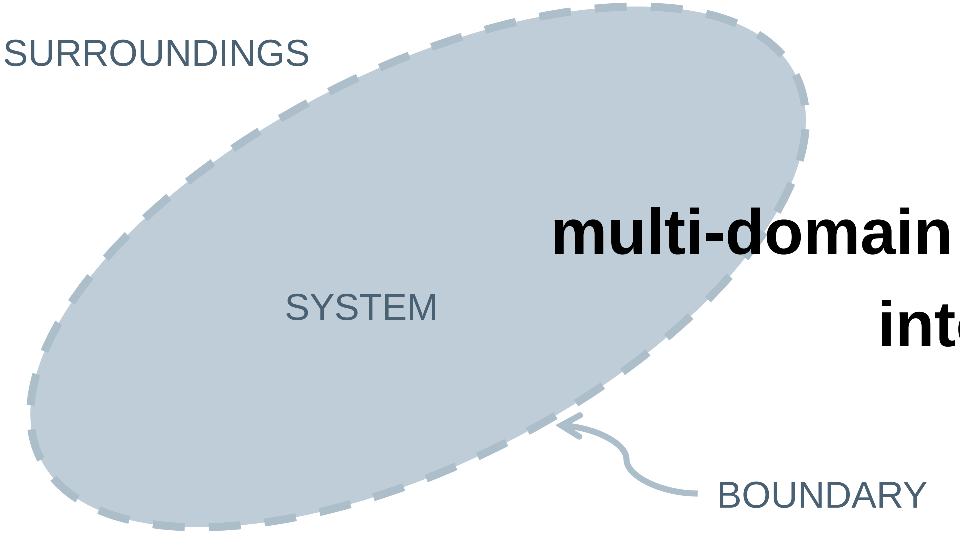
What is a system?

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

What is a system?



A **group**

of

multi-domain | multi-physics components

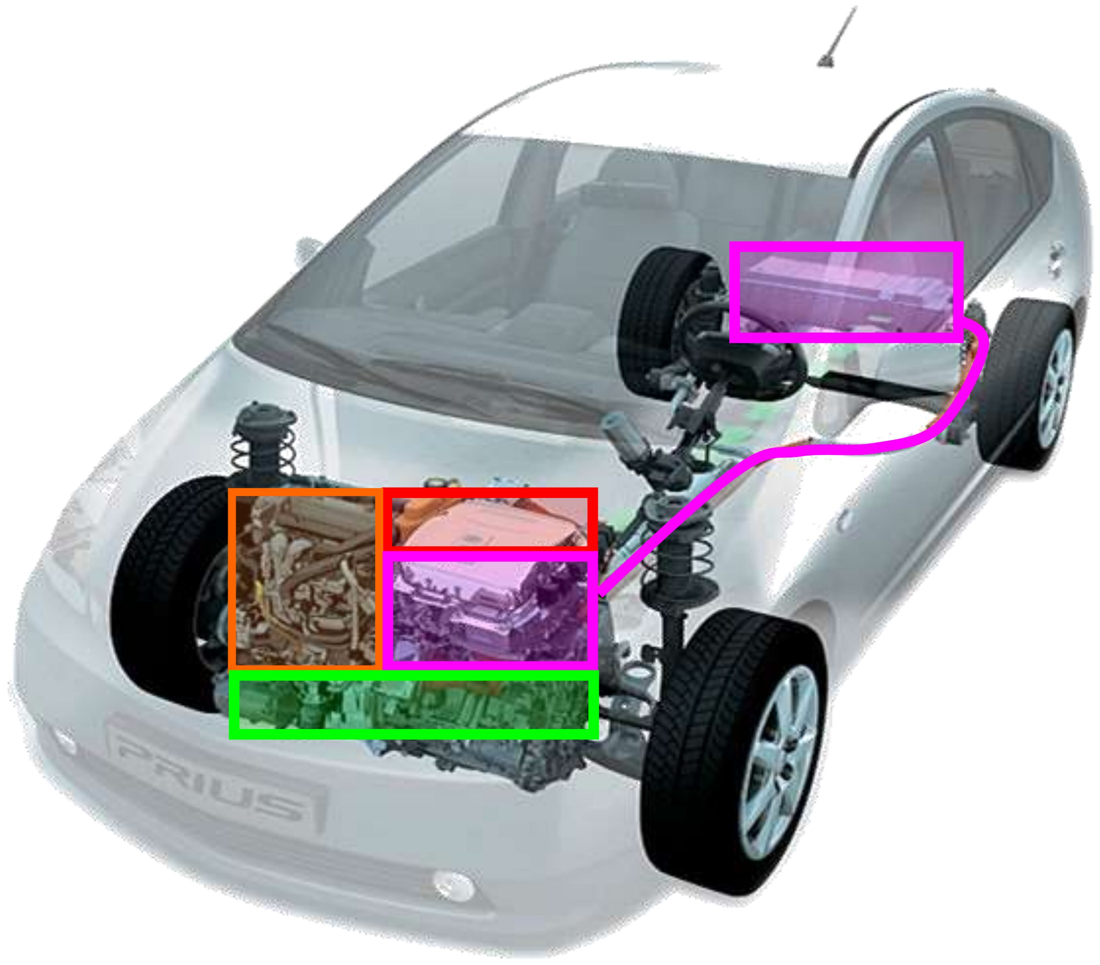
interacting together

- Systems have **structure**, defined by parts and their composition
- Systems have **behavior**, which involves inputs, processing, outputs of material, energy or information
- Systems have **interconnectivity**: the various parts have functional and structural relationships
- Systems have by themselves **functions** or **groups of functions**

What is a system? Examples

Hybrid vehicle

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



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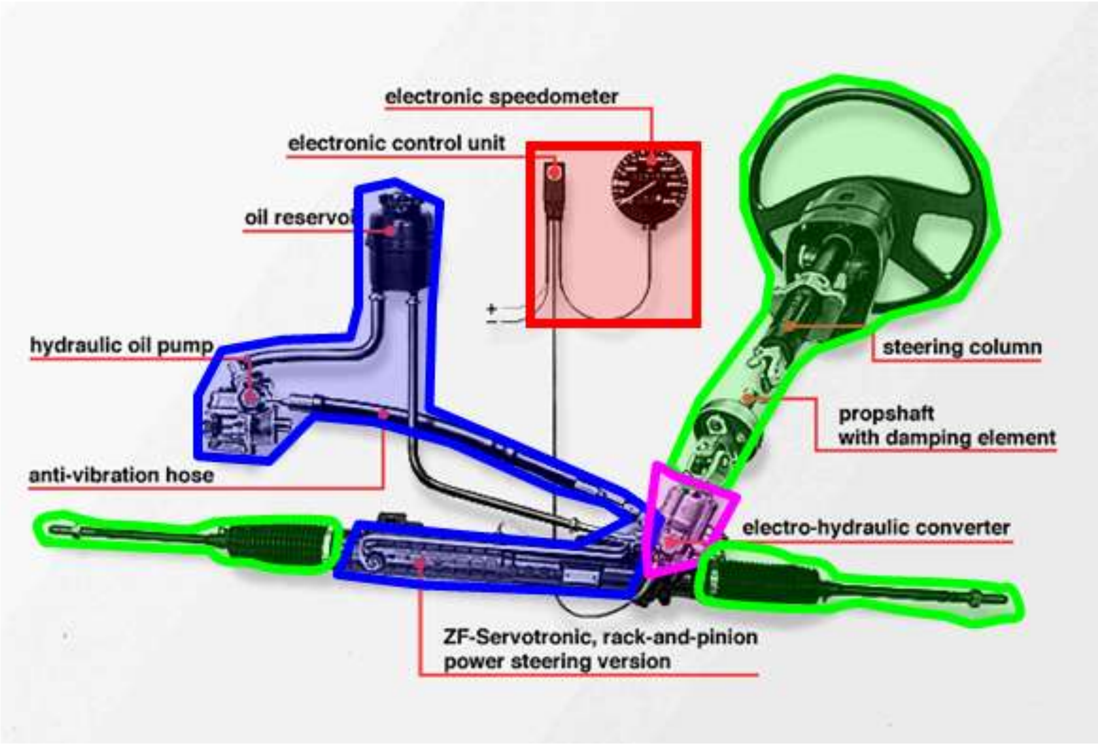
Electro-hydraulic power steering

