Multi-disciplinary simulation of Cyber-Physical Systems – The OpenCPS approach

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AZ INNOVÁCIÓ LENDÜLETE
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MEGVALÓSULÓ PROGRAM

IncQueryLabs Ltd
SAAB
ITEA 3
SHERPA ENGINEERING

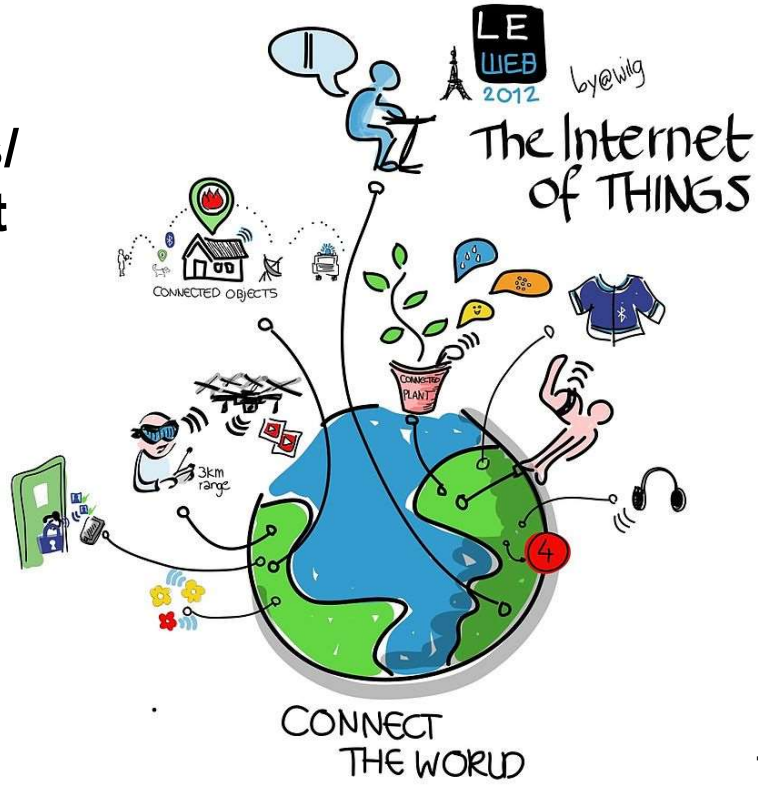
Internet of Things

Cyber-physical systems

Smart home

Digitial Industries/ Industrial Internet
- GE

CityNext
- Microsoft



Connected Society
- EU-ECSEL

Smart city, smart grid
- IBM

Industry 4.0
- German goverment

Networked Society
- Ericsson

(Global Situation Awareness)
- Saab

Perspectives of IoT

User

Applications addressing real-world / everyday problems embedded in a natural/human environment:

Well-known

- Cities, buildings, Energy grids, Healthcare, sport, etc-

"Cyber Physical Systems"

- Transportation, defence, espionage, building security, etc.

Engineer

Short Overview

NEMZETI KUTATÁSI, FEJLESZTÉSI ÉS INNOVÁCIÓS HIVATAL

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openCPS

Open Cyber-Physical System Model-Driven Certified Development

- Duration 3 years, December 2015 to December 2018

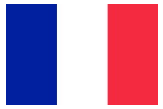
  → continues in the **EMBRACE ITEA3** project.

- 4 countries: Sweden, France, Finland, Hungary

- Current status: 46.5 person-years, 6.5 M€, 18 partners

Consortium Overview
Industrial Domains & Applications

- **Sweden**
- Equa Simulation
- Ericsson
- KTH
- Linköping University
- **Saab**
- SICS East
- **Siemens Industrial Turbomachinery**
- SKF



France
- CEA LIST
- EDF
- ESI Group
- Inria
- RTE
- **Sherpa Engineeing**
- SIREHNA

Finland
- **VTT**

openCPS

Hungary
- **IncQuery Labs**
- ELTE-Soft

Buildings & infrastructure

Communications technology

Energy & Power plants

Aeronautics

Naval

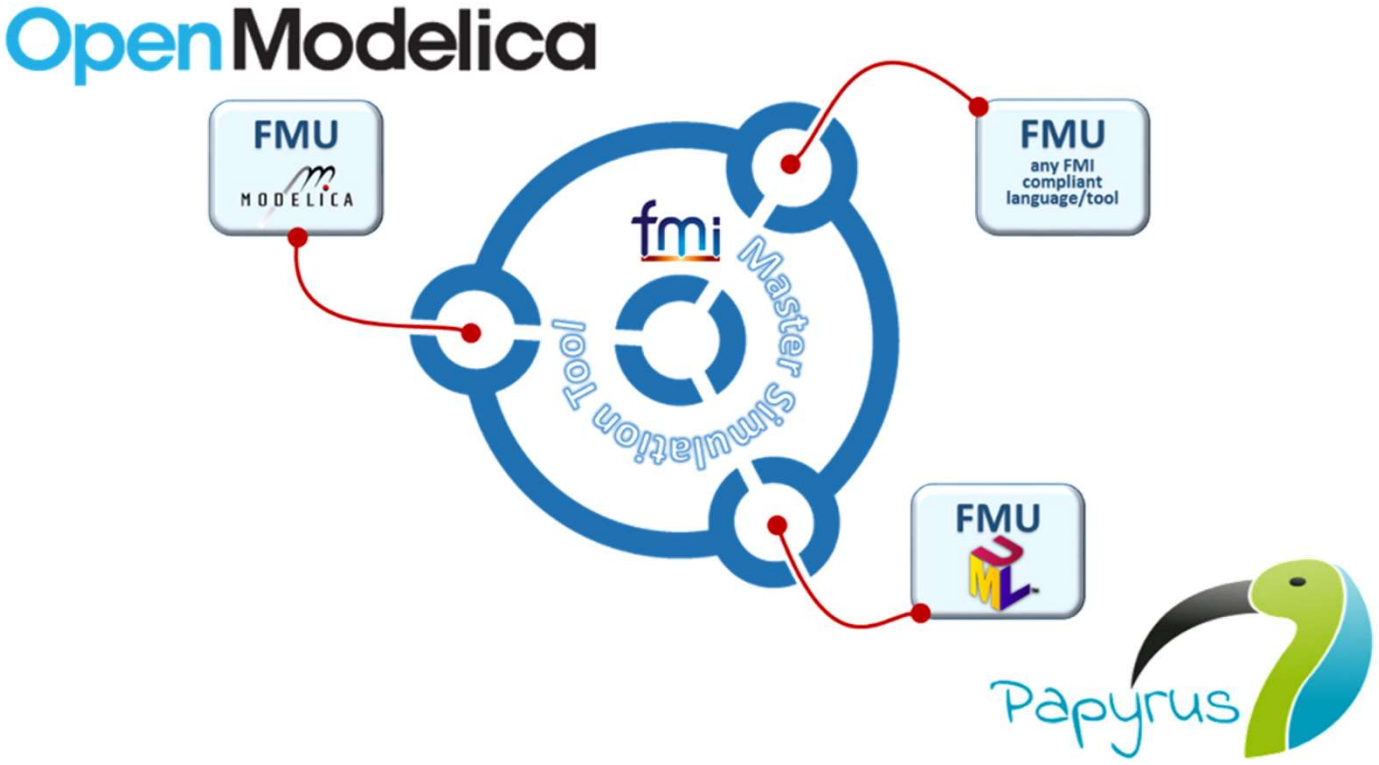
Automotive

Bearings

Red = Project Leader
Green = National Coordinator

Top 3 Key Innovation Areas
Targeted Innovations

- Validation of project results in a **wide range of advanced industrial demonstrators!**



