SYSTEMS MODEL INTEGRATION & DISTRIBUTION USING THE FUNCTIONAL MOCK-UP INTERFACE AT JAGUAR LAND ROVER LTD.

– FMI USERS MEETING: 11TH MODELICA INTERNATIONAL CONFERENCE 2015 - VERSAILLES, FRANCE

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SYSTEMS MODEL INTEGRATION & DISTRIBUTION USING FMI – Contents

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SYSTEMS MODEL INTEGRATION & DISTRIBUTION USING FMI
– Jaguar Land Rover Company Overview

Jaguar Land Rover is built around two iconic brands with a wonderfully rich heritage and powerful consumer appeal and loyalty.

Jaguar Land Rover was formed in 2008 when Tata purchased Jaguar Cars and Land Rover from Ford Motor Company. Jaguar Land Rover is a subsidiary of Tata Motors Limited.

Jaguar Land Rover is headquartered in the UK and is the largest employer in the UK automotive sector.   Almost 34,000 of our 36,000 employees globally are UK-based.

Customer focus is at the heart of our business, with the primary aim of providing products and experiences that customers love, for life.

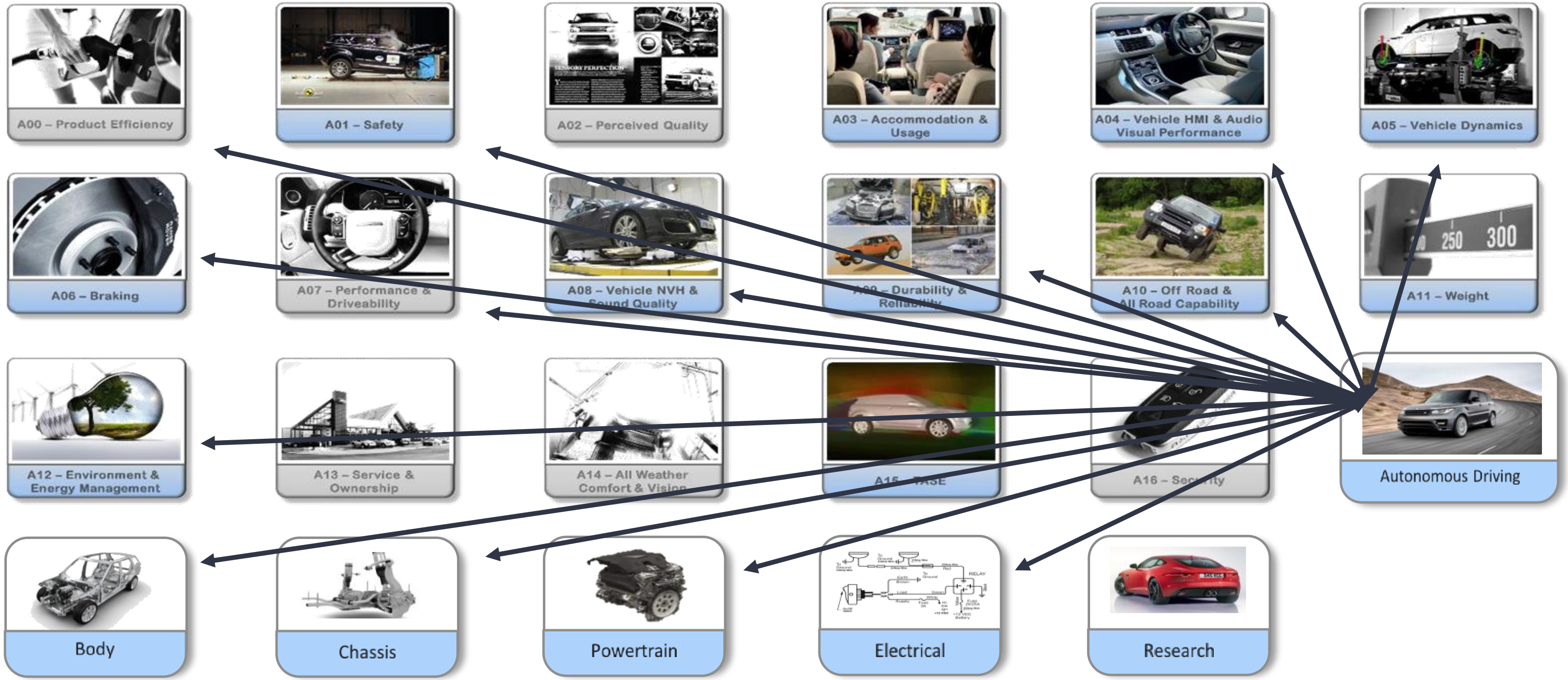
SYSTEMS MODEL INTEGRATION & DISTRIBUTION USING FMI
– Jaguar Land Rover Company Overview