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



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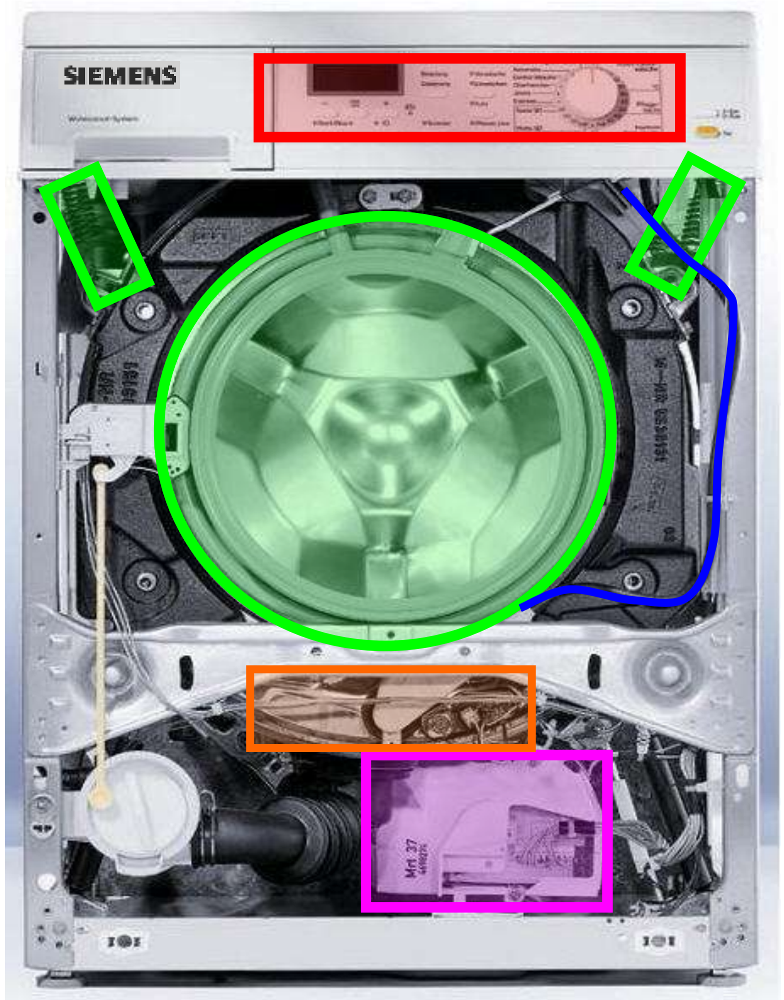
Washing machine