Top 3 Key Innovation Areas
Targeted Innovations

- **FMI run-time and master simulation framework including UML/Modelica Interoperability**
  - **Scalable, reliable co-simulation** of discrete-time software parts with continuous-time physical processes, designed for **handling large numbers of events**
  - **Integration of the UML and Modelica domains** utilizing the FMI standard
  - Open source **FMI Master Simulation Tool**
- **State Machine and Real-Time Debugging & Validation**
  - Industry-strength support for **advanced state-machine modeling and debugging**
  - Several levels: limited debugging of connected black-box FMUs, full debugging capabilities for components for which the model source code is available
- **Efficient Multi-Core Simulation**
  - Improved compilation and simulation capabilities for **large models**
  - Several levels: coarse-grained, **running whole simulations and/or FMUs in parallel**, to more fine-grained by **parallelization of equation models and algorithmic code** inside model components

Background:
Functional Mockup Interface

- FMI (Functional Mockup Interface)
  - Emerging standard for multi-domain simulation
    - https://fmi-standard.org/
    - Encapsulation of component level information
      FMU (Functional Mockup Unit)
  - Enables multiple compliant modeling and simulation tools to interoperate
    - **Co- simulation**: encapsulation of simulation models and simulators into black-box components
    - **Model-exchange**: black box simulation model with API for external simulator
  - Particularly interesting for designing CPS (Cyber Physical Systems)
    - Heterogeneous systems → different skills and paradigms → specific modeling and simulation tools. (Modelica, Simulink, Dymola, etc.)
    - Lack of apparatus for large-scale simulation design

Background:
System Structure and Parameterization of Components (SSP)

- Definition of large scale simulation scenarios
  - Extending the FMI standard
    - Encapsulates system level information: defining complex simulation scenarios
    - https://github.com/modelica/ssp-standard-dev
  - Standardized (SSD- XML)
    - Simulation design and connection definition
    - Simulation parameter definition
    - Harmonization with corresponding OMG and ASAM standards
  - Supporting all stages of development process (architecture definition, integration, simulation, test in MiL, SiL, HiL).

