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Establishing Interoperability in Aircraft System Simulator Development

Robert Hällqvist, Magnus Eek, Petter Krus

Agenda

- Background and Introduction
  - M&S of Aircraft vehicle systems at Saab
  - Compact and Efficient Platform
  - OpenCPS
  - Aim and Stipulated Impact
- Enablers
  - FMI, SSP, TLM
  - OMSimulator
- Development and Evaluation Use-Case
  - Description
  - Architecture
  - Tool interoperability
  - Automated flight test evaluation & model validation
- Results and Conclusions

ITEA 3
EUREKA
innovation across borders

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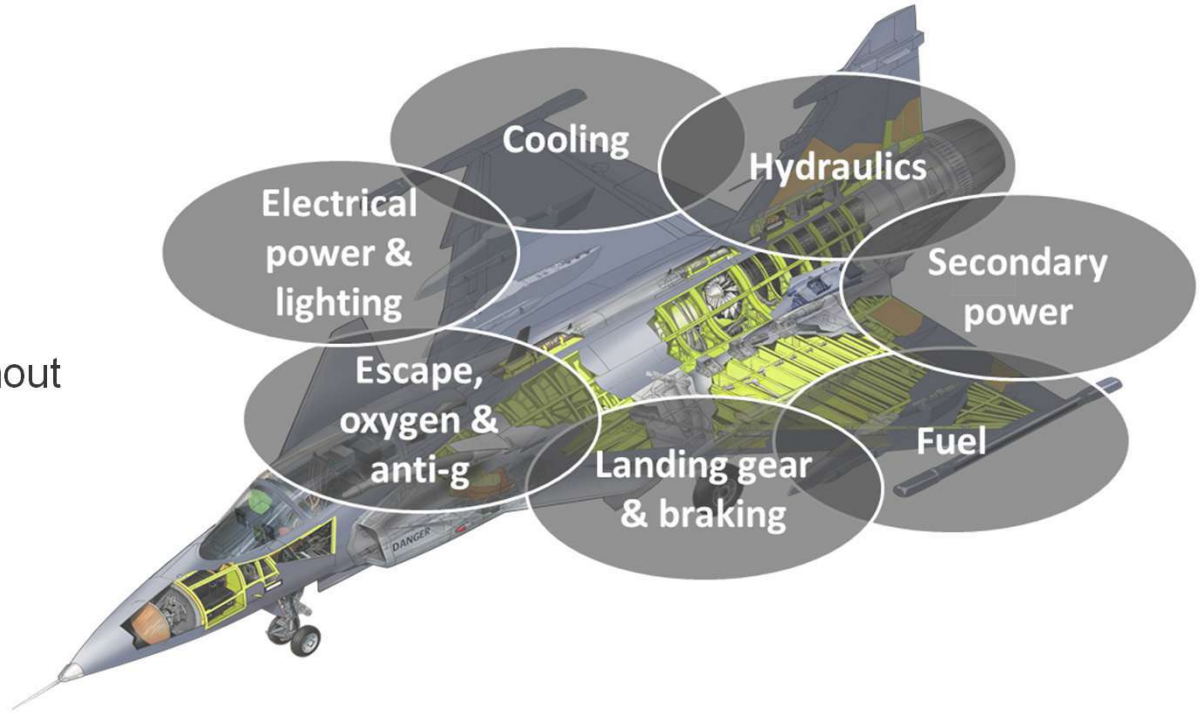
Background and Introduction

- Aircraft Vehicle Systems
  - In civil and military aircraft
  - Complex H/W & S/W
  - Tightly integrated
  - Highly interconnected
  - Multiple tasks per system
  - Extensive use of M&S needed throughout system development



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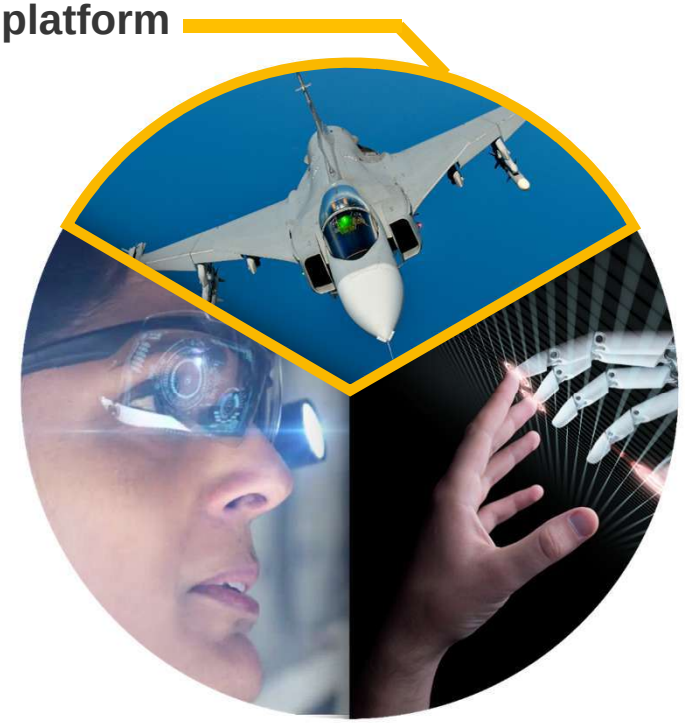
Background and Introduction
Compact and Efficient Platform

- Identified **key technology** area
  - Objective: From clean sheet design to customer delivery in **3 years**
- Available evaluated concepts necessary to meet time requirement
  - Storage of validated models
  - Verified M&S methods

Compact and efficient platform



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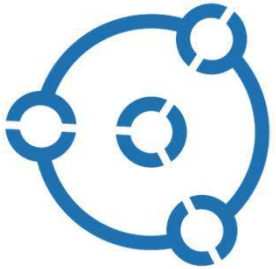
Background and Introduction

Open Cyber-Physical System Model-Driven Certified Development

- *Open Cyber-Physical System Model-Driven Certified Development (OPENCPS)**
  - EU financed research project R&D on methods, standards & tools for cyber-physical system simulation
- Duration ~3 years, December 2015 to March 2019
- 4 countries: Sweden, France, Finland, Hungary
- Key innovation: Development of FMI run-time and master simulation framework
  - **Scalable, reliable co-simulation** of discrete-time software parts with continuous-time physical processes, designed for **handling large numbers of events**
  - Open source **FMI Master Simulation Tool**



openCPS

- Duration 3 years, December 2015 to March 2019
- 4 countries: Sweden, France, Finland, Hungary
- Current status: 46.5 person-years, 6.5 M€, 18 partners