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



IC engine

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

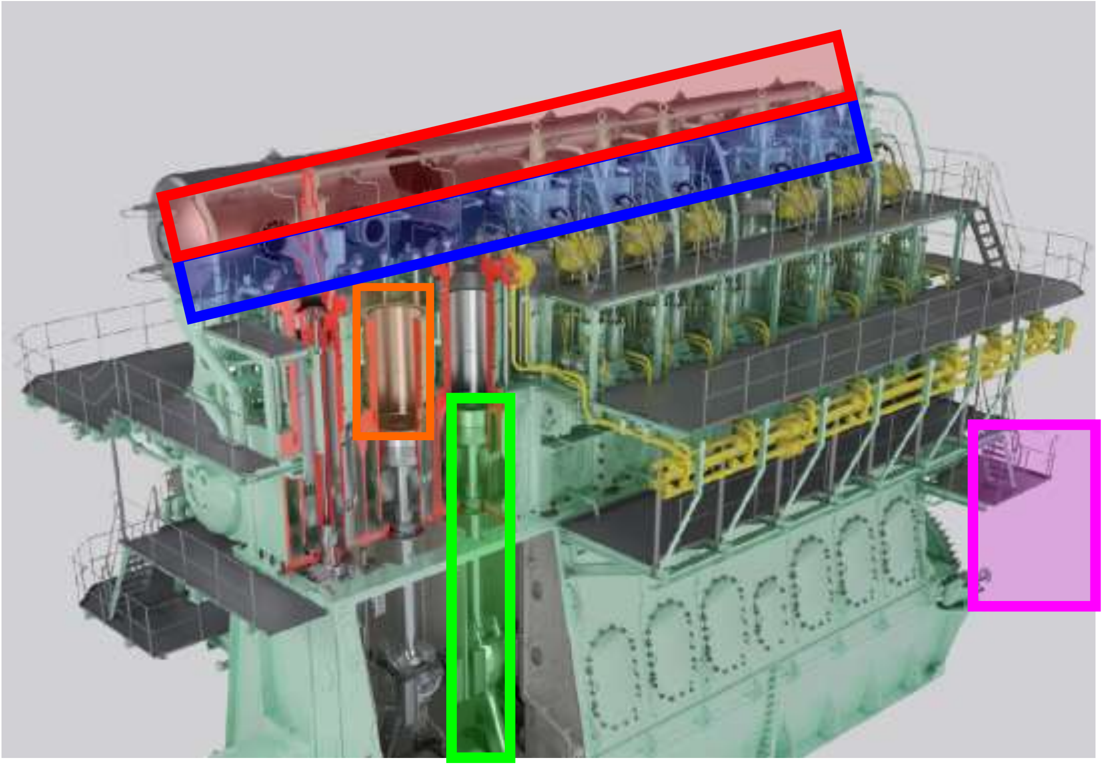


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Table of content

“Mechatronics” definition

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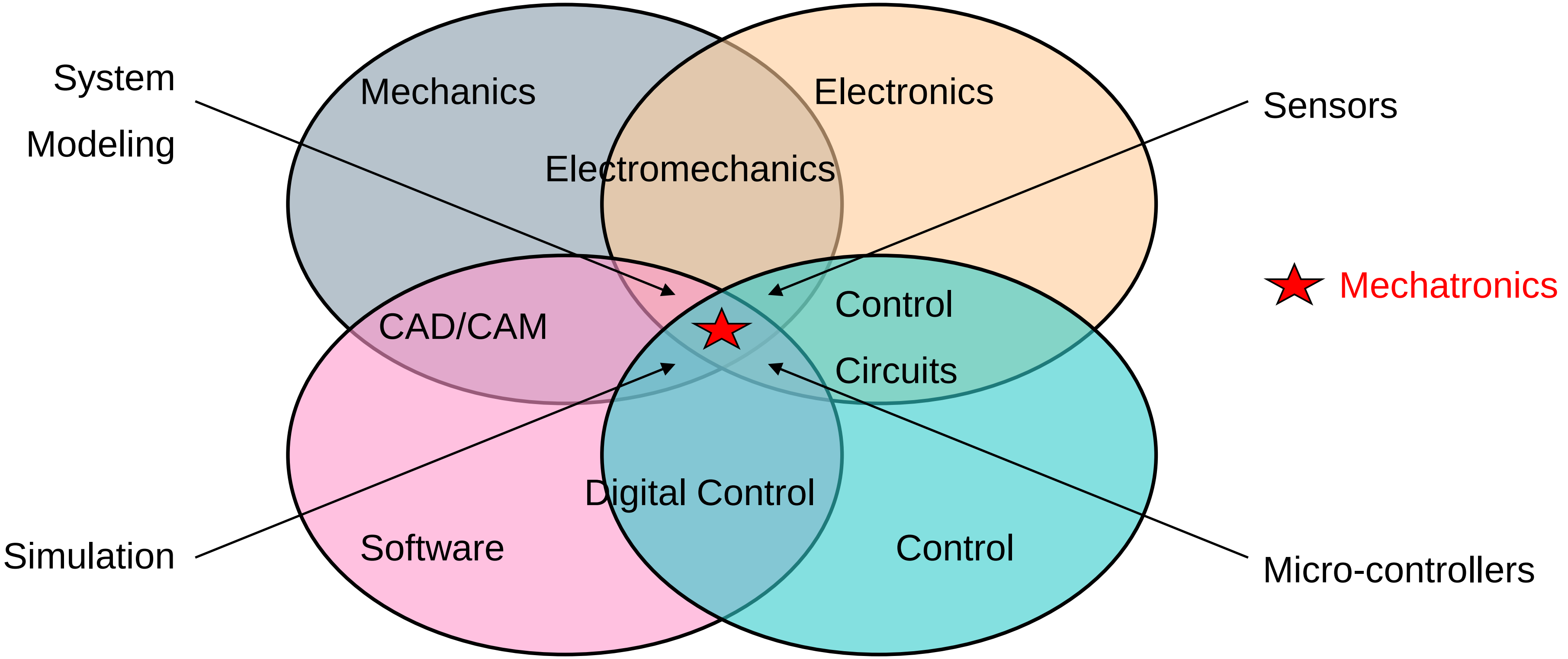
“The synergistic combination of mechanical, electronic, control and software engineering” (Wikipedia)

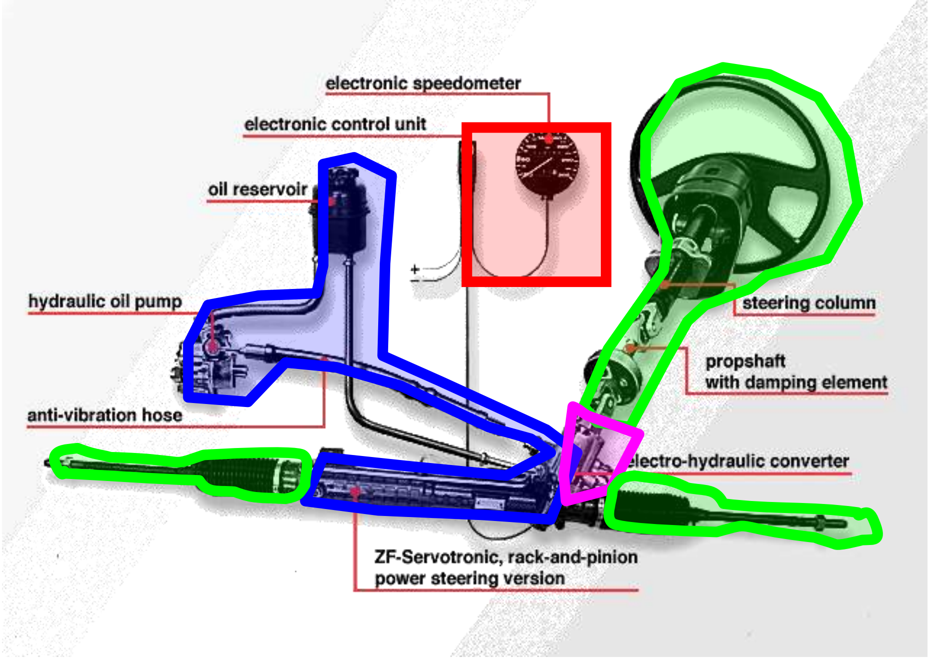


From Tamburini & Deren, PLM World ’06

http://eislab.gatech.edu/pubs/conferences/2006-plm-world-tamburini/

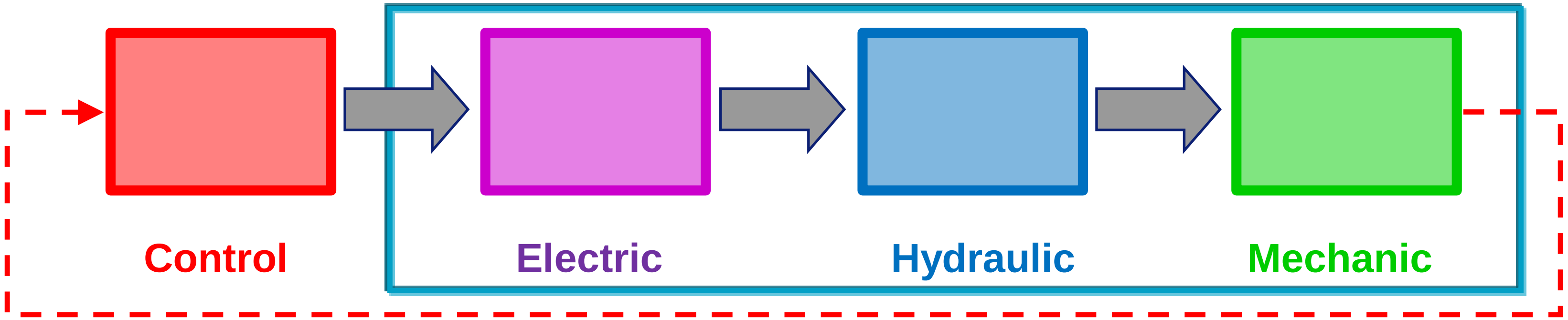
What is mechatronic system simulation?

- **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?

