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

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openCPS

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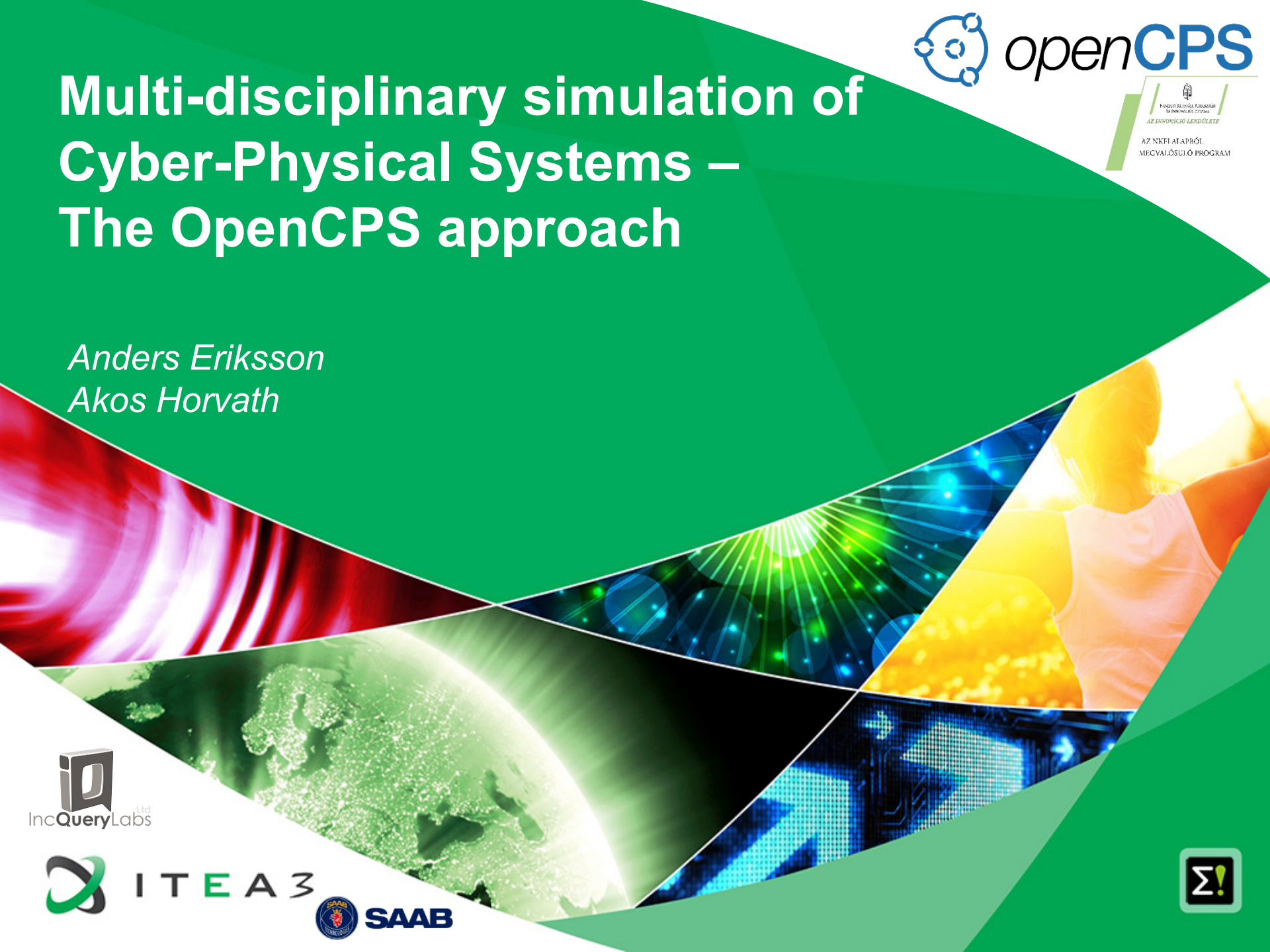

IncQueryLabs Ltd

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SAAB

Short Overview

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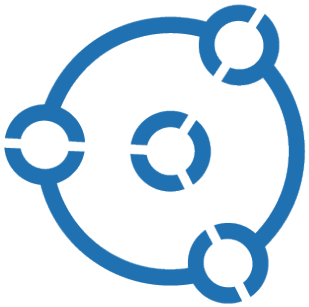

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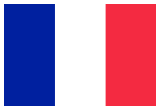
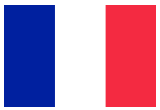
Open Cyber-Physical System Model-Driven Certified Development

- Duration 3 years, December 2015 to December 2018
- 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**

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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