Industrial demonstrators

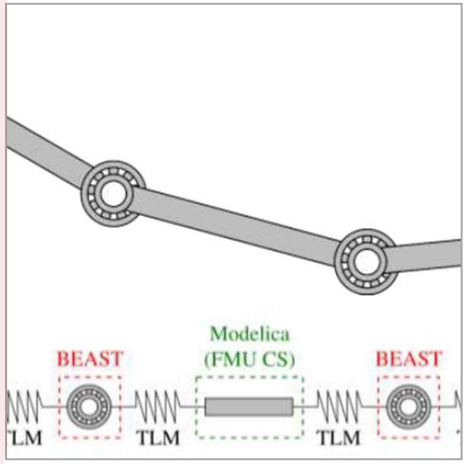
Building

EQUA

Aeronautics

Saab AB, LIU

Mechanics

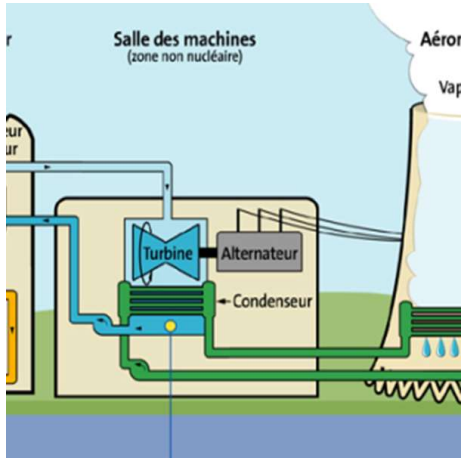


SKF, LIU

Naval

Sirehna

Power plant



EDF, LIU

Gaz turbines

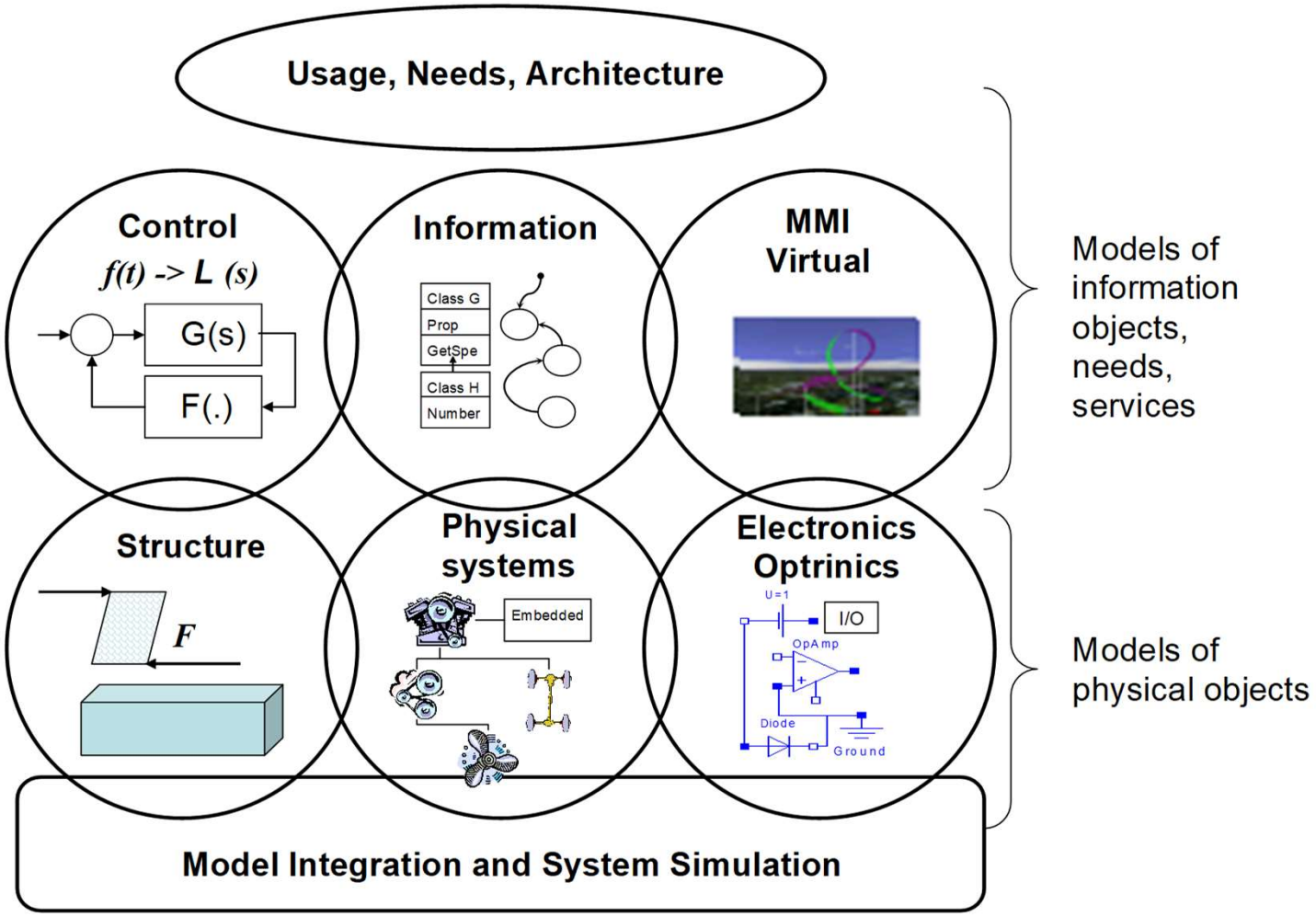
Siemens TU, KTH, VTT

Automotive

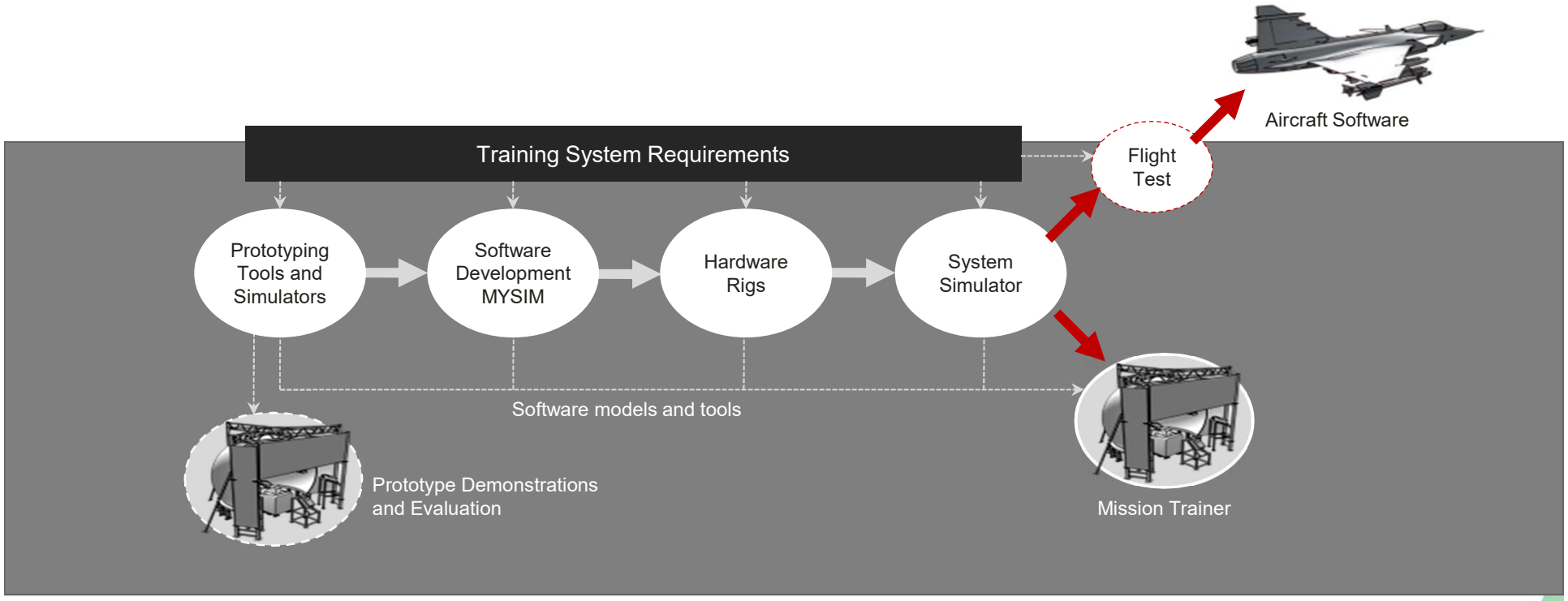
Sherpa, CEA

Industrial Use Case
Saab Aeronautics

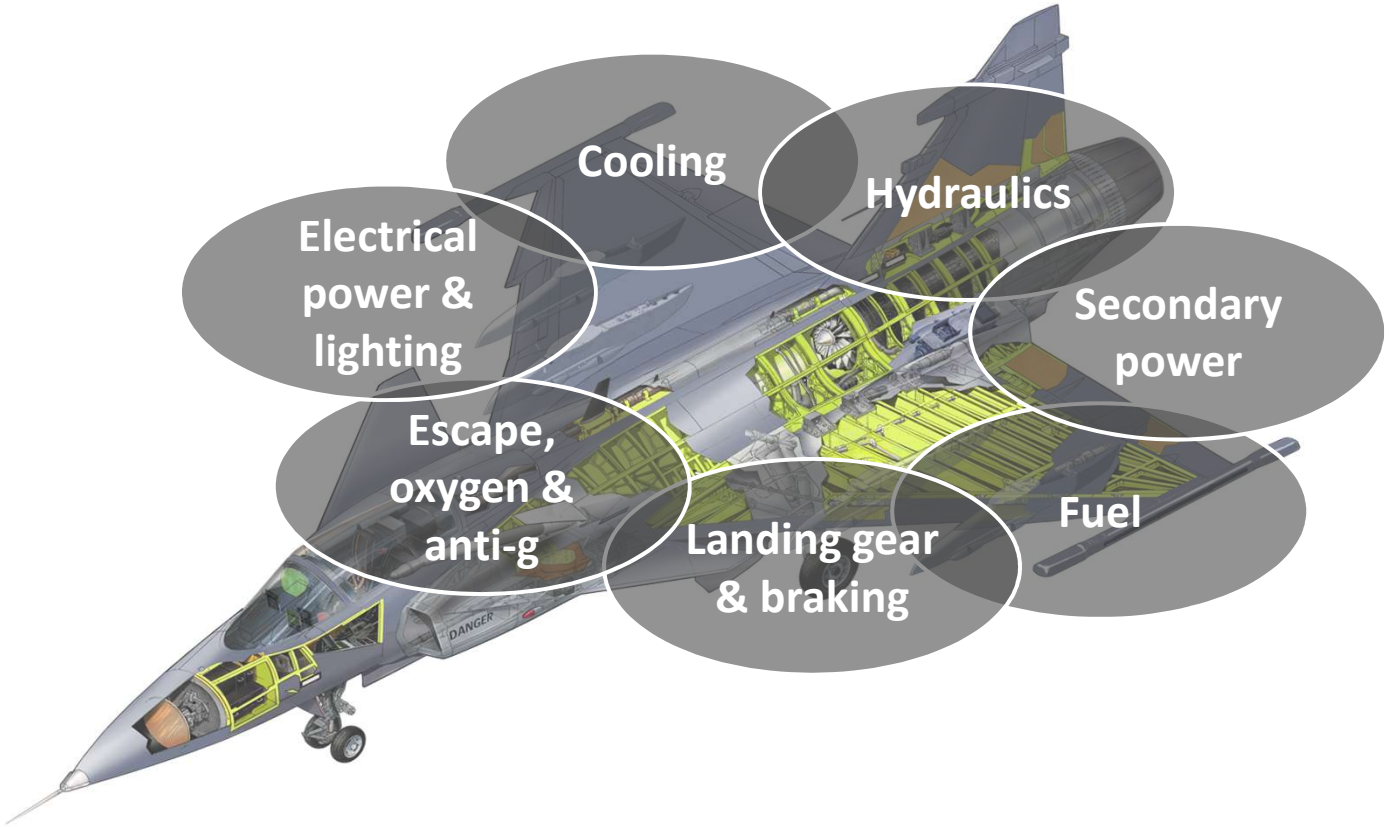
MODELING DOMAINS



MODEL integration and system simulation



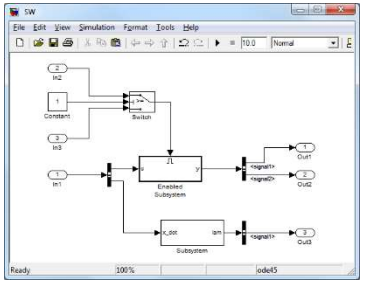
Industrial Use Case
Saab Aeronautics



Flight mechanics | Avionics | Vehicle systems | Engine | Sensors

Industrial Exploitation & Business Impact

Industrial use case

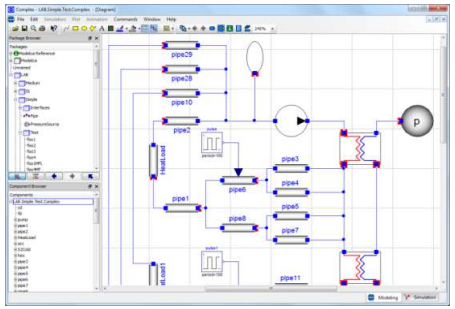


Model of S/W