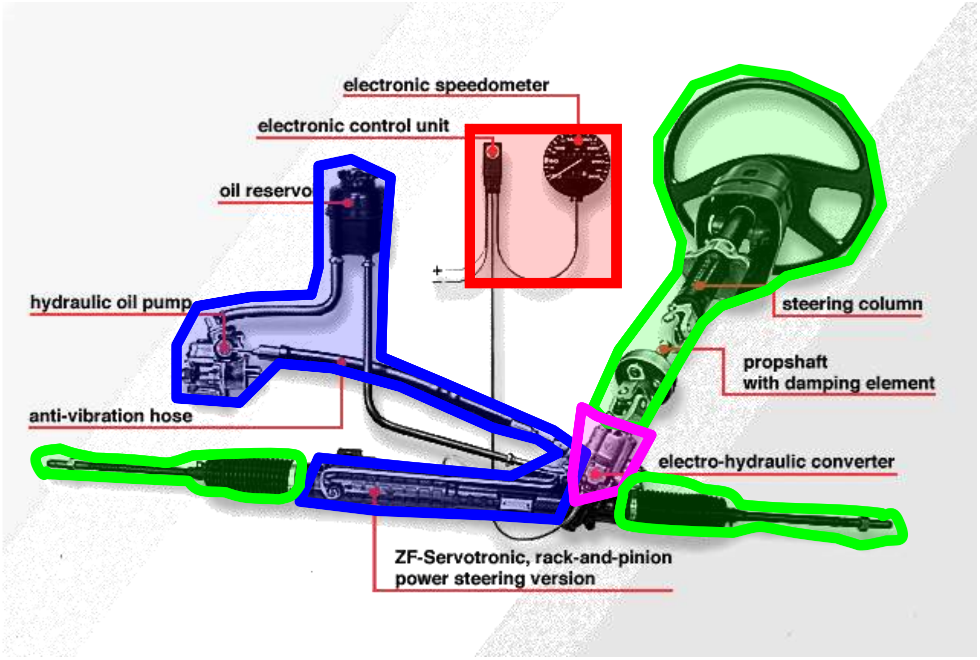


- **Key words :**
  - **Multiphysics** with **power exchange**
  - Dynamic system (function of **time**)
  - Physical system model = **plant model**

LMS Imagine.Lab Amesim plant model



Abstraction level: power steering example



Power steering example

- Can we build the complete system model with a CAD-based software?

  No, since we have no CAD at this stage of design
- Can we simulate it within an acceptable simulation (computational) time?

  No, no 3D software is able to do that

Model

- We need another approach to:
  - Pre-design such systems
  - Choose an architecture (hydraulic, electro-hydraulic, electric)
  - Assess key functions of the system

Abstraction level – Equations – Representation

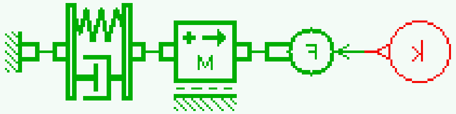
- Equations are usually written as **time dependent** with a focus on computing state derivative of variables to assess transient evolution
- Physical equations of component behavior are represented by ***readable objects (icons)***

Equations level — ***Physical icon representation***

Mechanics

$$M * dx/dt^2 = F - R dx/dt - Kx$$

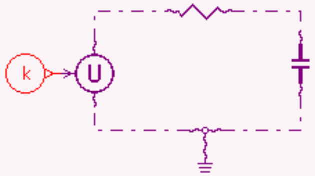
$$s^2 + 2 \cdot z \cdot \omega_n \cdot s + \omega_n^2 = 0$$



Electric

$$U = R * I$$

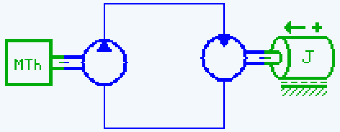
$$dU/dt = I/C$$



Hydraulics

$$Q = displ * \Omega$$

$$T = displ * \Delta P$$

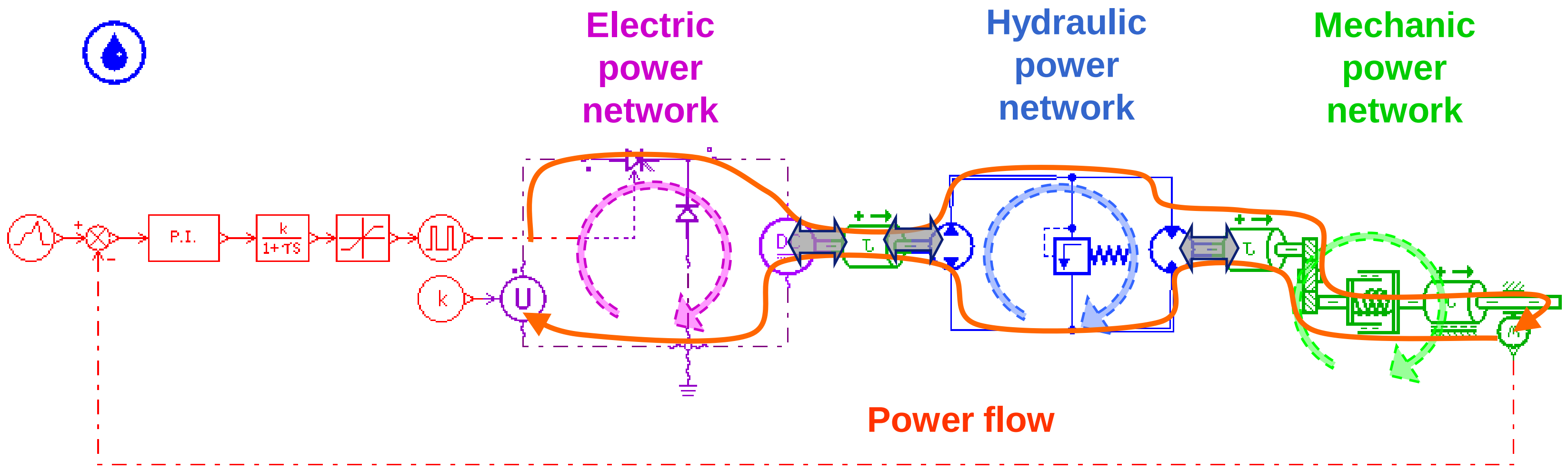


And many other physical domains…

Power flow and power conservation

- 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**	**Tension**	**U**	***Current***	***I***
• **hydraulic**	**Pressure**	**P**	***Flow rate***	***Q***
• **mechanic**	**Torque**	**T**	***RPM***	Ω



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

What is mechatronic system simulation?

1D system simulation

- Is (*usually*)

- Equations dependent of **time** (ODE, DAE)
- Linked to the **power flow** within a system
  - Where does the power go?
  - Where is power lost?
  - Where is power created?
  - Where is power exchanged?
- Linked to the **control** of this power
  - Linked to automation & control
  - Linked to electronics → mechatronics
- Based on direct input of a **reduced number** of parameters

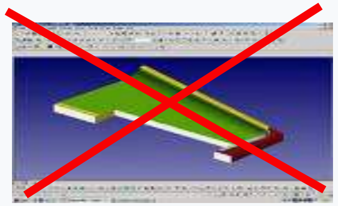
1D system simulation

- Is not (*usually*)

- Not equation dependent of space (X,Y,Z) (partial derivative equations)

$$\cancel{\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}=0}$$

- Not designed to simulate fixed structures



- Not designed to simulate a single physics

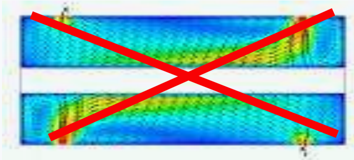
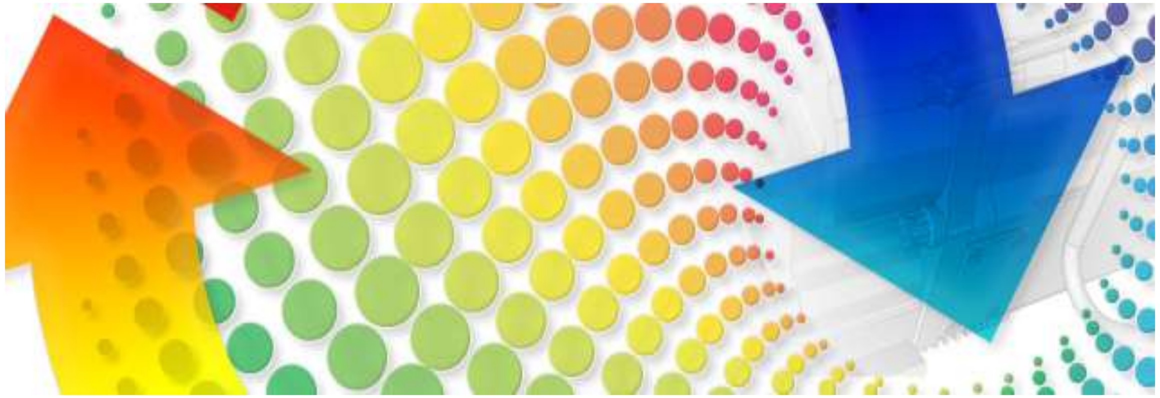


Table of content

A concept



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

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**.