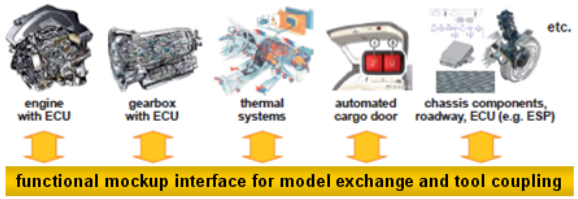
- **FMI run-time and master simulation framework including UML/Modelica Interoperability**
  - **Scalable, reliable co-simulation** of discrete-time software parts with continuous-time physical processes, designed for **handling large numbers of events**
  - **Integration of the UML and Modelica domains** 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

Top 3 Key Innovation Areas
Targeted Innovations

- **FMI run-time and master simulation framework including UML/Modelica Interoperability**
  - **Scalable, reliable co-simulation**
  - **Integration of the UML and Modelica domains** utilizing the FMI standard
  - Open source **FMI Master Simulation Tool**
- **Efficient support for V&V and certification activities**
  - **End-to-end traceability support.**
  - **Slim-down code generation support**
- **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

Standards interoperability

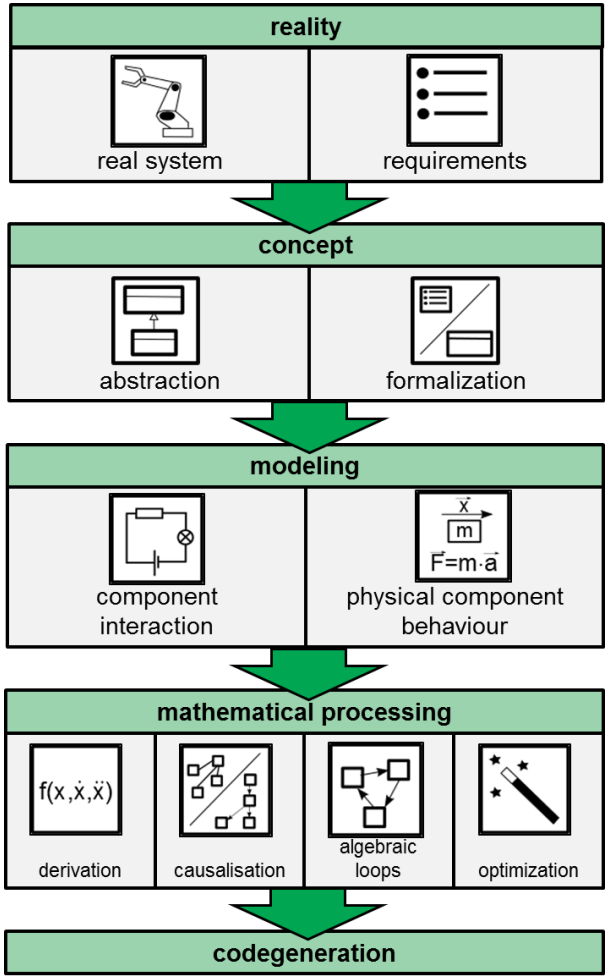
- In current industrial practice, Modelica and UML are two separate domains
- Advanced domain specific tools vs. general multi-purpose tools
- Interoperability of Modelica and UML via FMI enables simulation of a larger part of the total system functionality