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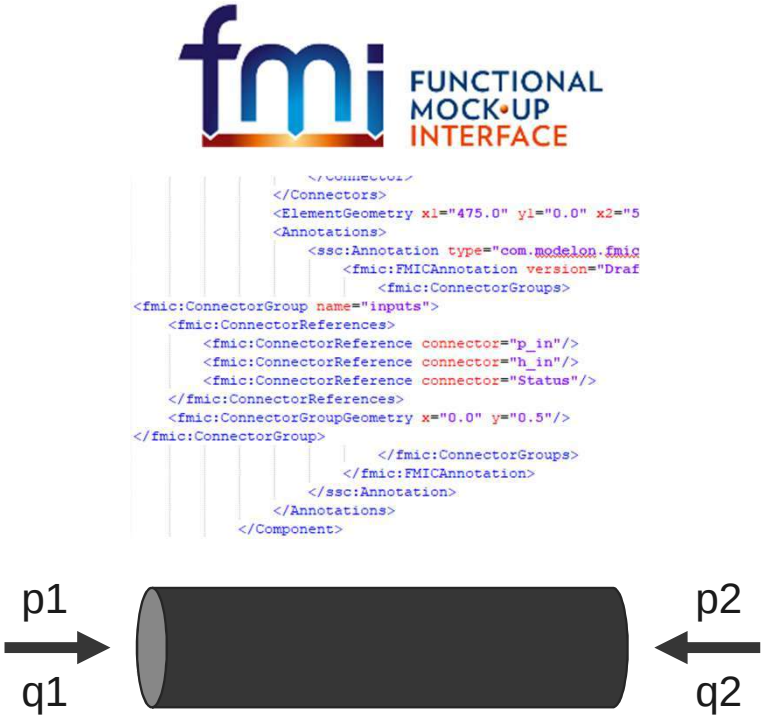
Enablers

Standards and methods

- Functional Mock-up Interface (FMI) Standard
  - Generic format for export of model (FMUs)
  - FMI 2.0 Supported by ~50 commercial and open-source tools
- System Structure and Parameterization (SSP)
  - Complement to FMI
  - Generic format for describing simulators
- Transmission Line Modelling (TLM)
  - Mature method for coupling of physics based models
  - Physically motivated time delays in information propagation are utilized
  - Guarantees simulator numerical stability if the modeled sub-systems are stable



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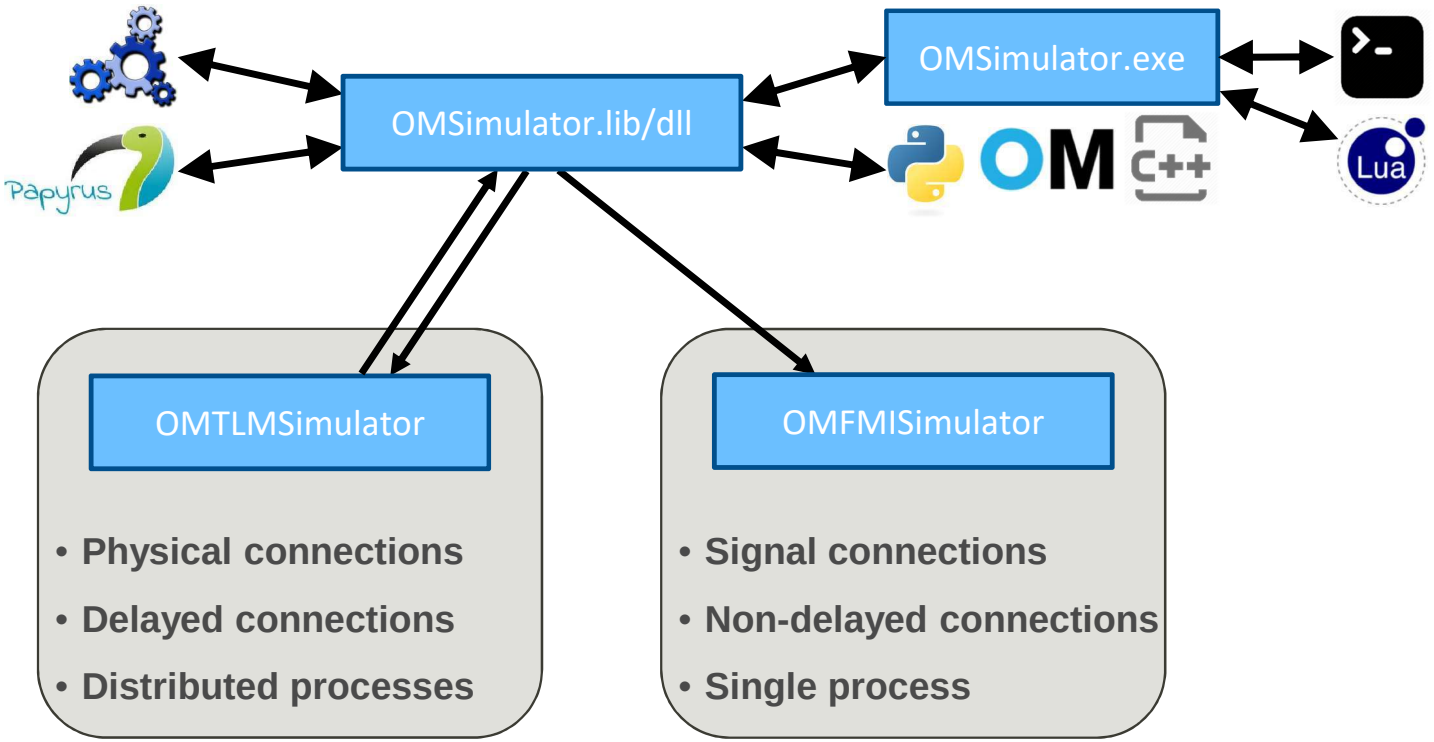
Enablers

OMSimulator[1]

- Open-source
  - Shipped with OpenModelica[2]
  - Available on github[3]
- Scripting
  - Lua, Python, C++, OM
- Graphical Editing
  - OpenModelica, Papyrus
- Information exchange
  - FMI, SSP



[1]Lennart Ochel et. al. ***OMSimulator-Integrated FMI and TLM-based Co-simulation with Composite Model Editing and SSP.*** Proceedings of the 13th International Modelica Conference, 2019

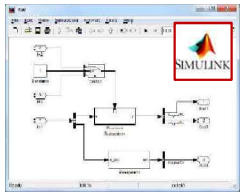
[2]https://openmodelica.org/

[3]https://github.com/OpenModelica/OMSimulator

Aim and Stipulated Impact

Current way of working

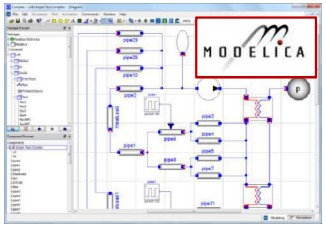
- Hosted simulation
  - H/W specification & development
  - S/W specification & development
  - Early detection of design errors
- Large-scale soft and HIL simulators
  - S/W verification
  - Model verification
  - Early detection of design errors
- Flight testing
  - Calibration and validation of model
  - Minor updates of system design