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.

LMS Imagine.Lab transmission solutions example

Modeling interactions between all transmission subsystems

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Engine

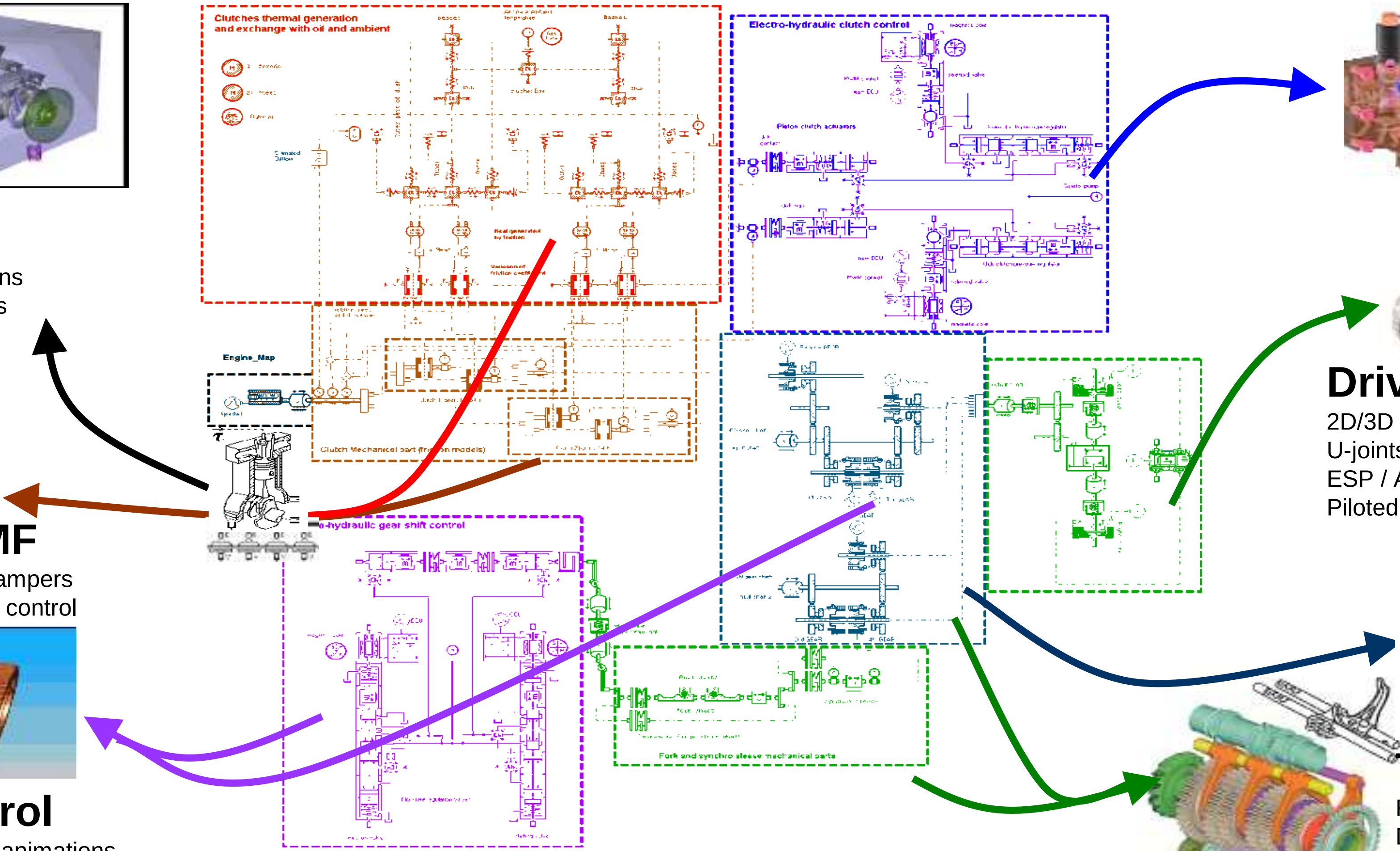
Crankshaft
Camshaft Vibrations
Torque oscillations

Clutch / DMF

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

Shift control

Synchronizers, 3D animations
Planetary gear trains
Gearshift control



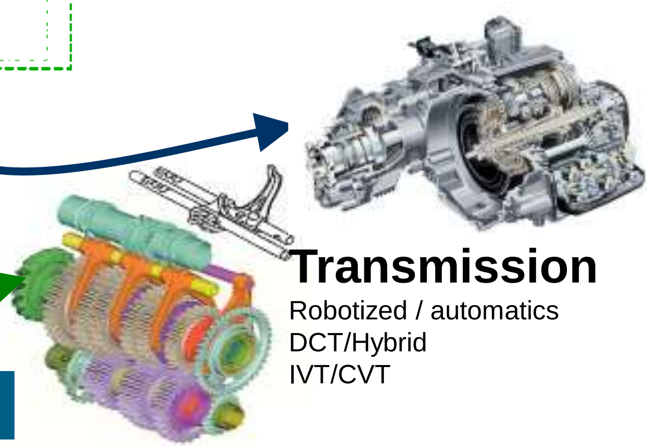
DCT model for Gear shift Comfort analysis (0-40Hz)

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

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**.

A concept

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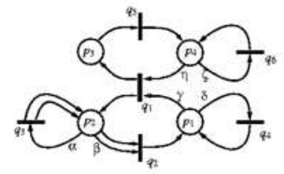
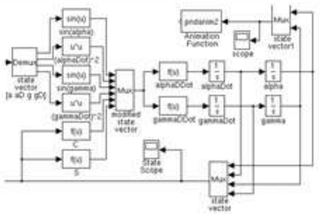
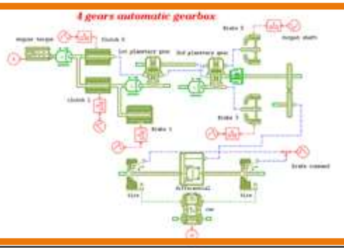
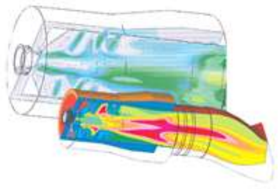
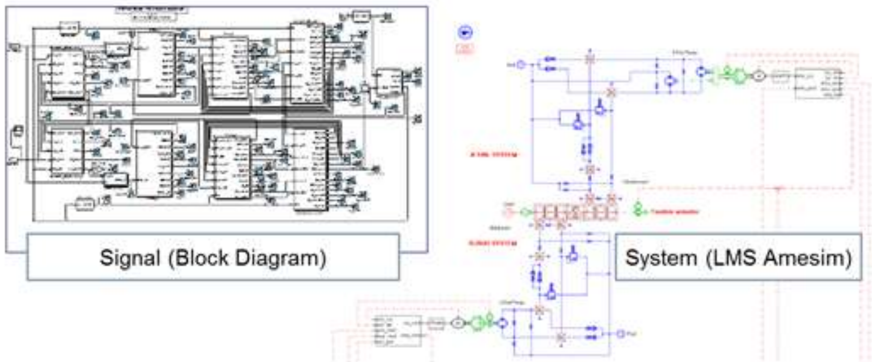
1D CAE calculations are **very efficient**. The components are **analytically defined**, and have input and output ports. Causality is created by connecting the inputs of a component to the output of another one (and vice-versa).