Efficient model integration and simulation

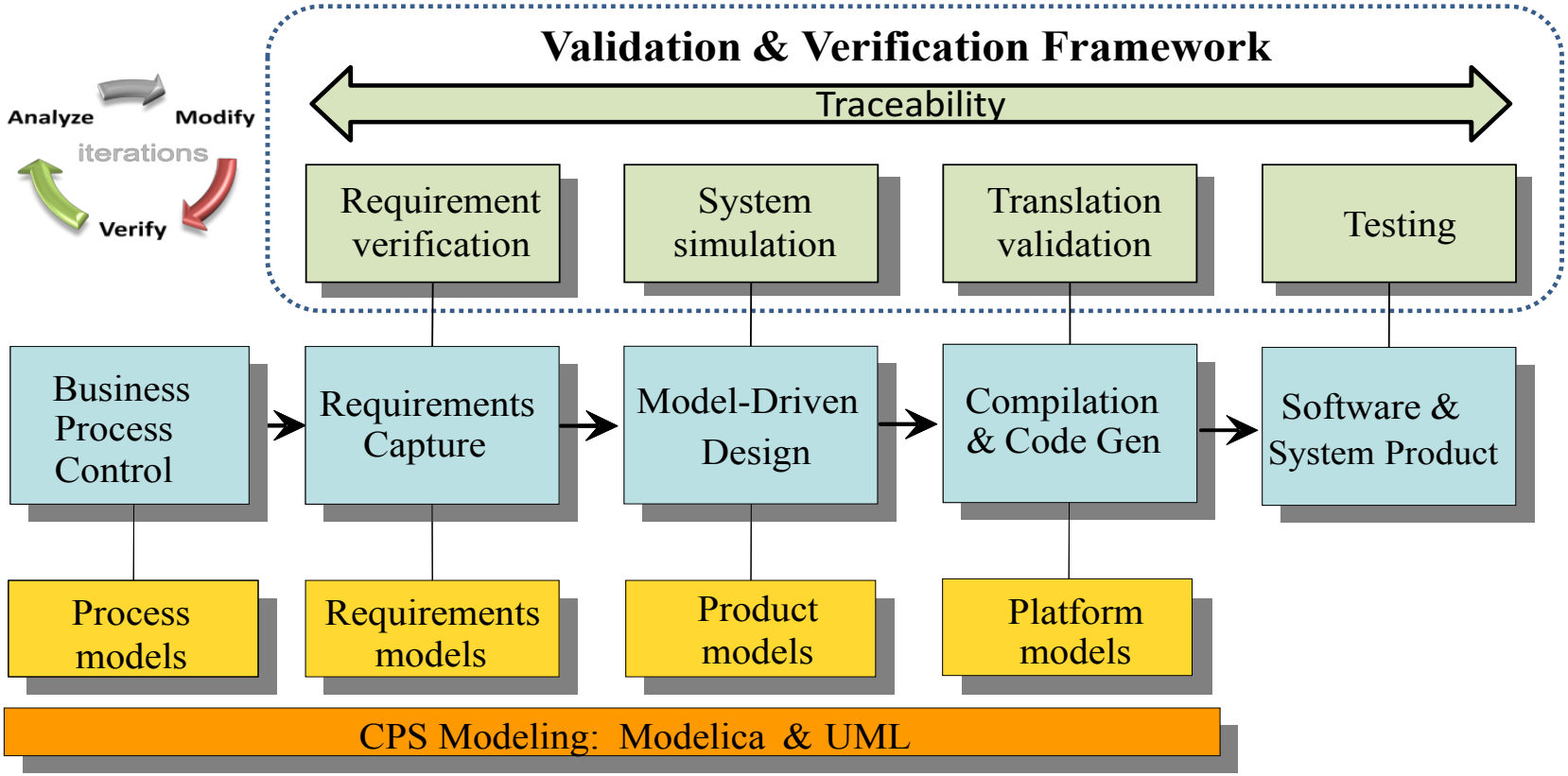
- Conflicting requirements: physical fidelity vs. real-time performance. Critical to increase simulation speed.
- Great industrial need of an advanced open source tool for import, connection, and efficient co-simulation of Functional Mock-up Units (FMUs). Focus for industrial applicability:
  - *Efficiency*: Utilize multi-core technology based on the Transmission Line Method (TLM)
  - *Robustness*: Allow tailored solver settings for each FMU, handling of problems related to scheduling, stiffness, instability, etc.