Design & Implementation of S/W

Test rigs & simulators

Test A/C



M&S of physical systems

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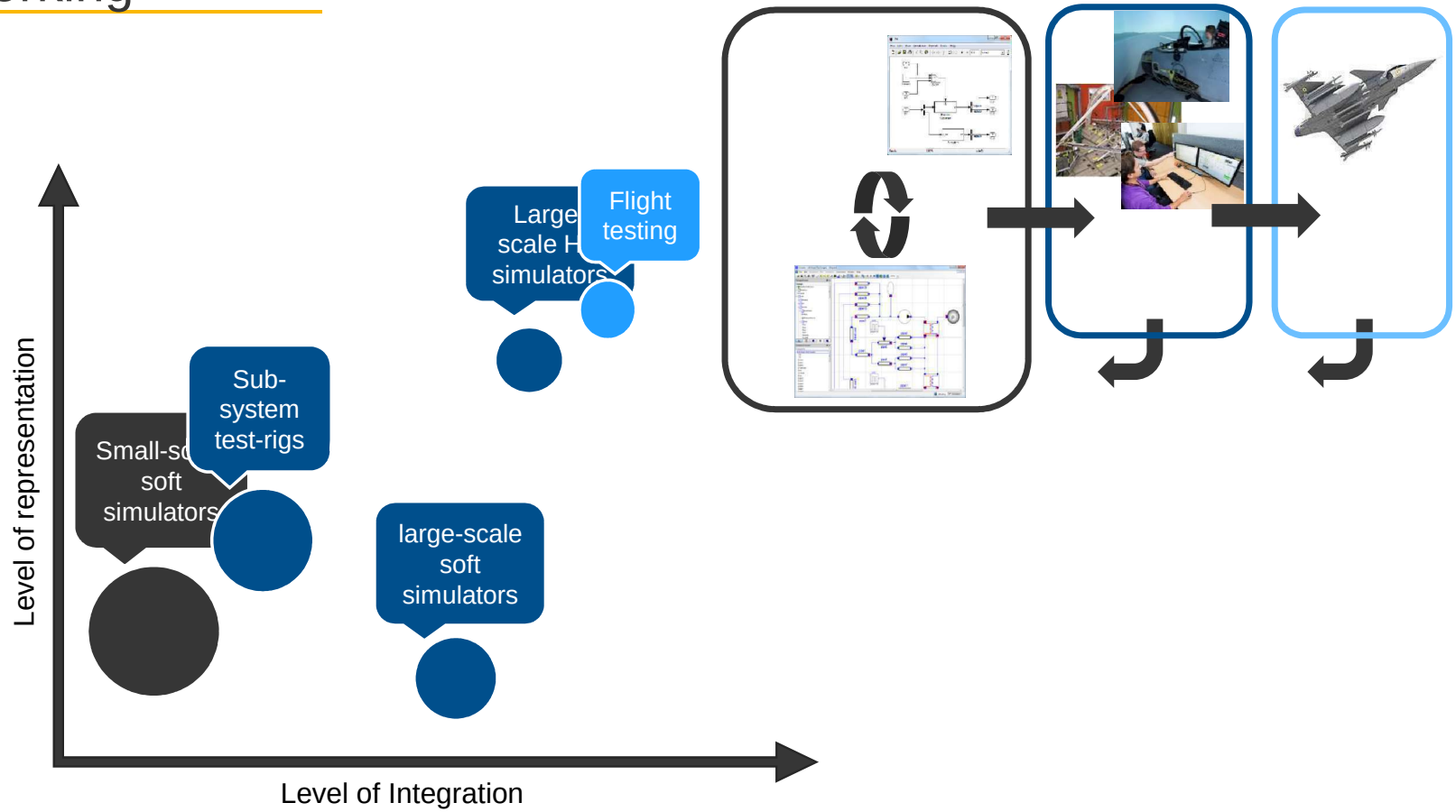
Aim and Stipulated Impact

Current way of working



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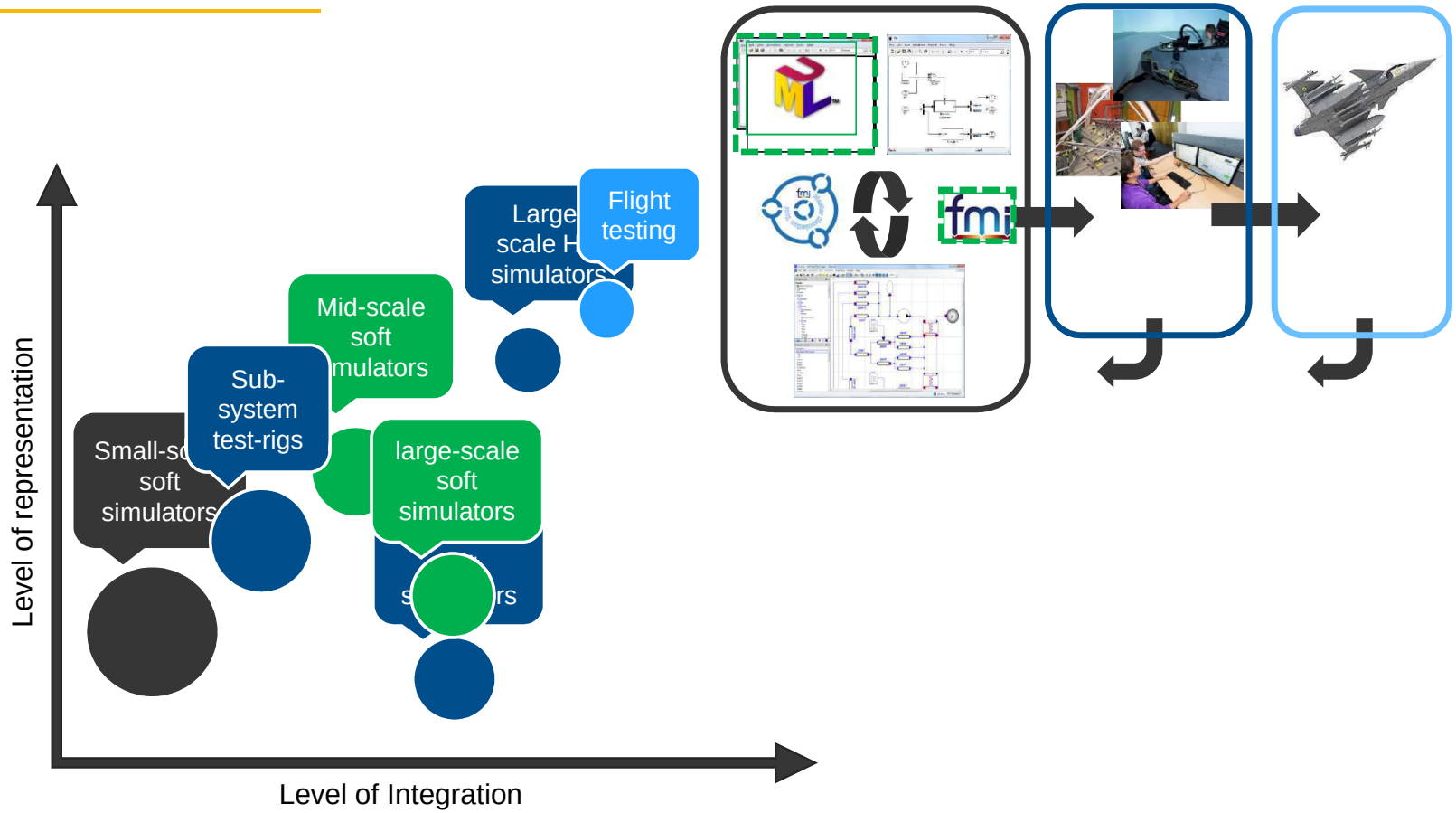
Aim and Stipulated Impact