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.

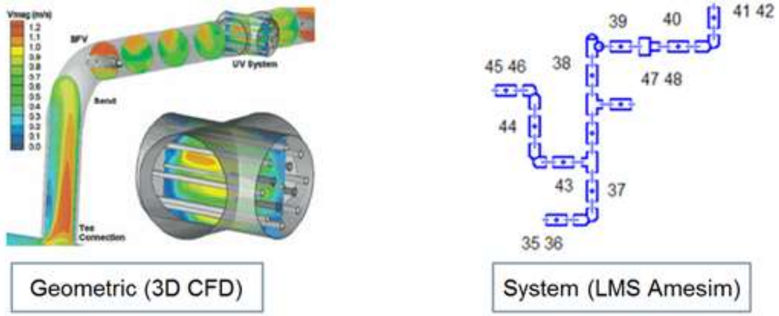
1D CAE offers you an open development approach, starting from **functional requirements** to **physical modeling and simulation**, enabling concurrent engineering of mechatronic systems in a **collaborative** design environment.

System Simulation positioning
Comparison with other Modeling & Simulation (M&S) approaches

Schematic representation	Modeling approach
	**Functional Level** Description of system functions and system states Example: Petri Net
	**Signal Level** Control modeling including simplified model of physical Components Example: Block Diagram
	**System Level** Detailed modeling of physical components which cover different physical domains. A dynamic model of the whole system is available at this level which is also called physical system modeling. Example : 1D Gearbox Simulation
	**Geometric level** The detailed geometry of a component is sized or optimized at this level. Example: 3D CFD simulation



Comparison of the Signal vs System levels – Model of an Electro-Hydraulic Actuator



Comparison of the Geometric vs System levels – Model of a Piping system

Positioning in the CAE world

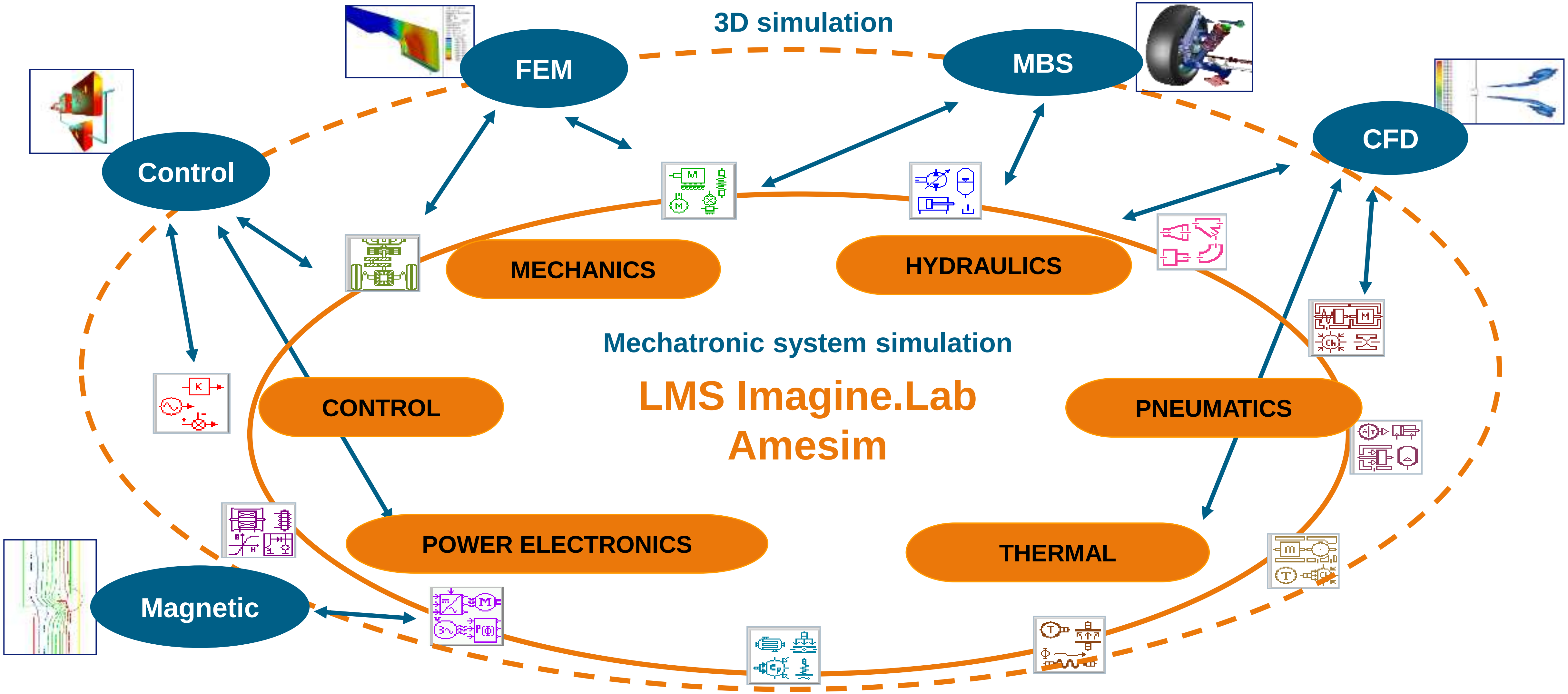


Table of content

LMS Imagie.Lab technology based on 4 critical pillars

Ready-to-use physical components

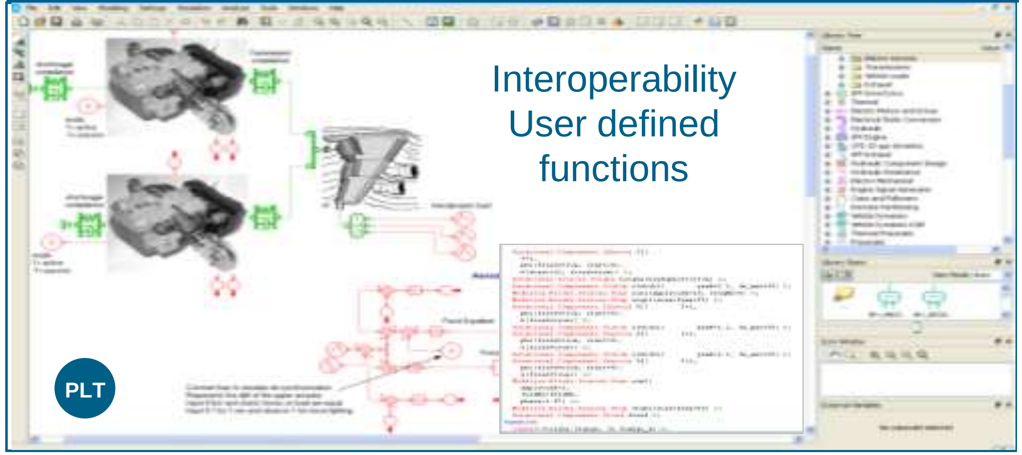
PHY Over 5,000 multi-physics component models