  - *Scalability*: Designed for use in development of large-scale and complex cyber-physical systems

Certified translation & validation



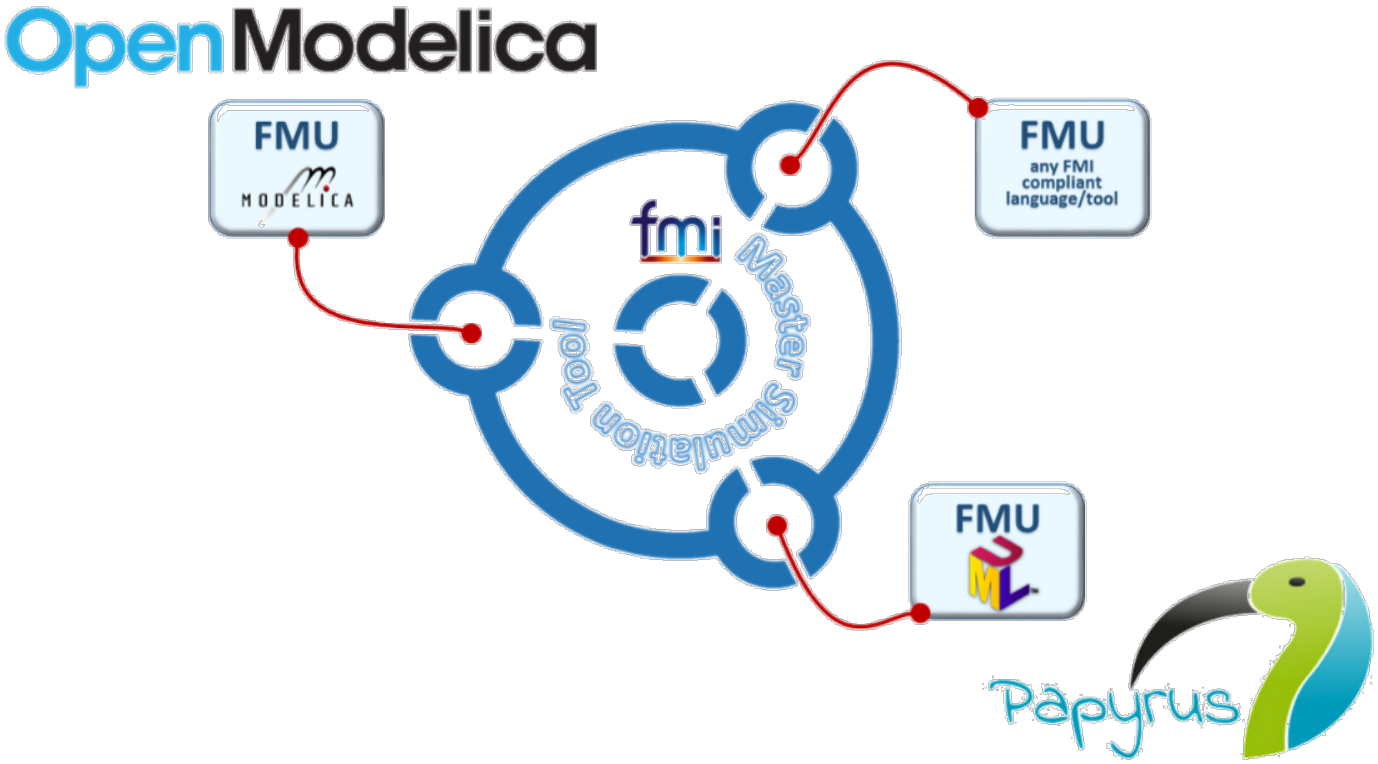
- Code that runs on a controller has to fulfill functional safety terms (IEC 61508, ISO 26262, DO 178…)
- Going from high level representation to generated code is a complex process
- Currently: transitions rely on many proprietary tools and manual transformation
- Code generated from Modelica-models cannot currently be run on a controller (manual review necessary)