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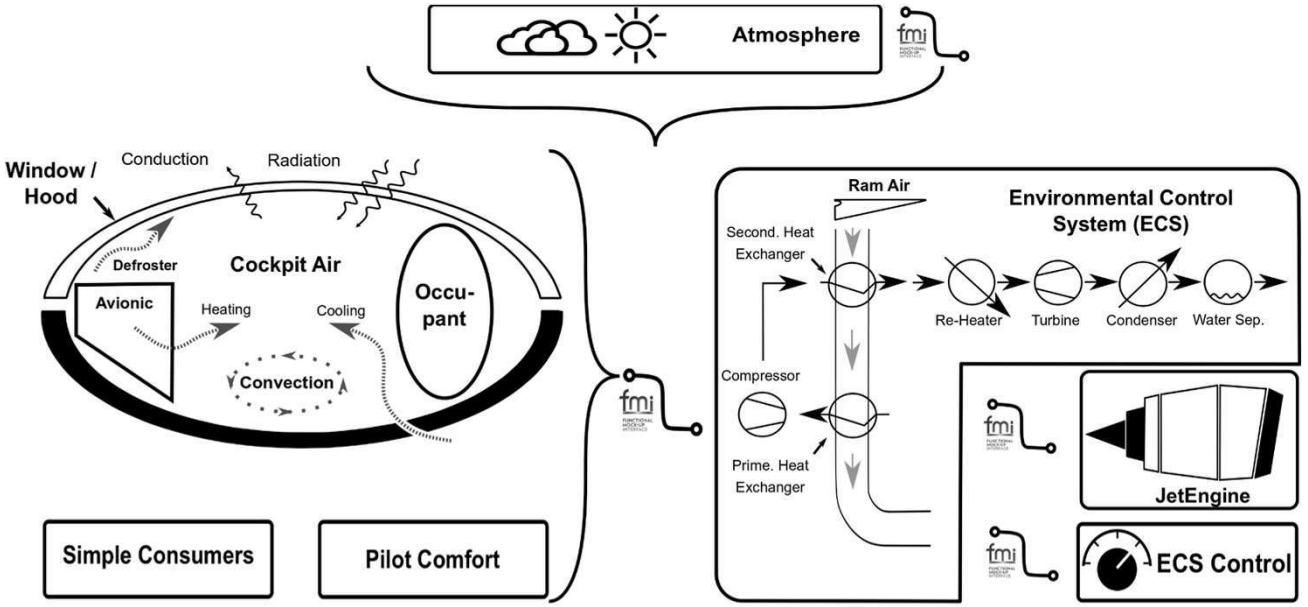
Development and Evaluation Use-Case
Overview

- Mid-scale soft simulator
  - Multiple domains: HW, SW, Human factors, Architectural modelling
  - Included in OMSimulator test-suite
- Intended use
  - Evaluation of tools for model simulator integration
  - Development of OMSimulator
  - Testing of methods for distributed and robust simulation
  - Demonstrate functionality in industrial context
- Used for conceptual study of pilot thermal comfort coupled to ECS performance[1,2]



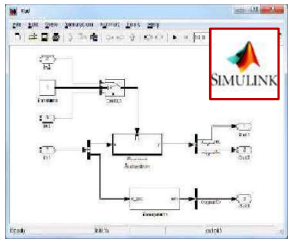
[1]Robert Hällqvist, Jörg Schminder, Magnus Eek, Robert Braun, Roland Gårdhagen, Petter Krus. ***A Novel FMI and TLM-based Desktop Simulator for Detailed Studies of Pilot Thermal Comfort.*** Proceedings of the 31st Congress of the International Council of the Aeronautical Sciences, 2018

[2]Jörg Schminder, Robert Hällqvist, Magnus Eek, Roland Gårdhagen. **Pilot Performance and Heat Stress Assessment Support Using a Cockpit Thermoregulatory Simulation Model.** Proceedings of the 31st Congress of the International Council of the Aeronautical Sciences, 2018

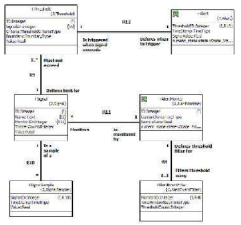
Development and Evaluation Use-Case

Tool interoperability

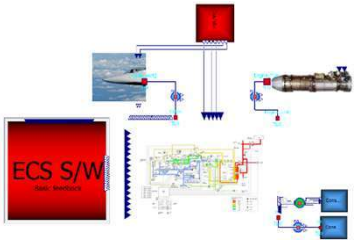
- Demonstrate flexibility
- Interoperability between targeted tools
  - Simulink
  - Dymola (Modelica)
  - Bridgepoint
  - OMSimulator
  - OMEdit
  - Papyrus