Test rigs & simulators

Flight test

1 *H/W specification & development*
S/W specification & development
Early detection of design errors



Model of physical system

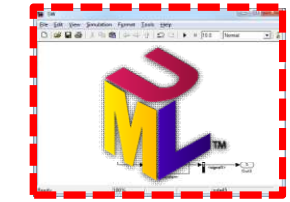
2 3

Calibration and validation of models
Minor updates of system design

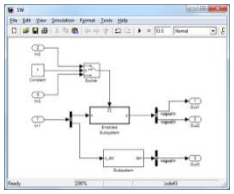
16

Industrial Exploitation & Business Impact

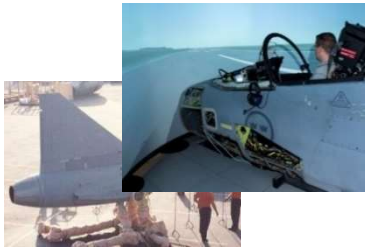
Industrial use case



Model of S/W



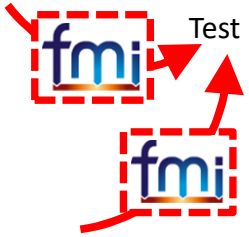
Model of S/W

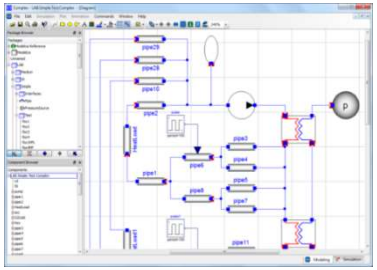


Test rigs & simulators

Flight test

1





Model of physical system

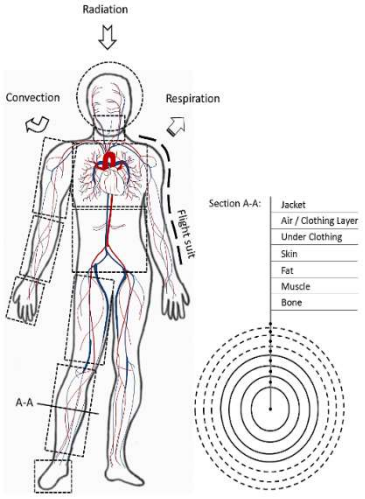
2

3

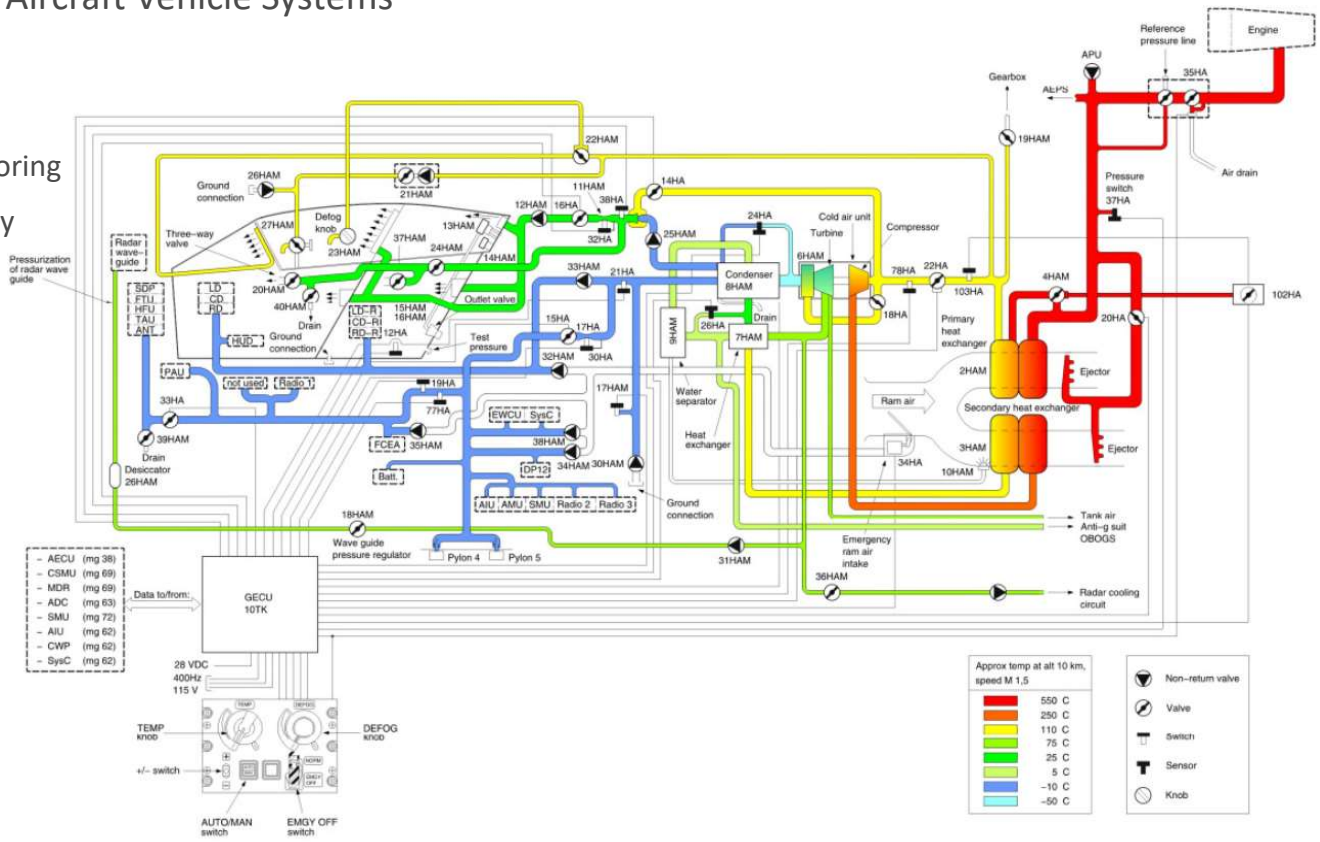
Calibration and validation of models
Minor updates of system design