Validation and verification, debugging, traceability



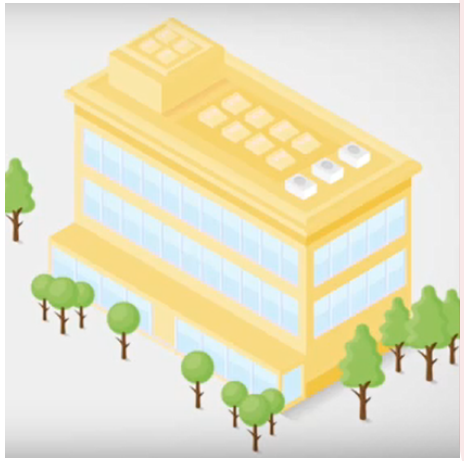
Top 3 Key Innovation Areas
Technical Innovations

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



Industrial demonstrators

Building

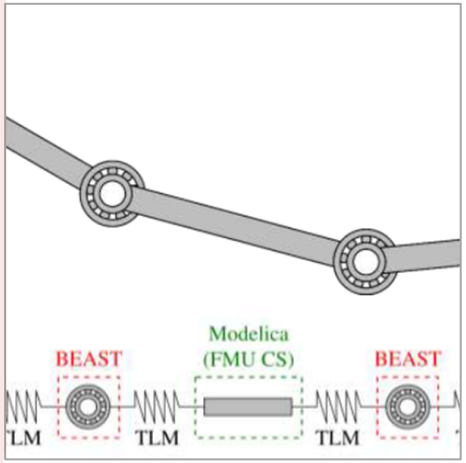


EQUA

Aeronautics

Saab AB, LIU

Mechanics

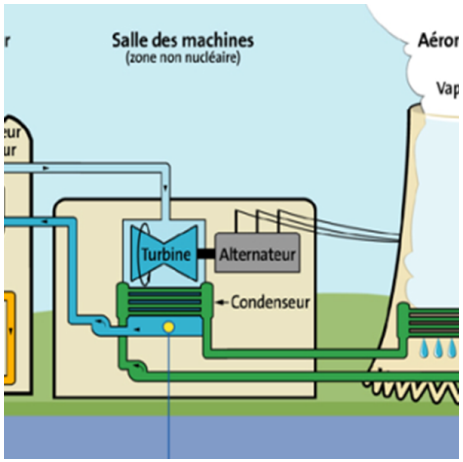


SKF, LIU

Naval

Sirehna

Power plant



EDF, LIU

Gaz turbines

Siemens TU, KTH, VTT

Automotive

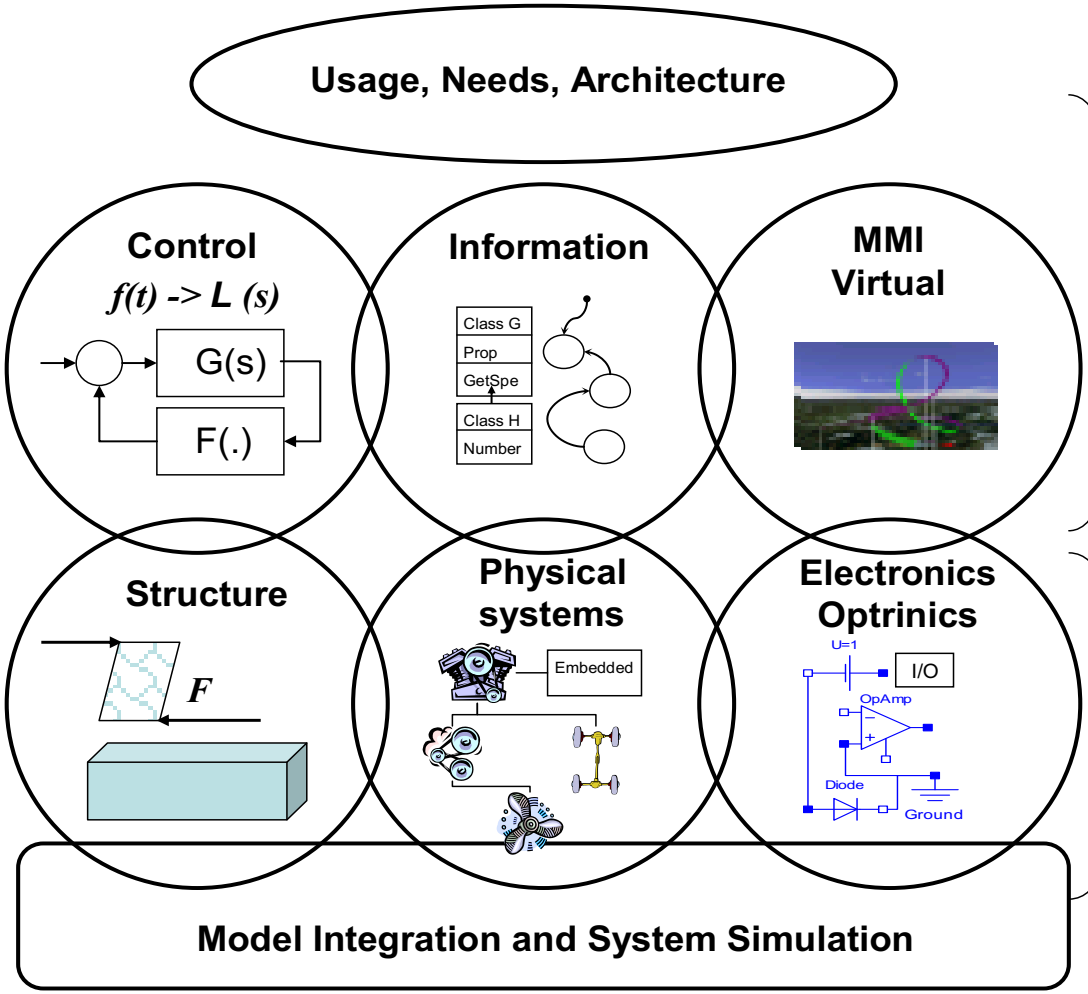