- 12 vehicle lines – with ambitious expansion plans to extend product offerings.
- 3 UK vehicle assembly plants, with 2 UK design and engineering facilities.
- 36,000 people globally – headcount doubled in last few years.
- Employs over 8,000 engineers and designers.
- Global sales reach, network covering 170 countries.

- Significant investment in technology & innovation core to future success.
- Responding to consumer demand for enhanced, interdependent & connected features.
- Commercial pressure to reduce cost & delivery time, improve quality, reliability & safety.
- Virtual engineering critical to achieving these goals.

SYSTEMS MODEL INTEGRATION & DISTRIBUTION USING FMI
– Engineering Challenge / System Complexity

Impact of increasing systems complexity on Vehicle Attributes, e.g. Autonomous Driving:



SYSTEMS MODEL INTEGRATION & DISTRIBUTION USING FMI
– Problem Statement: Model Sharing & Distribution

Within JLR, the **Virtual Hub** are responsible for delivering **vehicle system** simulation models to CoC / Attribute teams across Product Development.

Objective: To improve quality / robustness & efficiency through centralised co-ordination & asset reuse

- **Multiple Customers** – cross-functional reuse of models & code
- **Multiple Suppliers** – systems models from internal & external sources
- **Multiple Models** – mixed fidelity, increasing vehicle variants, complex systems
- **Multiple Simulation Tools** – incl. multiple versions (compatibility)
- **Multiple Platforms** – 32 / 64-bit, Windows / Linux, desktop / real-time etc.

“Aspiration to converge on a minimal set of best practice methods / model formats, with sufficient interoperability, customisable configuration rights and multi-platform / environment compatibility, to maximise model reuse across use cases and minimise the overhead of maintaining a single central library of systems models.”

SYSTEMS MODEL INTEGRATION & DISTRIBUTION USING FMI
– Functional Mock-up Interface

FMI presents a prospective opportunity to enhance our virtual engineering processes in response to the demands of delivering complex integrated systems

- **Capability –** Enhanced coupling of simulation toolsets to enable virtual assessment of dynamic interactions between multi-domain systems
- **Efficiency –** Minimise integration effort, enable greater reuse of models, cross-functional & cross-platform compatibility
- **Robustness –** Model standardisation & quality, to support robust design

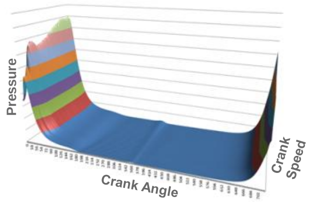
Current application areas:

- Powertrain NVH
- Engine Performance Analysis
- Vehicle Dynamics

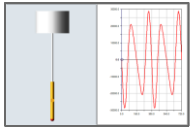
SYSTEMS MODEL INTEGRATION & DISTRIBUTION USING FMI
– USE CASE: Powertrain Development 1

Application of CAE methods for early specification of complex powertrain systems:

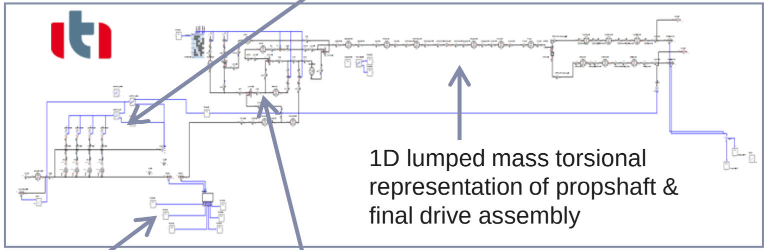
- **Use Case:** Powertrain matching / attenuation of Combustion Torque Oscillations in Driveline - Full Load
    - Torque convertor damper performance
- Collaborative project involving ZF / SACHS & ITI
- Torsional Damper model supplied / integrated using FMI v1.0 for Model Exchange
- Single simulation environment - Simulation-X
- Analysis of powertrain forcing & driveline vibrational behaviour, e.g. Driveline Boom
- Currently in use by Powertrain CAE



Measured cylinder pressure map at Full Load



Crankshaft assembly mass properties & piston inertia



1D lumped mass torsional representation of propshaft & final drive assembly

ZF SACHS Torsional Damper FMU

ZF 8 Speed Transmission torsional model, incl. shift control, gearsets & flexible shafts

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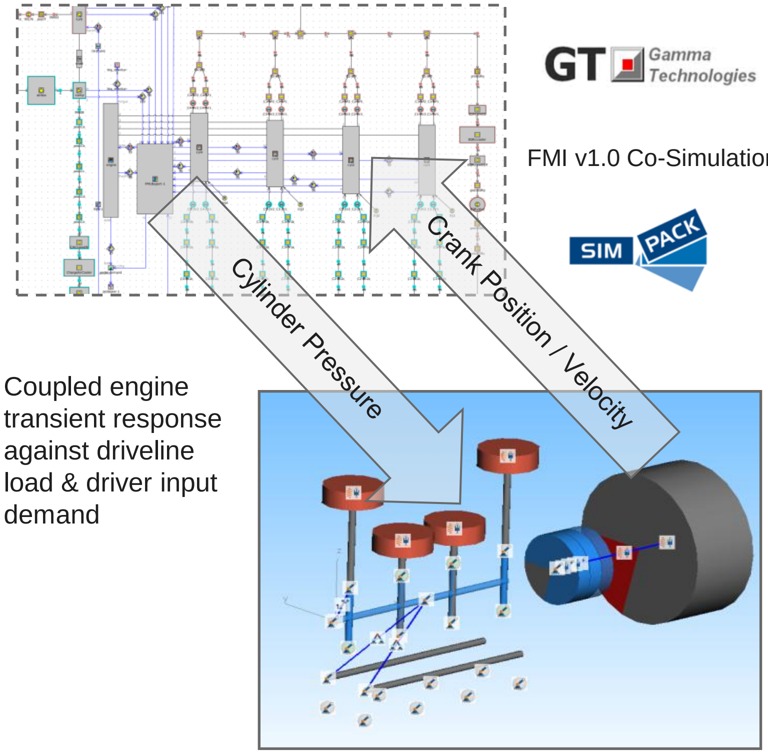
– USE CASE: Powertrain Development 2

Application of CAE methods for early specification of complex powertrain systems:

- **Use Case:** Requirement to couple MBS mechanical vehicle & driveline to load high fidelity engine performance models
- Representation of transient engine behaviour, incl. boosting system response
- Direct integration between SIMPACK (master) - GT Suite (slave) using FMI v1.0 for Co-Simulation
    - Dynamic coupling between combustion & mechanical processes
    - Significant simulation performance improvement over indirect integration via 3rd party environment
- Currently in development for Engine Performance Analysis & Powertrain NVH
- Future aspiration to include Simulink derived control systems to assess calibration changes under transient conditions