Industrial Use Case
Saab Aeronautics

- FMI-based co-simulation of Aircraft Vehicle Systems
  - Models of physical systems
  - Models of control software
  - Models of functional monitoring
  - Models of human physiology

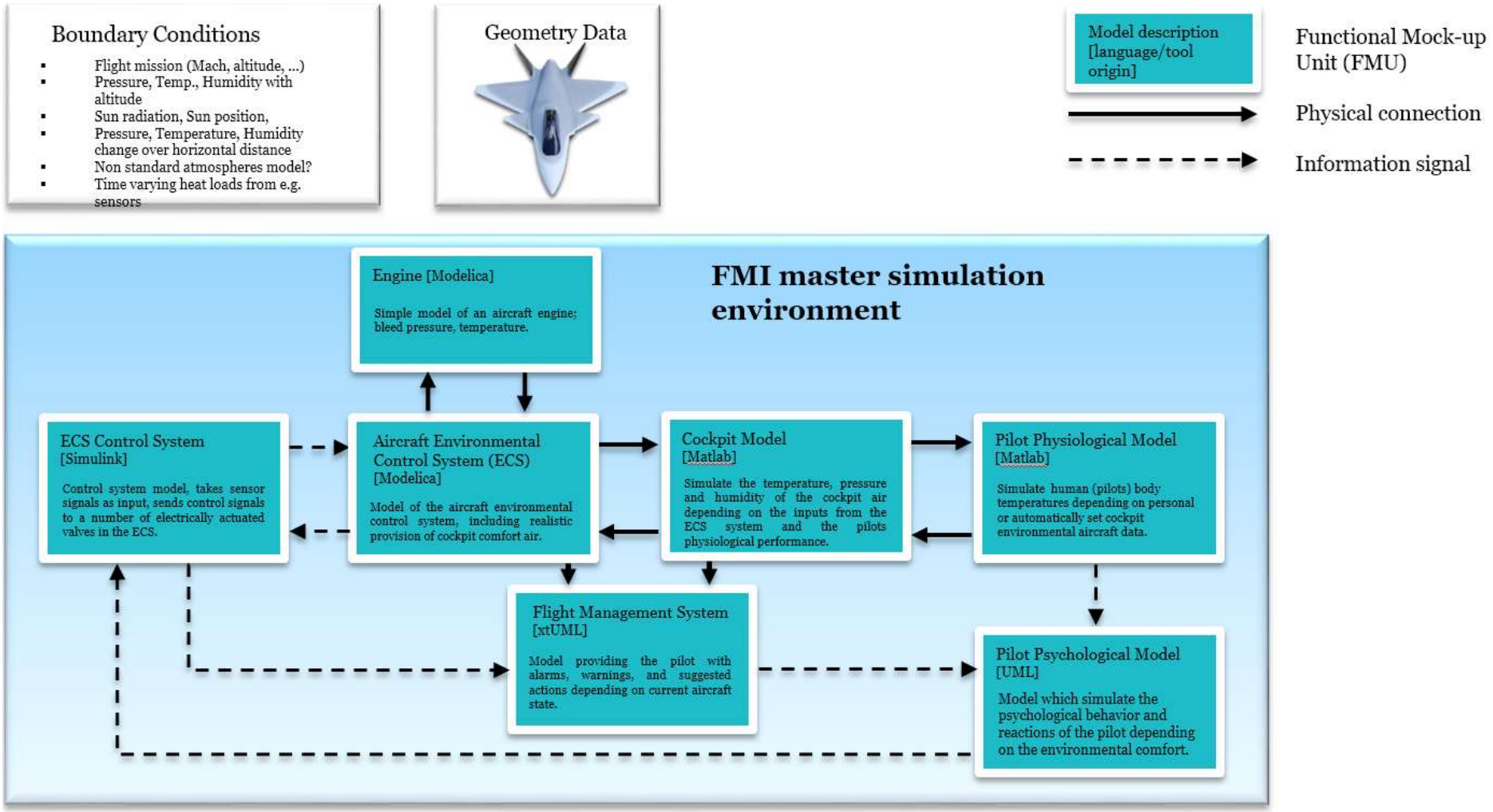


Thermal model of human



System schematics of an aircraft Environmental Control System (ECS)