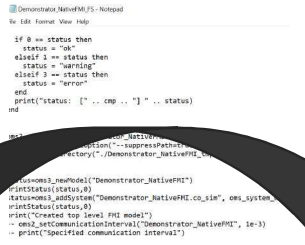
Simulink controlling software



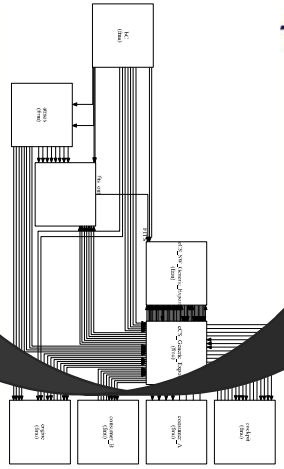
Bridgepoint discrete event software



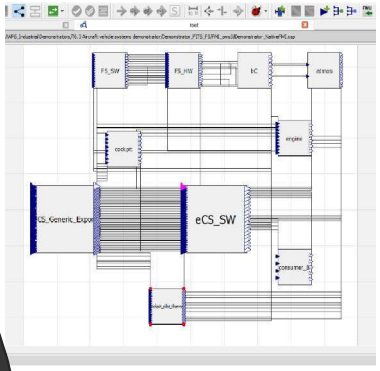
Modelica physics-based models



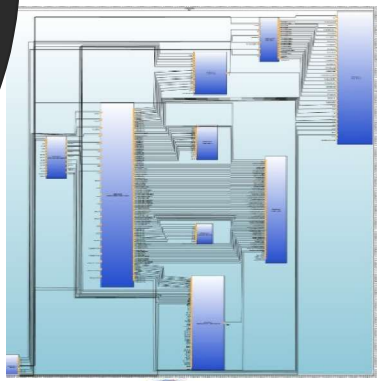
Lua description of simulator



OMSimulator visualization



MEdit graphical editing



Papyrus graphical editing

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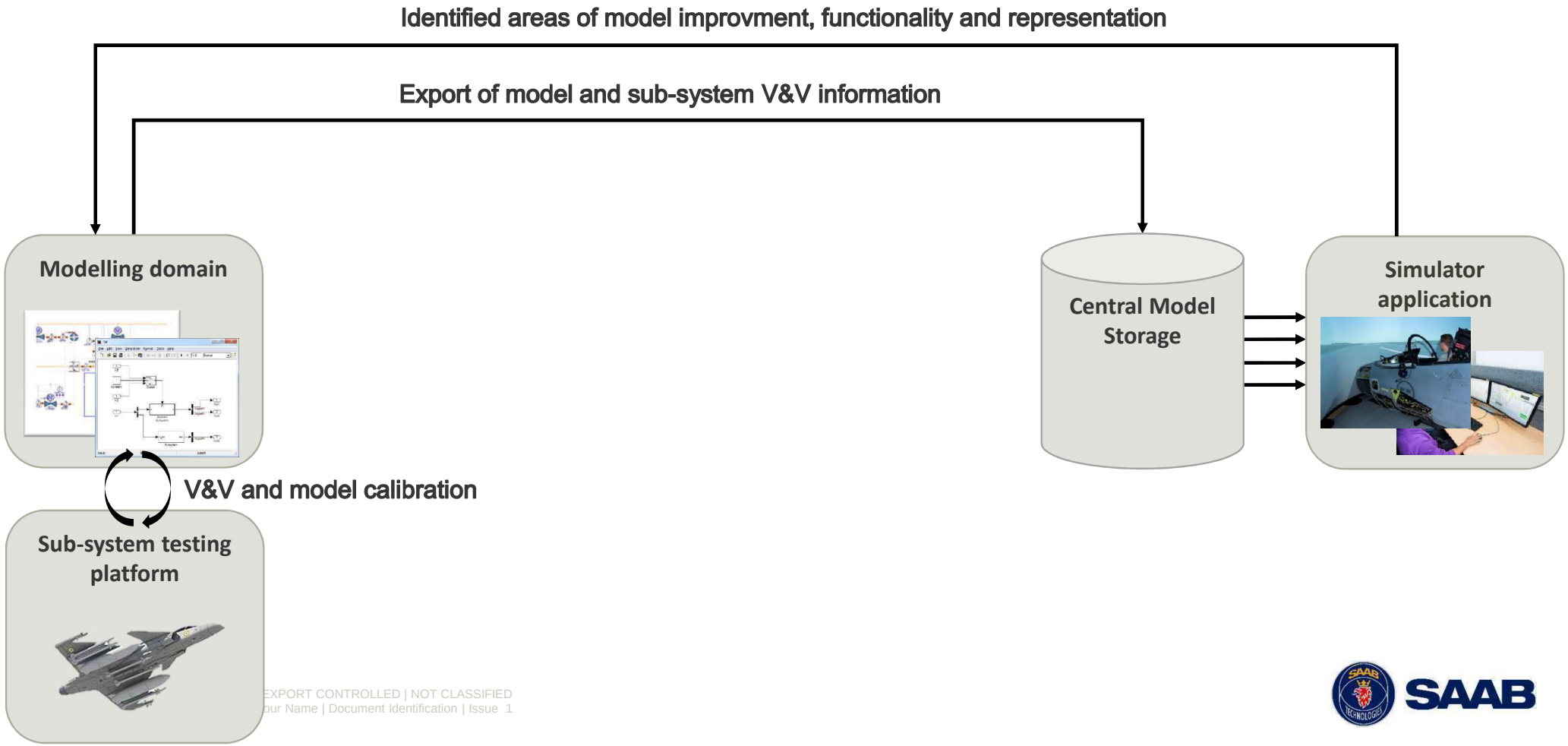
Automated flight test evaluation & model validation



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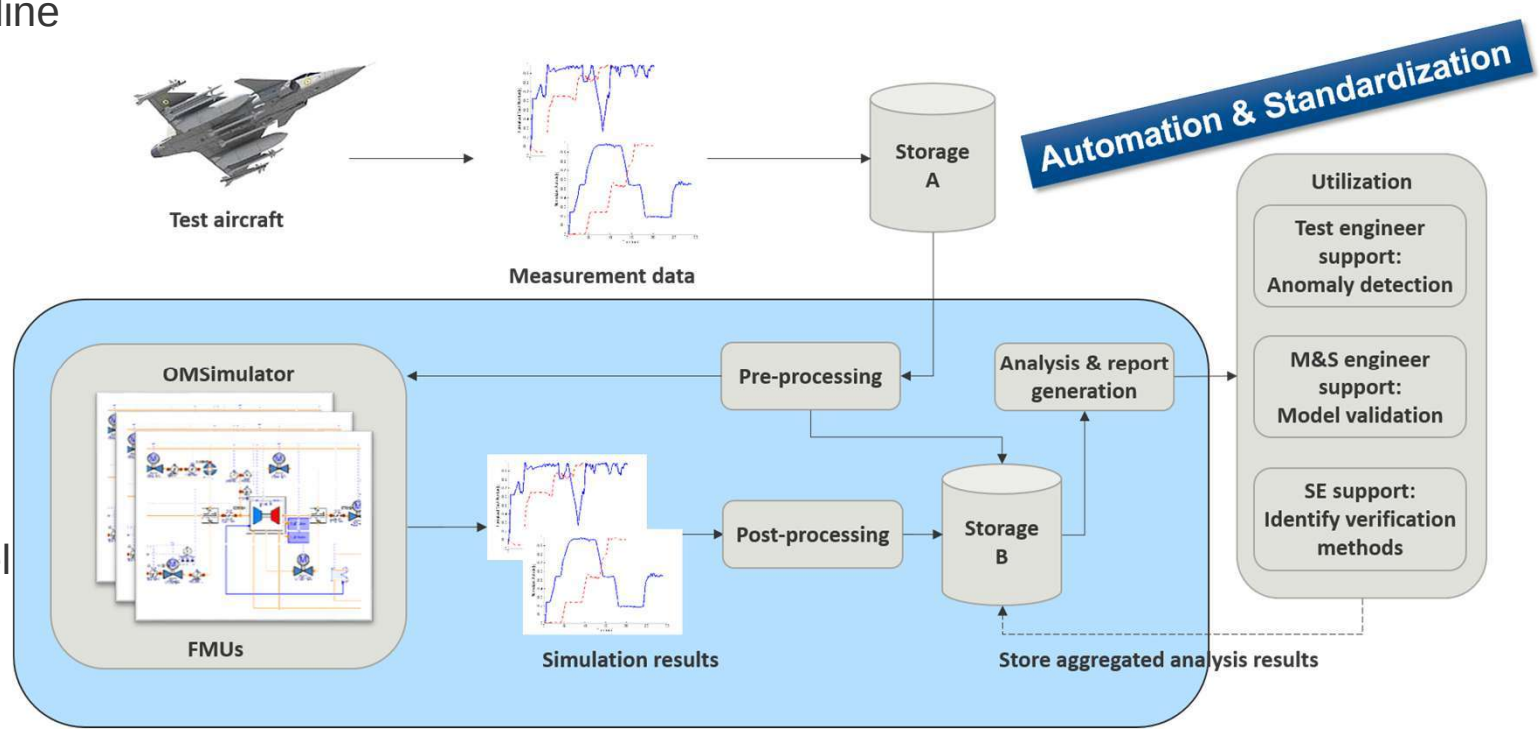
FMI-based Digital Twin

Compact and efficient platform

- Automated Jenkins pipeline
  - Pre-processing
  - Simulation
  - Post-processing
  - Storage and report generation
- Utilization
  - Anomaly detection
  - Model validation information to model developer
  - Verification of M&S methods