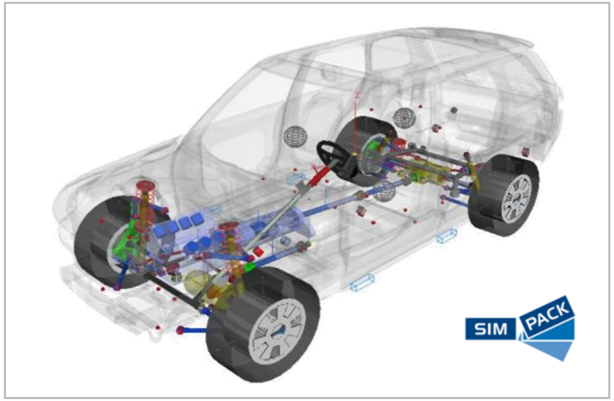
FMI v1.0 Co-Simulation

Coupled engine transient response against driveline load & driver input demand

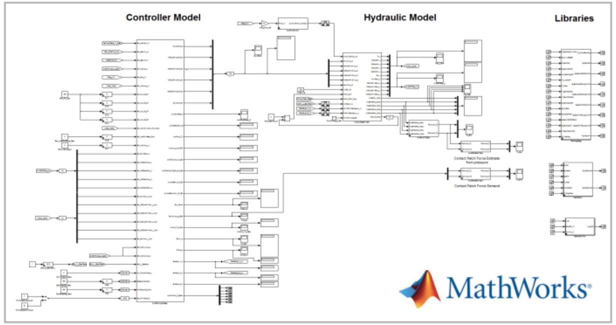
SYSTEMS MODEL INTEGRATION & DISTRIBUTION USING FMI
– USE CASE: Active Chassis Systems

Development of CAE methods for early target setting, enhanced performance prediction & calibration of integrated chassis systems:

- **Use Case:** Requirement to couple active chassis control systems to MBS & parametric (incl. real-time) vehicle models
  - e.g. CVD / ARC / EPAS / SCS / EDIFF etc.
  - e.g. Ride / Steering / Chassis Loads / Durability / NVH etc.
- Representation of coupled interactions between chassis components & systems during dynamic tests
- Direct integration of in-house Simulink derived control systems with SIMPACK MBS Vehicle models using Modelon FMI toolbox
- Currently in development for Vehicle Dynamics, incl. CVD & ARC
- Future aspiration to include additional Tier 1 supplier systems, e.g. SCS & EPAS, separate higher fidelity plant models, e.g. AMESim hydraulic systems, and integration with real-time simulation platforms, incl. IPG CarMaker / Driving Simulation



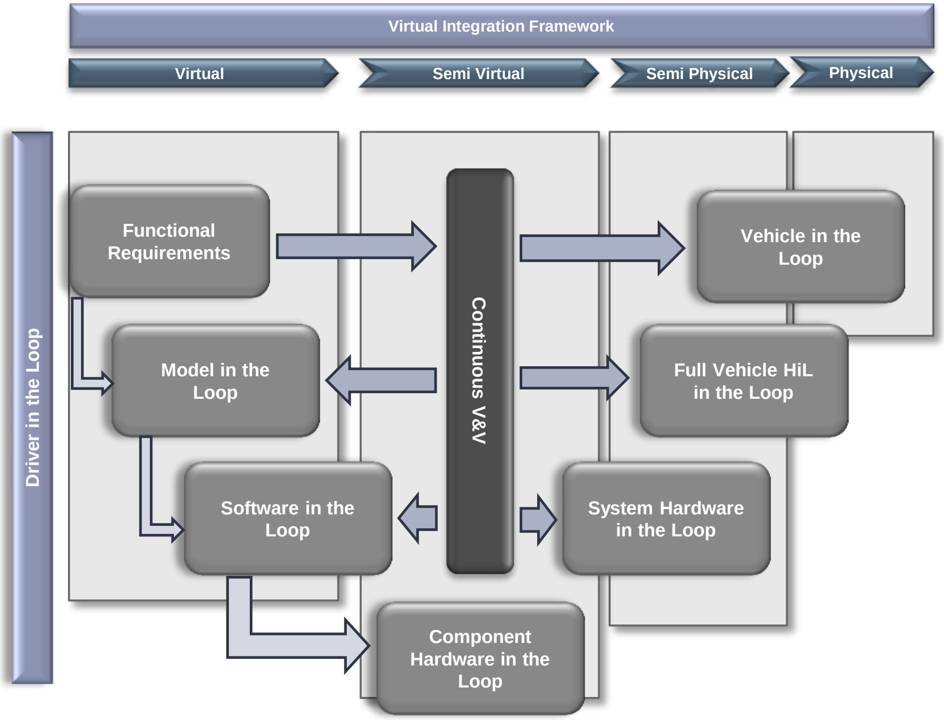
FMI v1.0 Model Exchange



SYSTEMS MODEL INTEGRATION & DISTRIBUTION USING FMI
– MBPE Virtual Integration Framework