Industrial Use Case
Saab Aeronautics



Industrial demonstrators

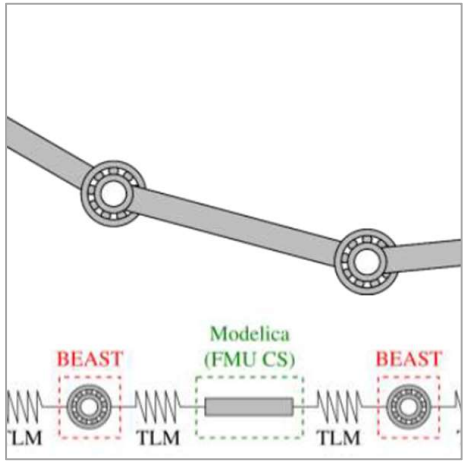
Building

EQUA

Aeronautics

Saab AB, LIU

Mechanics

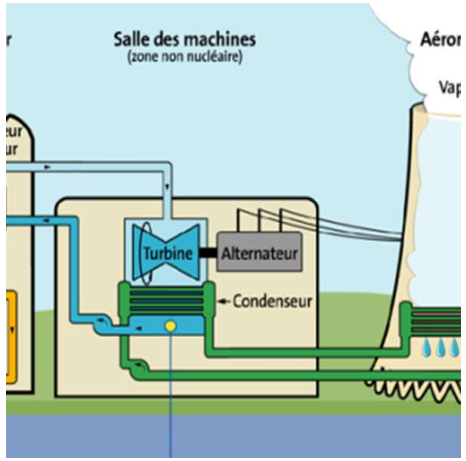


SKF, LIU

Naval

Sirehna

Power plant



EDF, LIU

Gaz turbines

Siemens TU, KTH, VTT

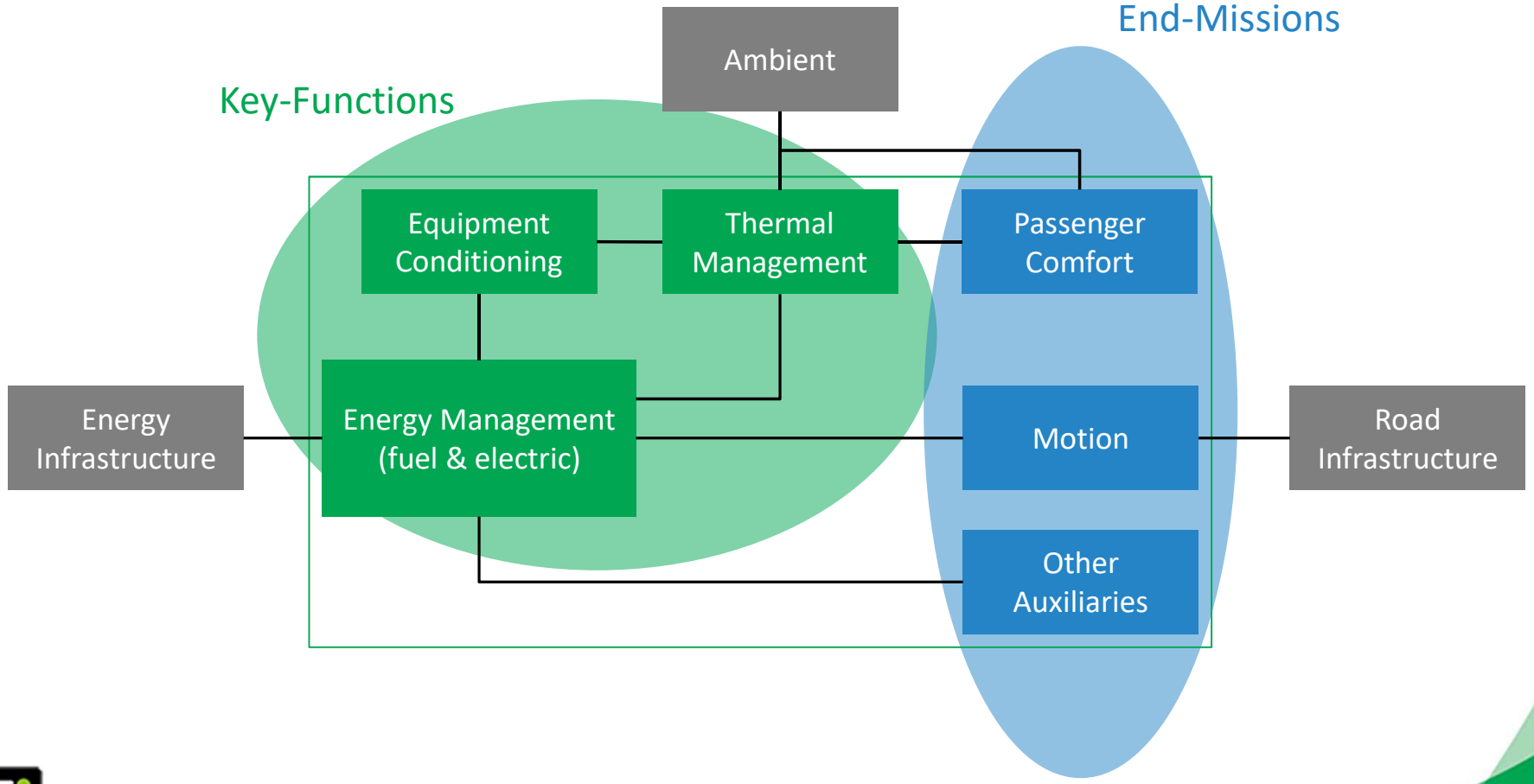
Automotive

Sherpa, CEA

Industrial Use Case
Sherpa Engineering

T6.5- Automotive demonstrator
Energy and resource optimization

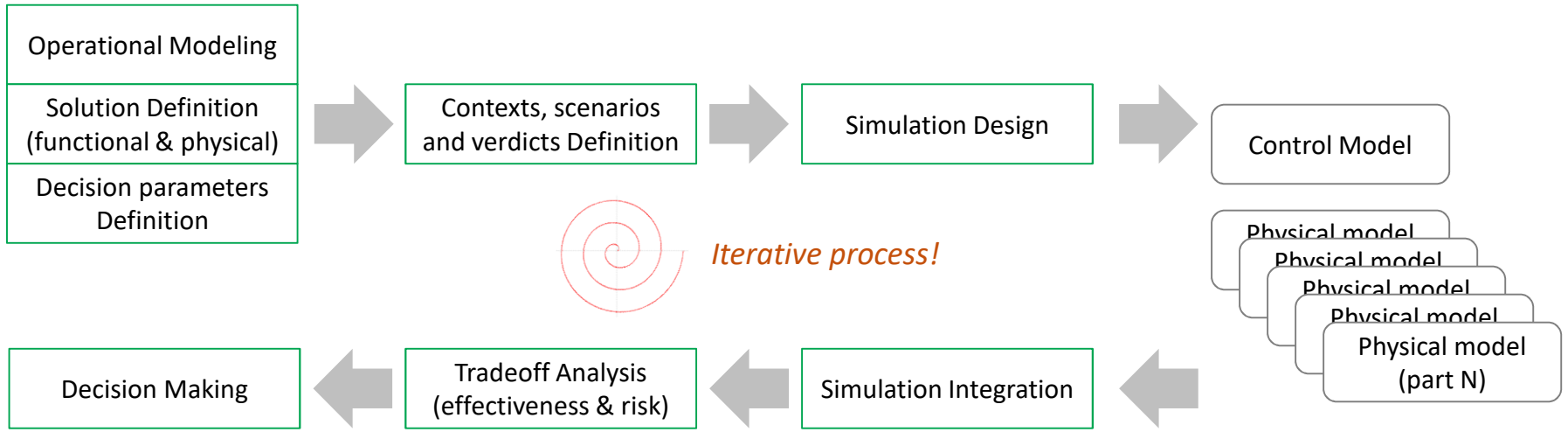
Plug-in Hybrid Electric Vehicle (PHEV)



Energy and resource optimization

Processes for System Design and Analysis

System Design	System Analysis	Simulation model development	Business models development



Decision representation
- Decision parameters shall be defined and calculated
- Property calculation using simulation results!