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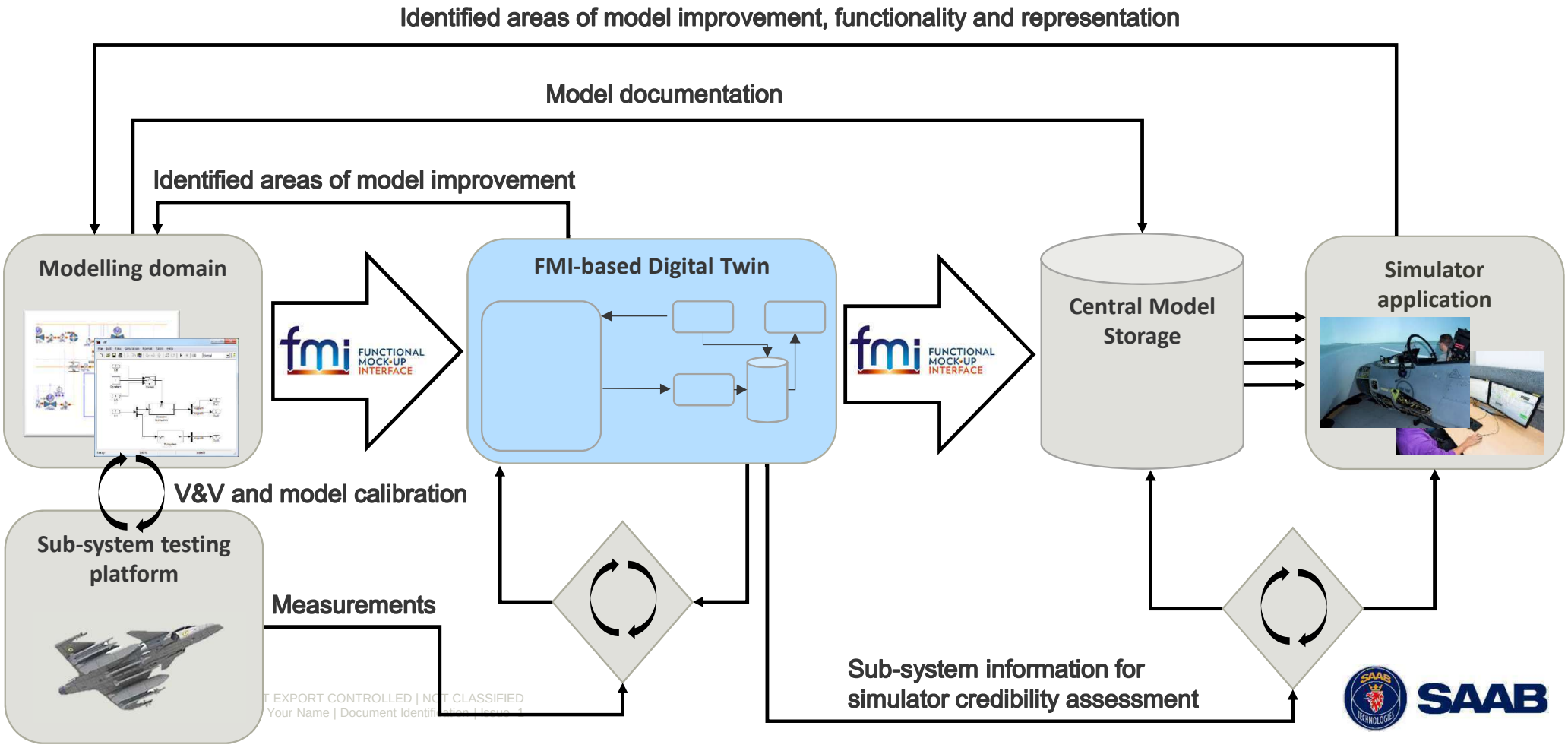
Automated model validation

-Outlook



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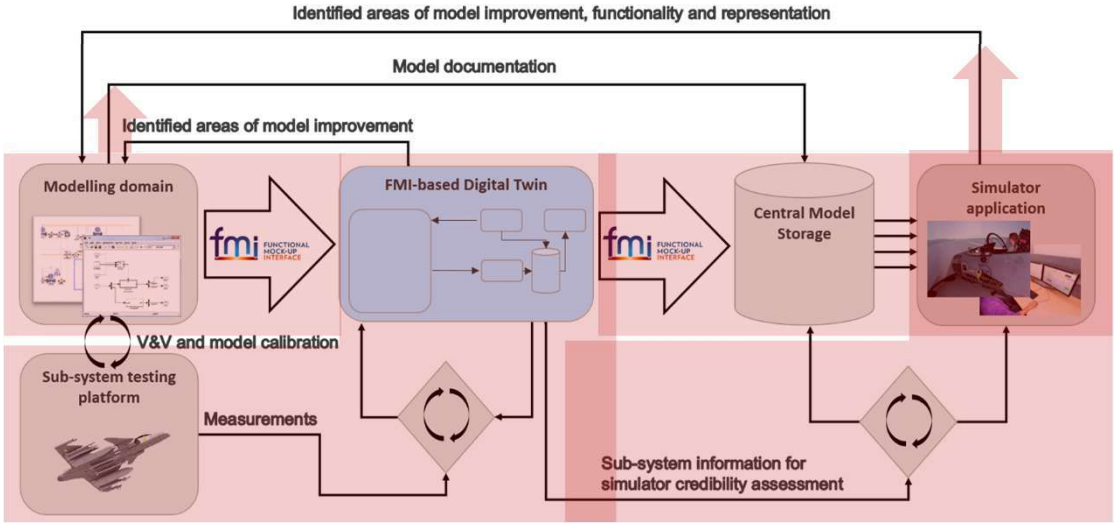
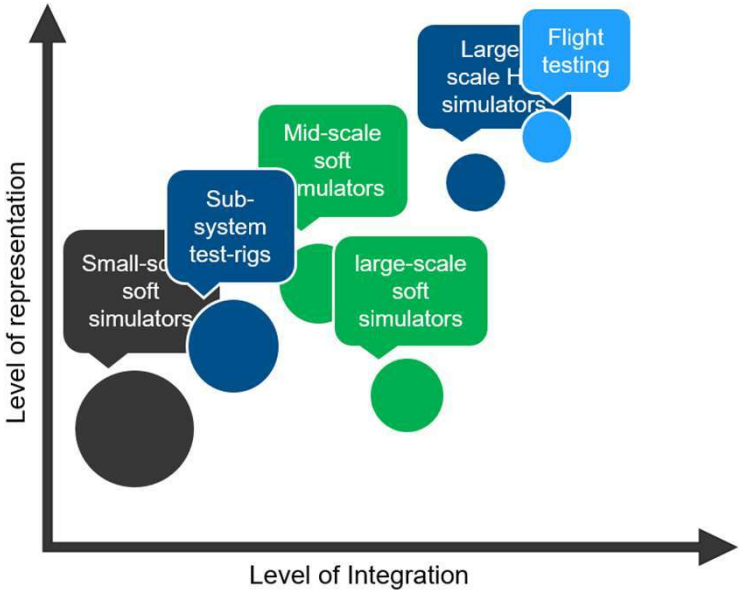
Automated model validation
-Outlook

- Physics-based modeling
  - Standardized export and integration
- Flight test
  - Trigger V&V framework iteration
- Central model storage
  - Models are passed on to storage along with incorporated V&V info
- Simulator applications
- Simulator credibility assessment
  - On-line
  - Connection to latest info from V&V framework



Key Results and Conclusions

- Key enablers advancing the targeted state-of-the-art in physics based M&S have been identified, developed/progressed, and evaluated
  - OMSimulator
  - FMI standard update
  - Interoperability
- Prototype of FMI-based digital twin developed and launched at Saab
  - Successively approach automated V&V and anomaly detection
- Continuation of research established via NFFP7-Call 2 (and possibly ITEA)