Sherpa, CEA

Industrial Use Case
Saab Aeronautics

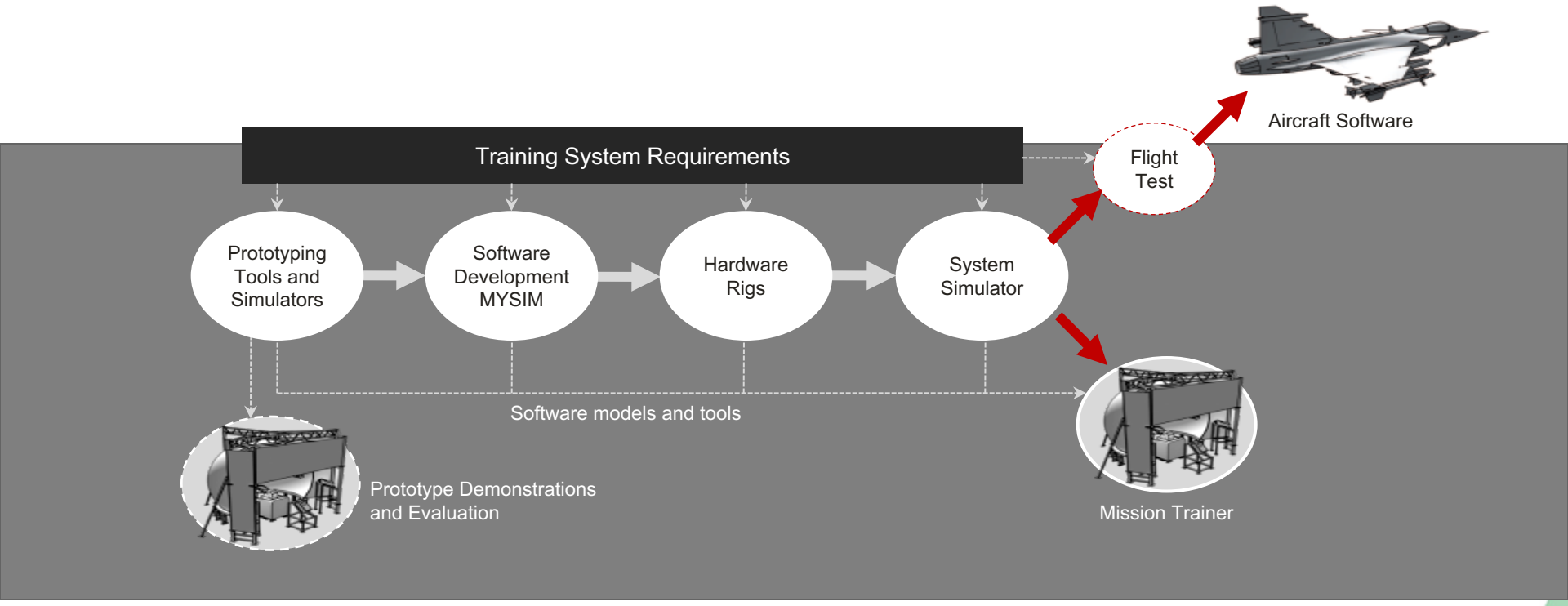
IN 1937 WE TOOK OFF

- A history from the 17th century through Alfred Nobel (Bofors) and the shipyard in Karlskrona (Kockums)
- In 1937, Saab was founded to protect Sweden's borders and its people
- Born smart – as a small country, we were forced to arm ourselves with good and cost-effective equipment
- On our journey we created Sweden's computer, missile and space industries