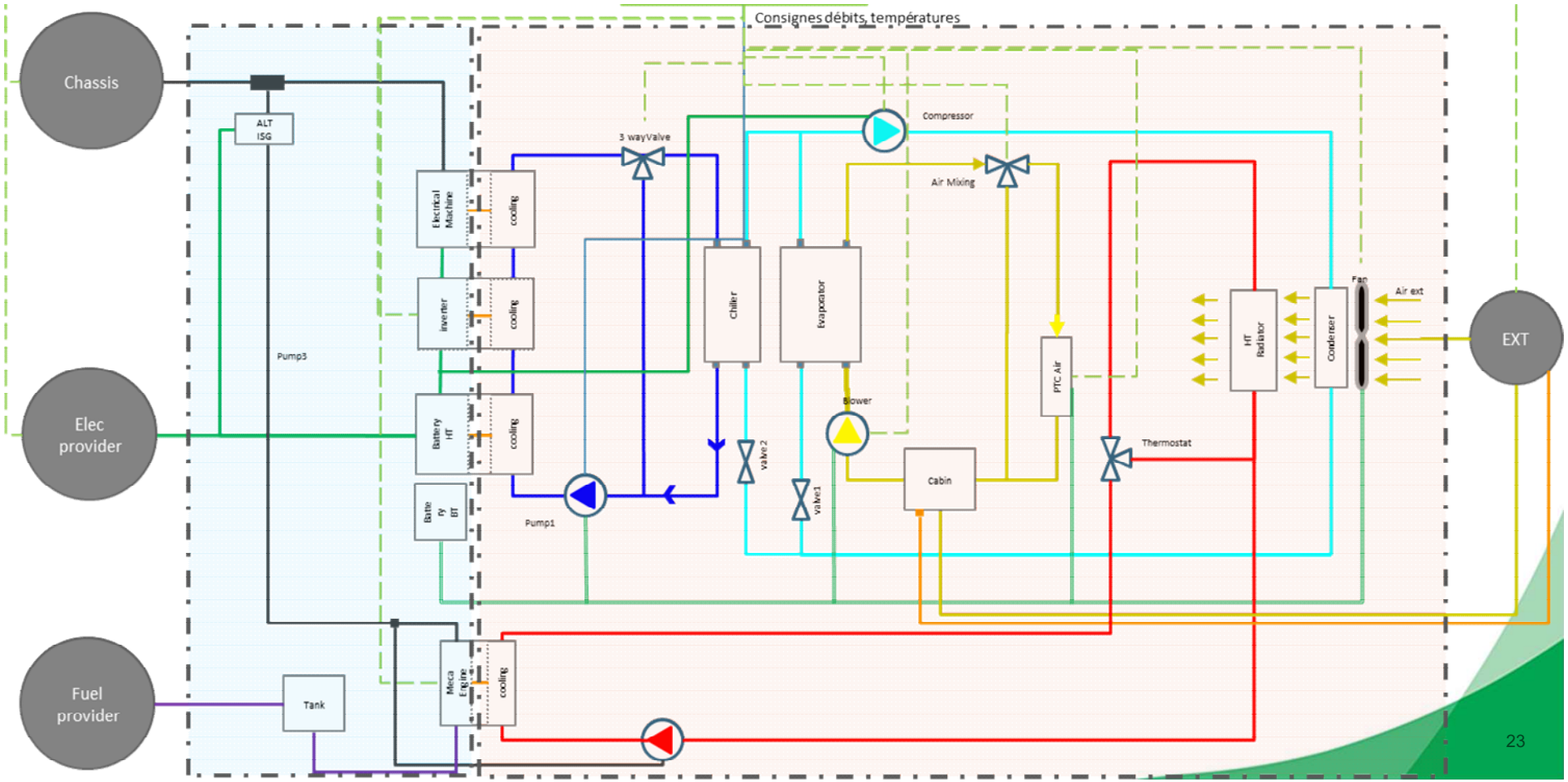
Tradeoff analysis requires a wide number of simulations
- Batch process
- Recording, logging …

Integration in a unique simulation environment
- FMI-FMU is a relevant standard
- Need for co-simulation capabilities

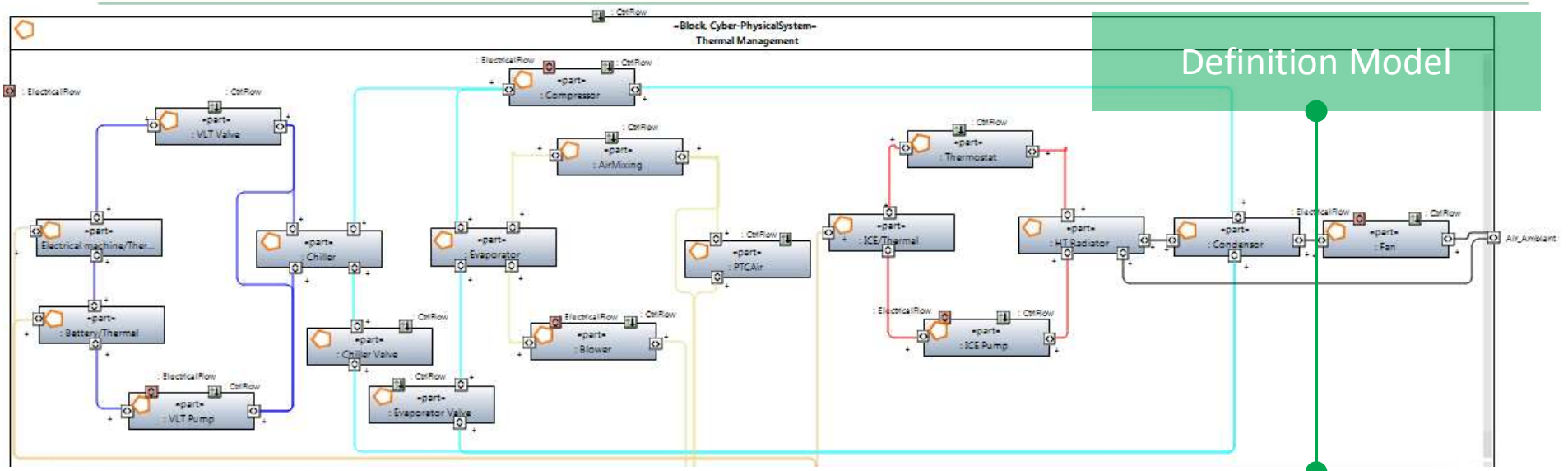
Several modeling environment
- SysML
- OpenModelica, Dymola
- Matlab-Simulink
- AMESim
- …

Thermal management modelling

Modelling and control of the thermal part of the vehicle
Equipment conditioning (battery, e-machine, engine) + Cabin comfort + Management