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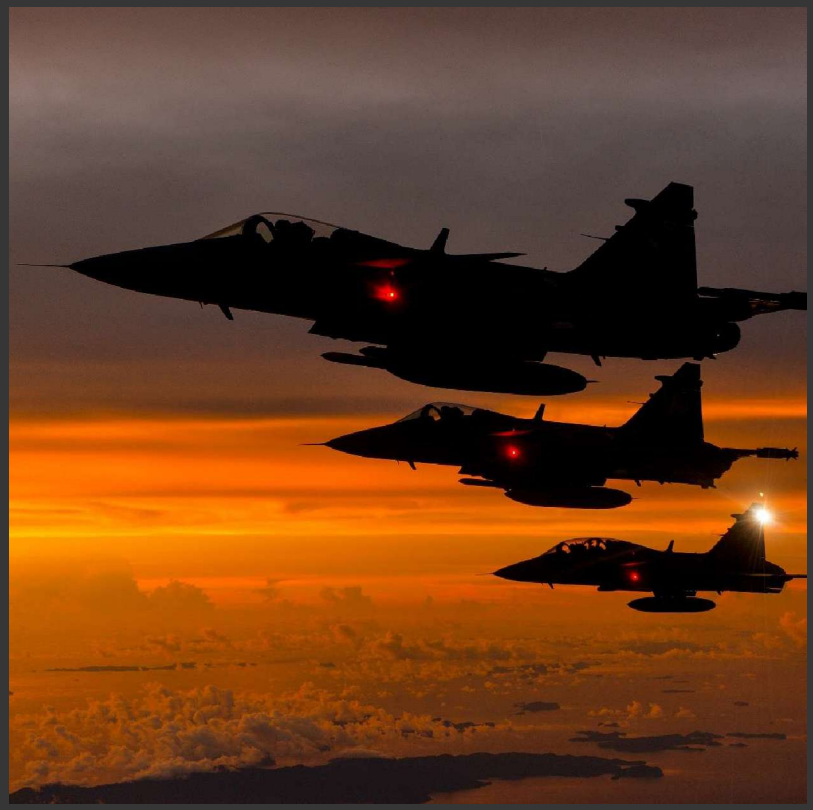
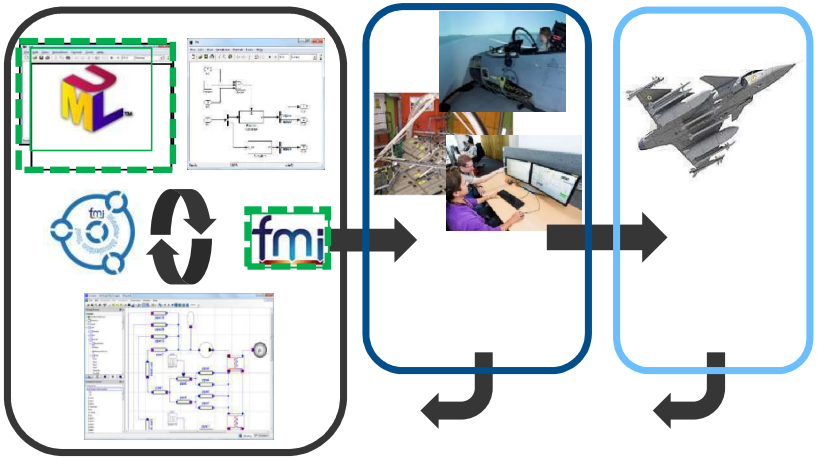


Background and Introduction

Stipulated Impact of Research Results

- Easier to setup new small-scale desktop simulators in 1st loop
- 1st loop covers a larger part of total system functionality
  - Possible to include FMUs of S/W developed in xtUML
  - Efficient distributed simulation of a connected set of large models (FMUs)
- Significant work share moved from 2nd to 1st loop
  - Further increased possibility for early discovery of design errors
  - Reduced pressure on test rigs and simulators
- Improved decision support in development phase



Quantitative estimation of business impact, regarding cost for development and V&V of a new aircraft vehicle subsystem:

15% cost increase in 1st loop
15% cost reduction in 2nd loop
20% cost reduction in 3rd loop

15% total cost reduction

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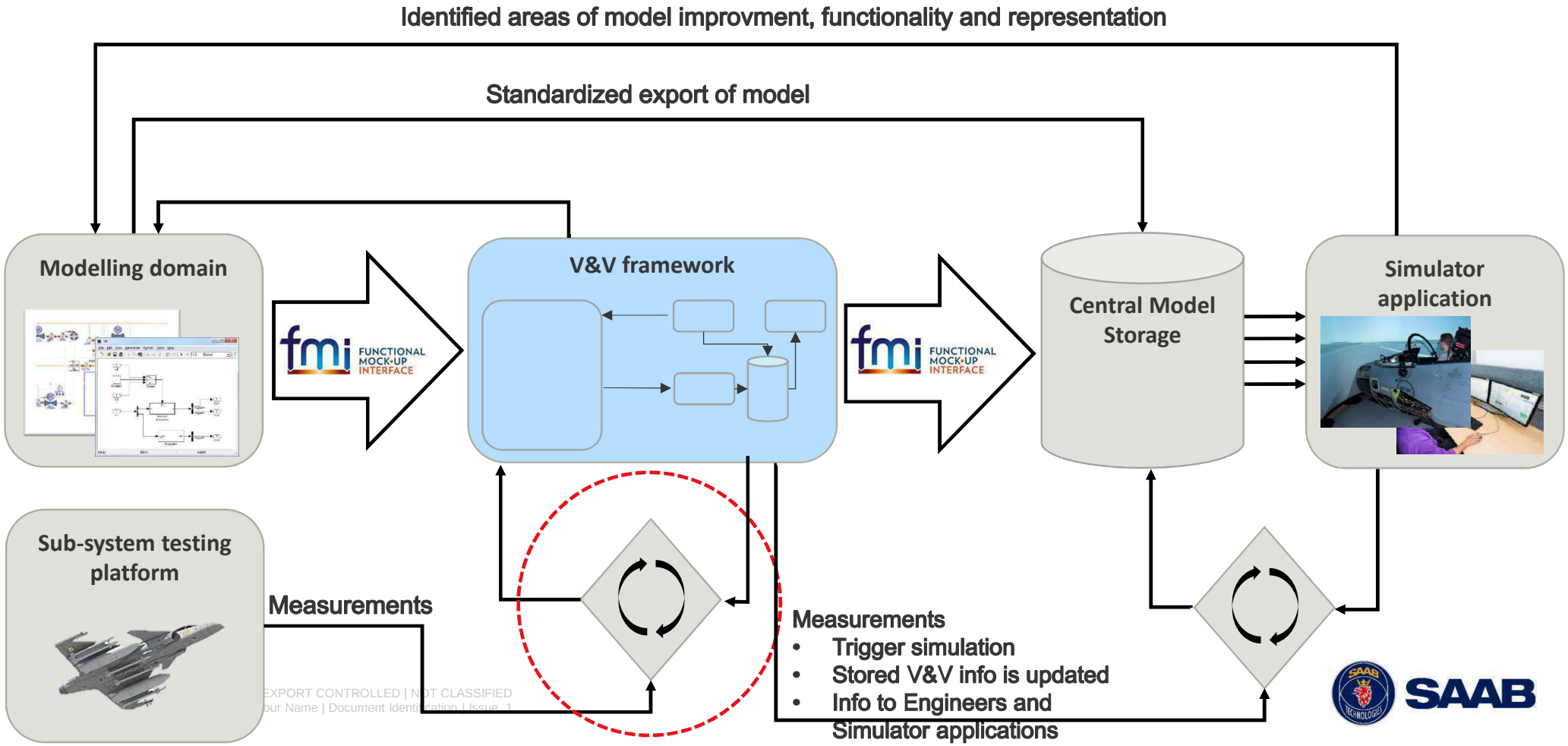
Automated model validation