Application-specific tools and solutions

- Automotive & transportation
- Aerospace & defense
- Heavy equipment
- Industrial machinery
- Marine & Ship building
- Energy

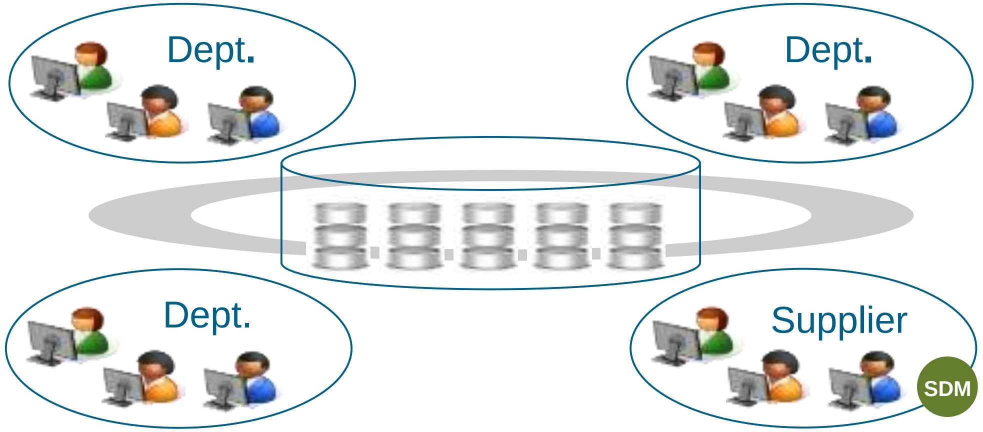
SOL

Open system integration platform



PLT

Integrated system data management



SDM

Best-in-class solution to further improve product – All industries

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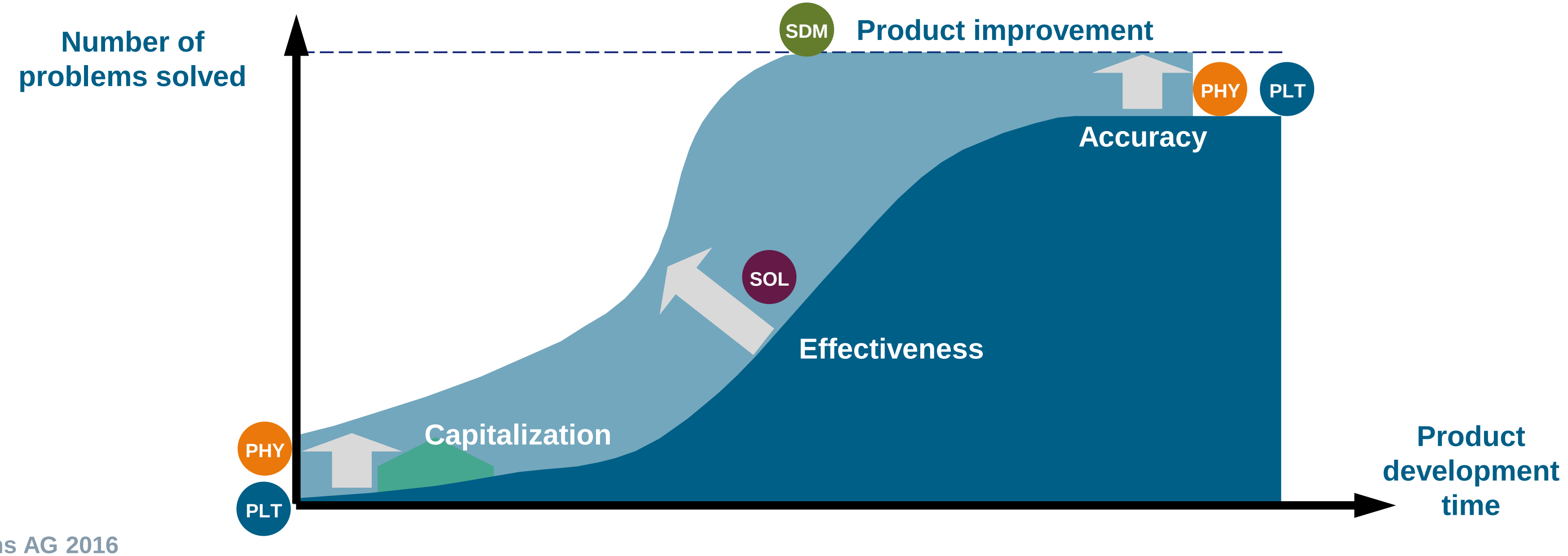
	Top values	LMS Imagine.Lab	Others
PLT	Open system integration platform	✓✓✓	✓
PHY	Ready-to-use physical components	✓✓✓	✓✓
SOL	Application-specific tools and solutions	✓✓	✓
SDM	Integrated system data management	✓✓	✗



Our technology in the supply chain

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TIER 3
Zodiac Hydraulics
Valves and pumps

TIER 2
Safran Landing Systems
Braking and steering

TIER 1
Safran Landing Systems
Landing gear

Aircraft OEM
Airbus
Assembly and validation

Law leakages

Smaller pump

More efficient and lighter

Less energy consumption

LMS mechatronic system simulation solution as a critical answer to the technological challenges