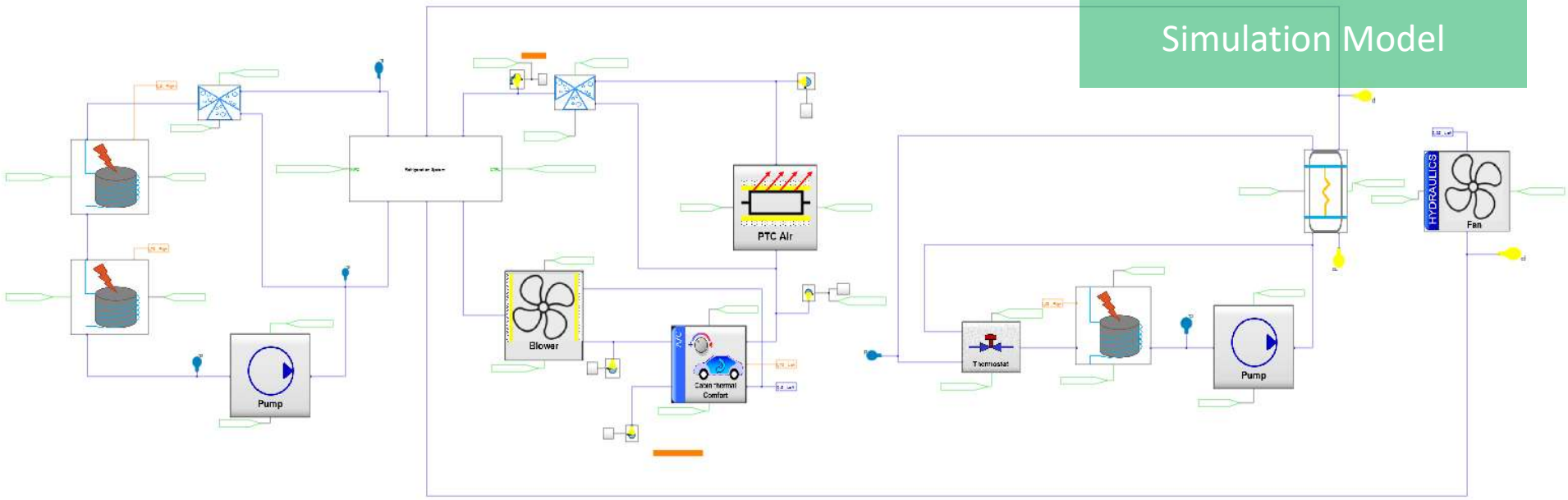


Thermal management modelling

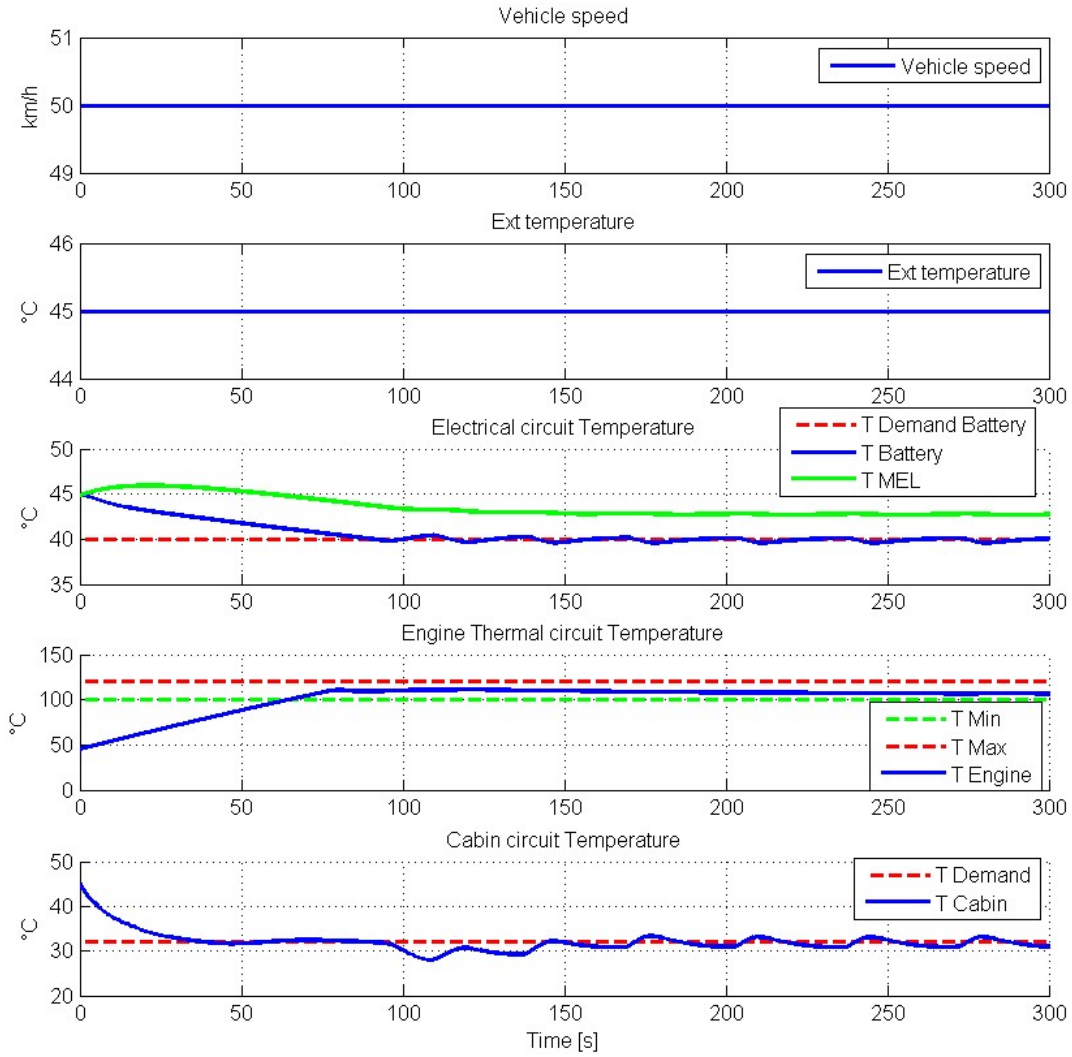


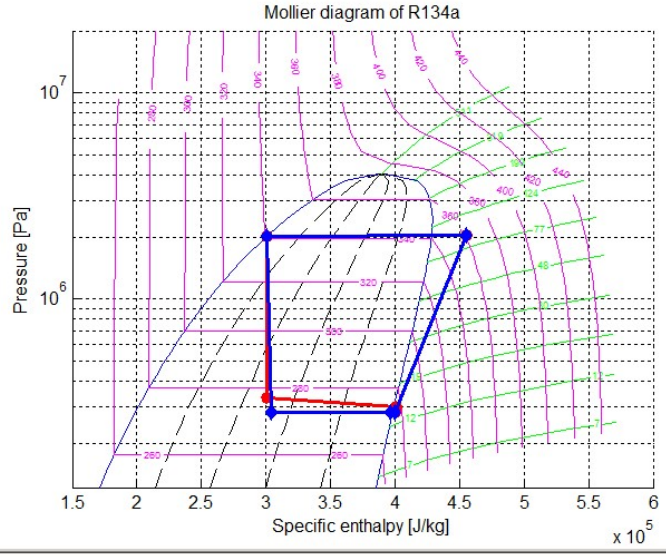
Definition Model

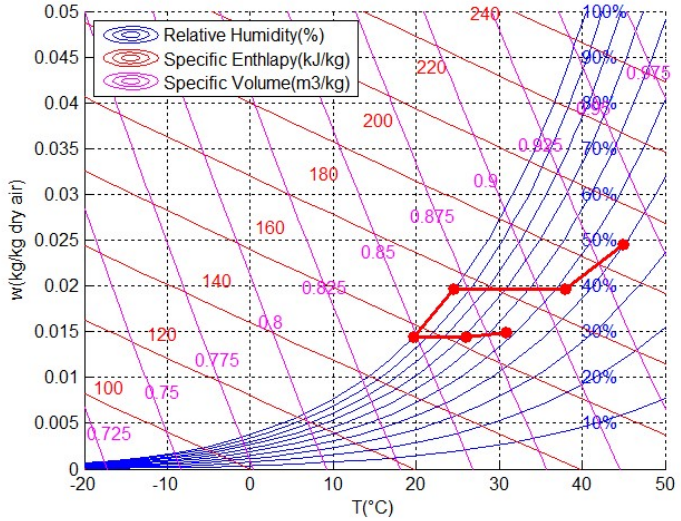
Simulation Model



Thermal management: simulation results







Conclusion

openCPS

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SAAB

Current Status of OpenCPS

- Industry grade benchmark models developed
- Supporting both early and later phase simulation scenarios based on FMI integration
- Prototype implementations for real-time synchronization and clocked synchronous library
- Development/adaptation of the distributed TLM (Transmission Line Method) simulation algorithms

For more details:

https://opencps.eu/

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