-Outlook



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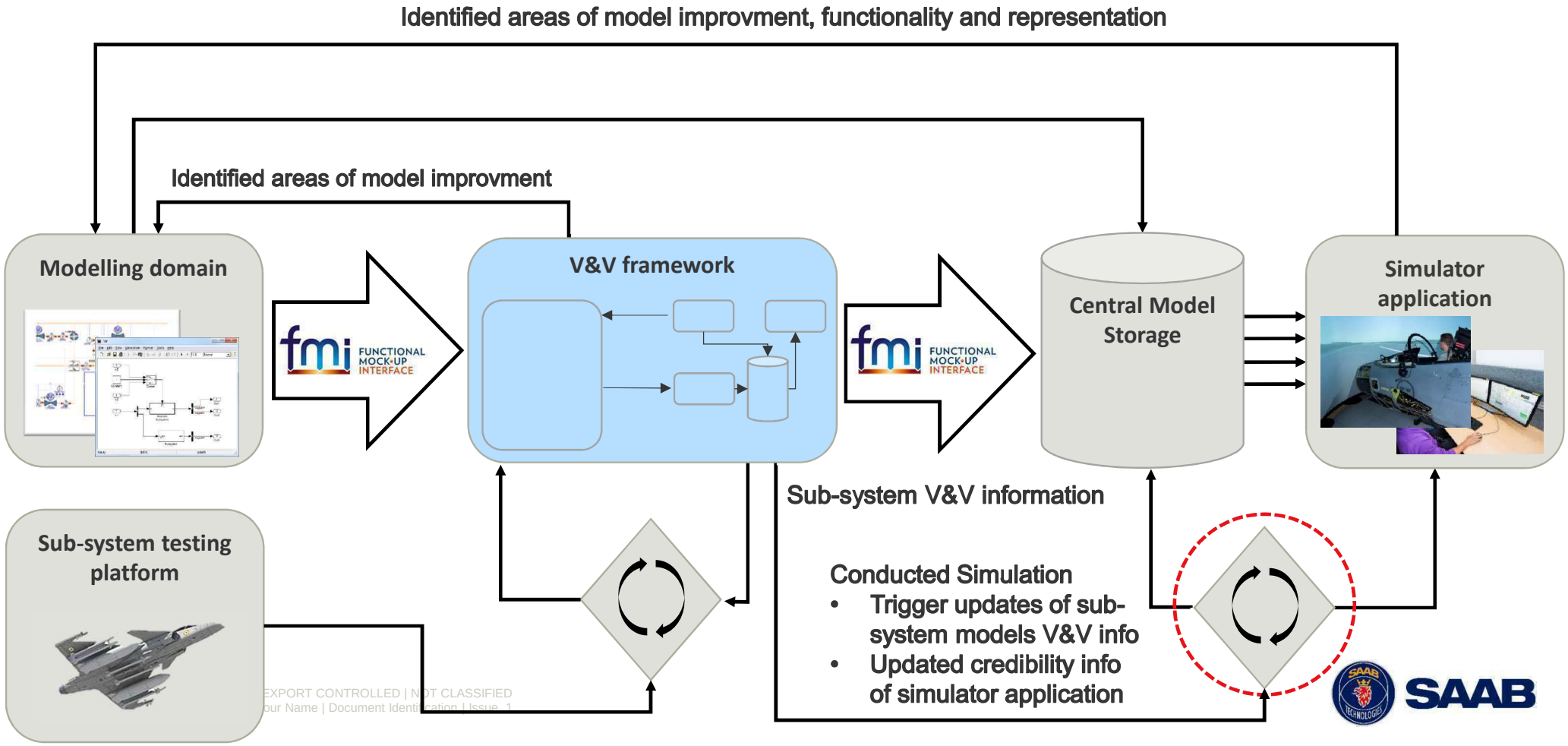
Automated model validation

-Outlook



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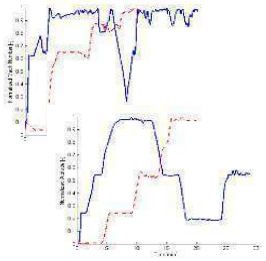
FMI-based Digital Twin

Compact and efficient platform

Test aircraft



Measurement data

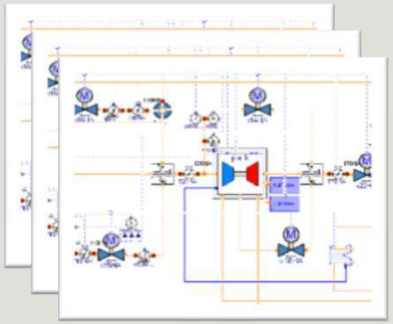
Storage A

Automation & Standardization

Utilization

- Test engineer support: Anomaly detection
- M&S engineer support: Model validation
- SE support: Identify verification methods

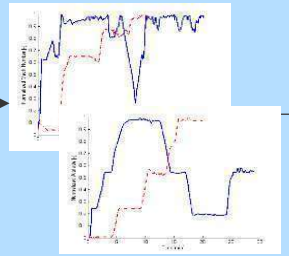
OMSimulator



FMUs

Pre-processing

Analysis & report generation



Simulation results

Post-processing

Storage B

Store aggregated analysis results

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Saab colour palette

55/55/55	225/225/220	250/185/0
190/175/150	0/80/140	230/20/25

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Enablers

Functional Mock-up Interface (FMI) Standard

- Standardization effort commenced in the EU financed research project (*MODELISAR)* previous to OpenCPS
- Specifies a generic format for export of model executables, Functional Mock-up Units (FMUs)
  - FMUs for co-simulation
  - FMUs for model exchange
- Standardized set of C functions for FMU execution
- Standardized interface description xml schema
- FMI 2.0 Supported by ~50 commercial and open-source tools

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Enablers

System Structure and Parameterization (SSP)*

- Under development as a *Modelica Association Project*
  - Standardized export of simulators
- SSD:
  - Standardized xml schema for integration and configuration specification of connected models
- SSP
  - Package containing SSD along with its referenced resources

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Enablers
Transmission Line Modelling (TLM)

- Mature method for coupling of physics based models
- Physically motivated time delays in information propagation are utilized

$$p1(t) = Zc\,[q1(t)+q2(t-T)]+ p2(t-T)$$
$$p2(t) = Zc\,[q2(t)+q1(t-T)]+ p1(t-T)$$

- Guarantees simulator numerical stability if the modeled sub-systems are stable

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