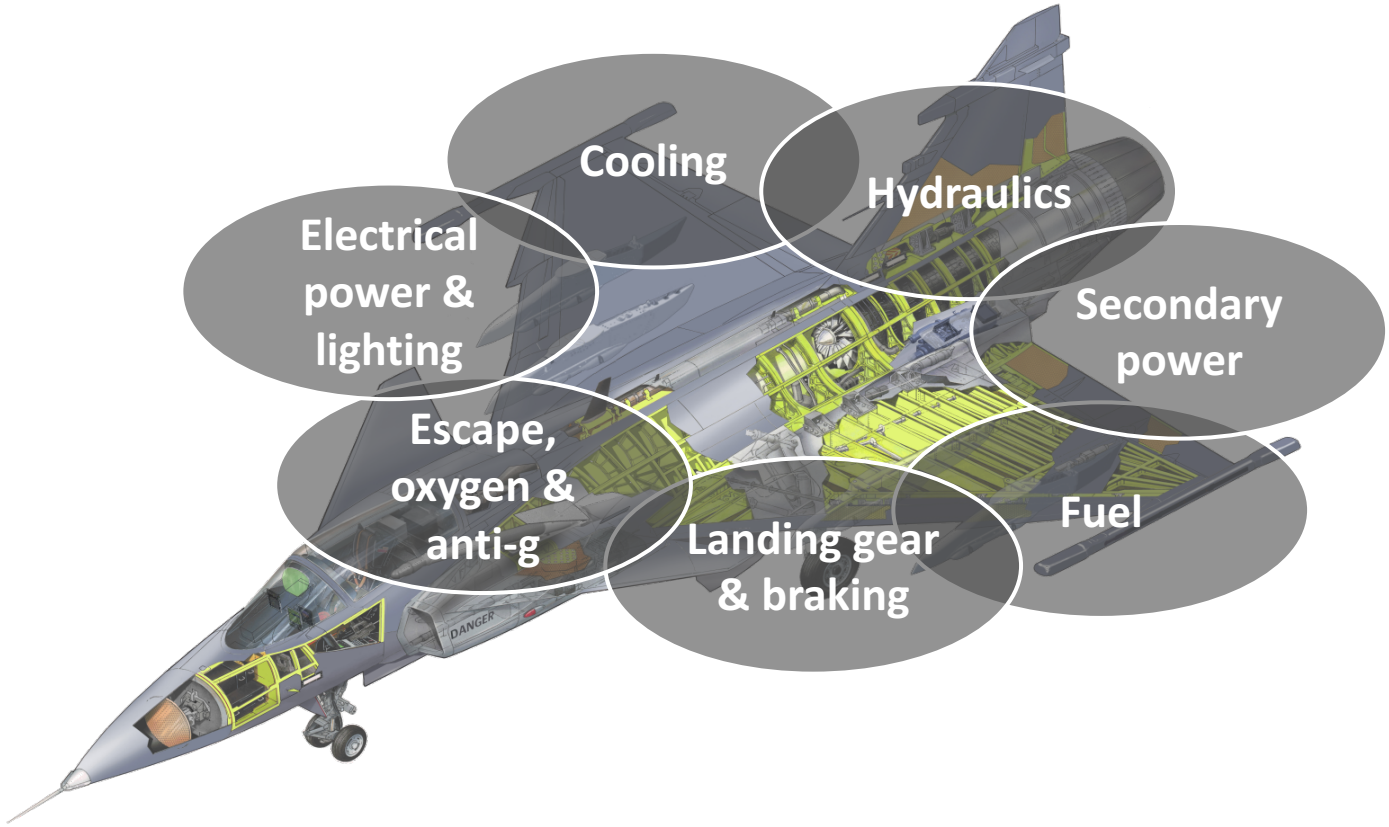
MODELING DOMAINS



MODEL integration and system simulation



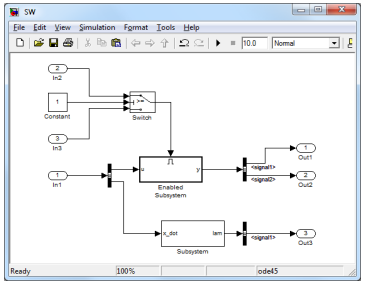
Industrial Use Case
Saab Aeronautics



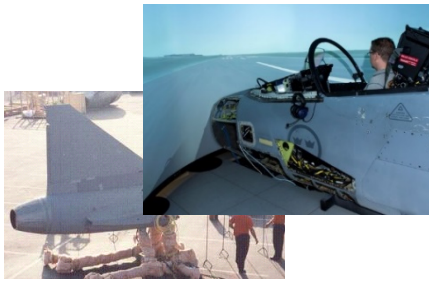
Flight mechanics | Avionics | Vehicle systems | Engine | Sensors