Engineering challenges in a nutshell

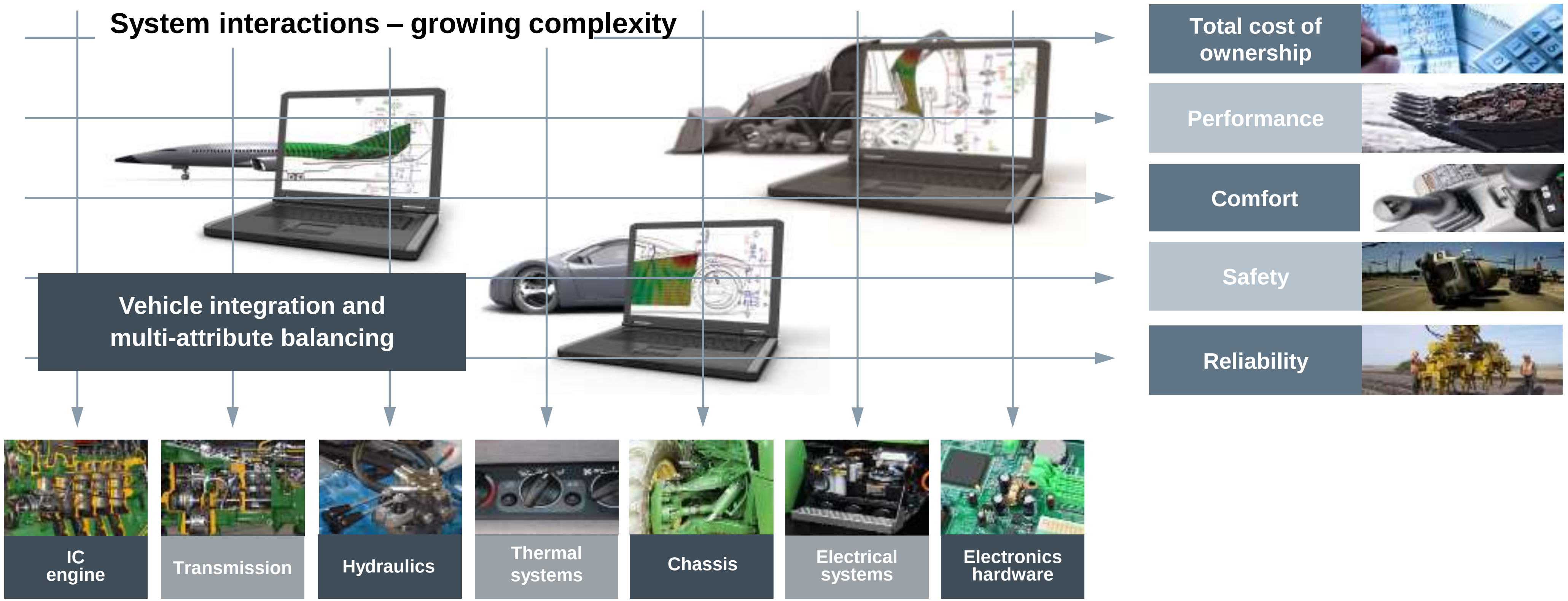

Table of content

- What is a system? Few examples
- What is mechatronic system simulation?
- Concept and positioning
- LMS technology with LMS Amesim
- **Solutions for all industries**
- Definitions

LMS mechatronic system simulation solutions

Bringing innovative product designs faster to market

Automotive & Transportation

Aerospace & Defense

Heavy Equipment

Engineering the passion

Industrial Machinery

Marine & Shipbuilding

Energy

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

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

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

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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

Table of content

Definitions

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- **Around “*mechatronic system simulation*”**
  - **CAE (Computer Aided Engineering):** CAE is the broad usage of computer software to aid in engineering analysis tasks. It includes Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), Multibody dynamics (MBD), Optimization, etc.
  - **Mechatronics:** Design process that includes a combination of mechanical engineering, electrical engineering, control engineering and computer engineering. Mechatronics is a multidisciplinary field of engineering. It includes control systems as well as numerical methods used to design products with built-in intelligence.
  - **Model:** A physical, mathematical, or otherwise logical representation of a system. We can find for example structural models or analytical models.
  - **Model Based System Engineering (MBSE):** A systems engineering methodology which focuses on creating and exploiting domain models as the primary means of information exchange between engineers, rather than on document-based information exchange. More recently, the focus has also started to cover aspects related to the model execution in computer simulation experiments, to further overcome the gap between the system model specification and the respective simulation software.

Definitions

- **Around "*mechatronic system simulation*"**
  - **Multidisciplinary models:** Multidisciplinary models combine various modeling techniques such as dynamic simulation in different areas like automatic control and signal processing.
  - **Multiphysics:** Multiphysics models include more than one equation and variable from different types of physics. These variables can be defined in different domains.
  - **Physics-based modeling:** Physical models in which the equations that constitute the model are those used in physics to describe or define physical phenomena being modeled.
  - **System Simulation:** A set of techniques that use computers to imitate the operations of real-world systems through simulation. Computers are used to generate numerical models for the purpose
  - **Virtual prototype:** A model or simulation of a system placed in a synthetic environment, and used to investigate and evaluate requirements, concepts, system design, testing, production, and sustainment of the system throughout its life cycle

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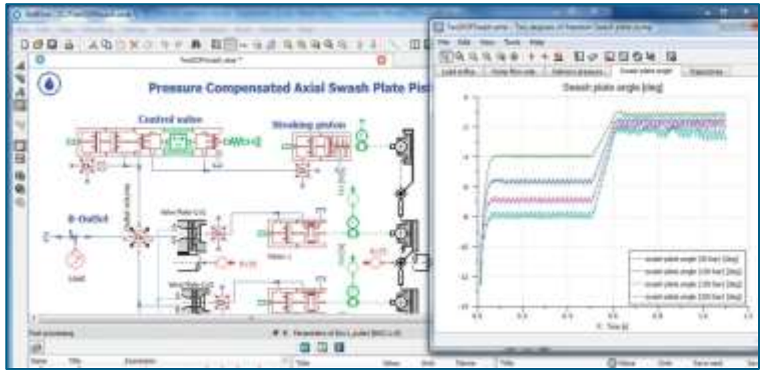

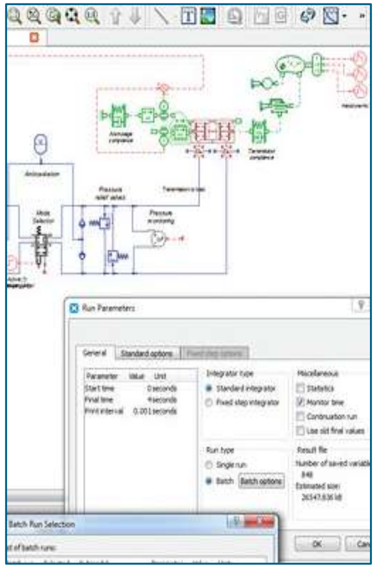

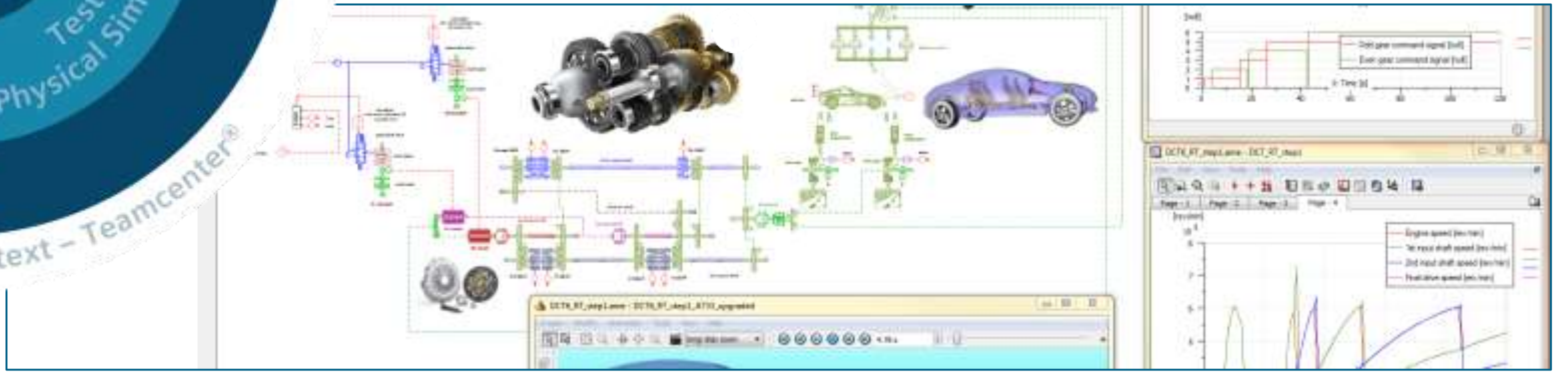

Collaboration & workflow

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Siemens Industry Software S.A.S.

Digital Factory Division

Product Lifecycle Management

Simulation & Test Solutions

DF PL STS CAE 1D

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