Improve virtual methods for development, verification & validation of embedded software systems:

- **Objective:** Develop a Virtual Integration Framework to enhance model-based development workflows, improve software quality & delivery timing
    - Greater reuse of virtual components & test cases
    - Representation of complex system interactions
    - Rapid closed loop test of design scenarios
    - Traceability to functional requirements
    - Automation of test cases
    - Left-shift software verification & validation
    - Support virtualisation of AUTOSAR
- Move from independent use case solutions (XiL) to generic reusable framework & continuous integration
- Progressive exchange of virtual / physical components throughout software development life-cycle within a common architecture



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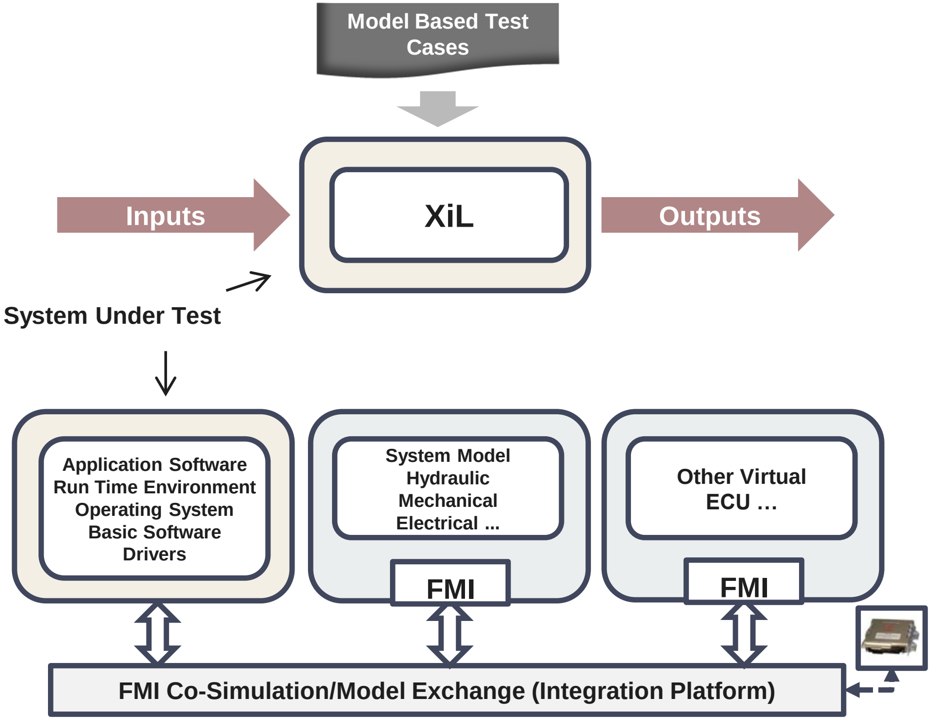

SYSTEMS MODEL INTEGRATION & DISTRIBUTION USING FMI
– Conclusions

Challenges / Requirements:

- Internal challenges:
    - Compatibility with legacy toolchains & processes
    - In-house expertise & training
- Industry maturity
    - Alignment of Tier 1 suppliers & OEMs
    - Software vendor adoption & robust implementation
- Model sharing & publication (internal / external), reconfiguration & IP protection etc.
- Optimisation of model architecture & solver configuration, i.e. stiff / multi-scale problems
- Robust cross-check & compliance, inclusion of real-world OEM use cases
- Visibility of FMI Technology Roadmap & concurrence among other automotive / engineering OEMs

THANK YOU

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