Industrial Exploitation & Business Impact

Industrial use case



Model of S/W

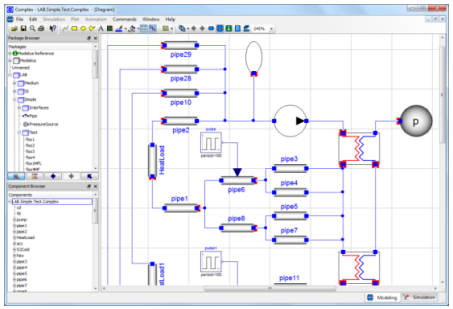


Test rigs & simulators

Flight test

1

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



Model of physical system

2

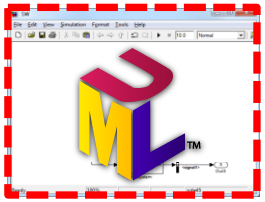
3

Calibration and validation of models
Minor updates of system design

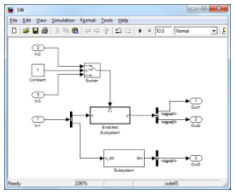
18

Industrial Exploitation & Business Impact

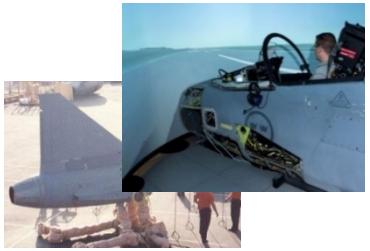
Industrial use case



Model of S/W



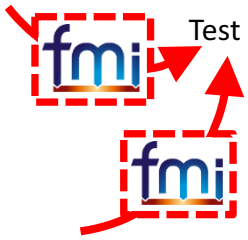
Model of S/W

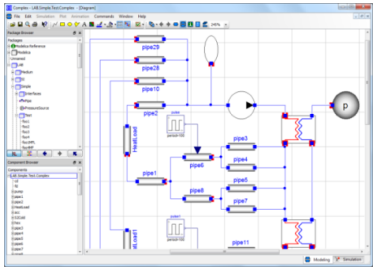


Test rigs & simulators

Flight test

1





Model of physical system

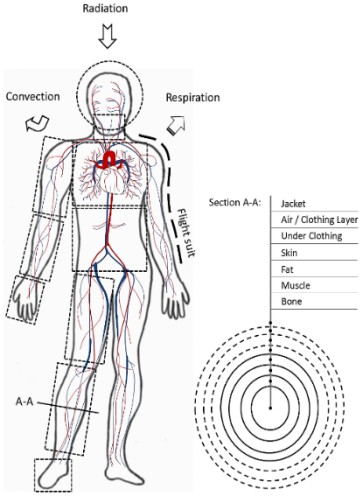
2

3

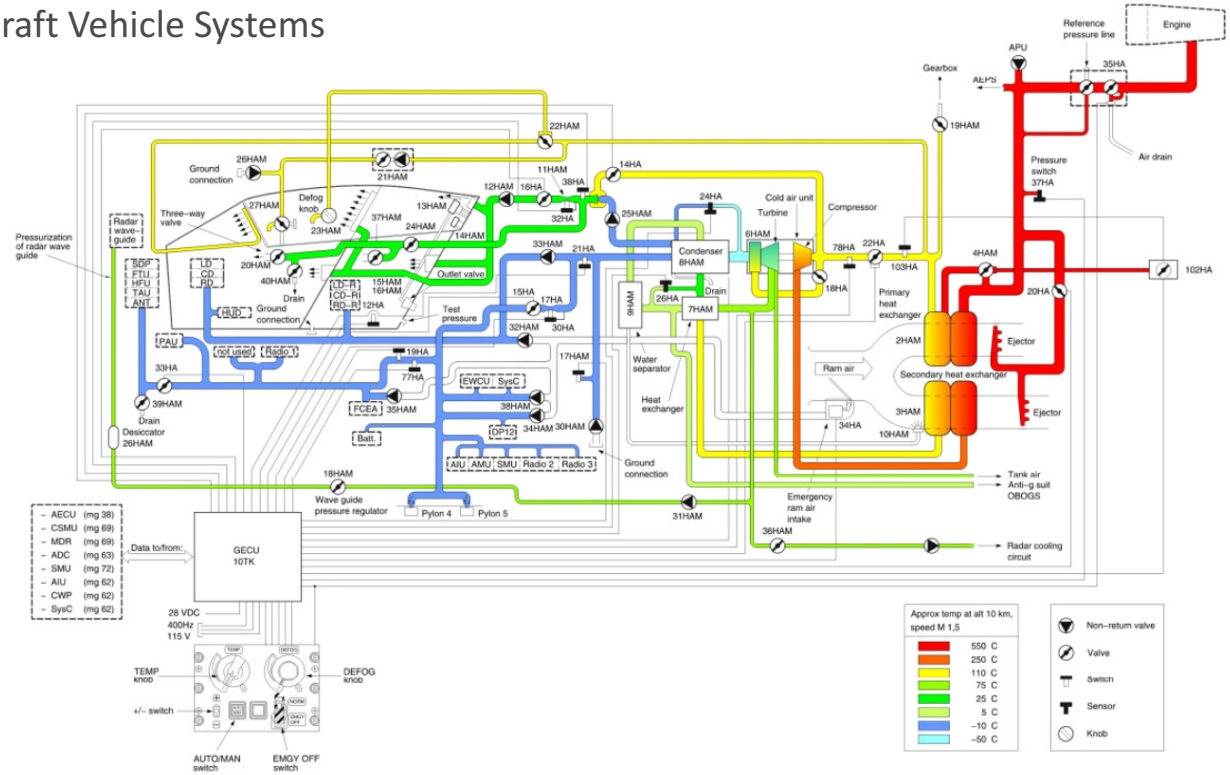
Calibration and validation of models
Minor updates of system design

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

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Boundary Conditions

- Flight mission (Mach, altitude, ...)
- Pressure, Temp., Humidity with altitude
- Sun radiation, Sun position,
- Pressure, Temperature, Humidity change over horizontal distance
- Non standard atmospheres model?
- Time varying heat loads from e.g. sensors

Geometry Data

Model description [language/tool origin]

Functional Mock-up Unit (FMU)

Physical connection

Information signal

FMI master simulation environment

Engine [Modelica]
Simple model of an aircraft engine; bleed pressure, temperature.

ECS Control System [Simulink]
Control system model, takes sensor signals as input, sends control signals to a number of electrically actuated valves in the ECS.

Aircraft Environmental Control System (ECS) [Modelica]
Model of the aircraft environmental control system, including realistic provision of cockpit comfort air.

Cockpit Model [Matlab]
Simulate the temperature, pressure and humidity of the cockpit air depending on the inputs from the ECS system and the pilots physiological performance.

Pilot Physiological Model [Matlab]
Simulate human (pilots) body temperatures depending on personal or automatically set cockpit environmental aircraft data.

Flight Management System [xtUML]
Model providing the pilot with alarms, warnings, and suggested actions depending on current aircraft state.

Pilot Psychological Model [UML]
Model which simulate the psychological behavior and reactions of the pilot depending on the environmental comfort.

Industrial Use Case
Saab Aeronautics

- More efficient processes for **model export & integration** supporting continuous model validation and improvement
  - Early validation of system safety and security
  - Supporting large-scale system simulator development

- Model based development has shown to increase the system knowledge and **errors are found in an earlier stage**
  - Simulation of system including both continuous and discrete event models

- **Modelling as a means for communication** has a great potential for development of complex systems
  - Both internally and externally with partners and subcontractors

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Conclusion

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Current Status of OpenCPS

- Industry grade benchmark models developed
- First prototype of run-time integrating FMI and UML
- Prototype implementations for real-time synchronization and clocked synchronous library
- Extensive testing/development of the Transmission Line Method (TLM) connection to Modelica tools
- Prototyping method for simulation of connected and mutually dependent FMUs

For more details:

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https://opencps.eu/

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