PMC2016 – LOUGHBOROUGH: MODEL-BASED REAL-TIME SYSTEMS ENGINEERING (MORSE)

Alessandro Renna – AVL
Stephen Gallagher – Ford

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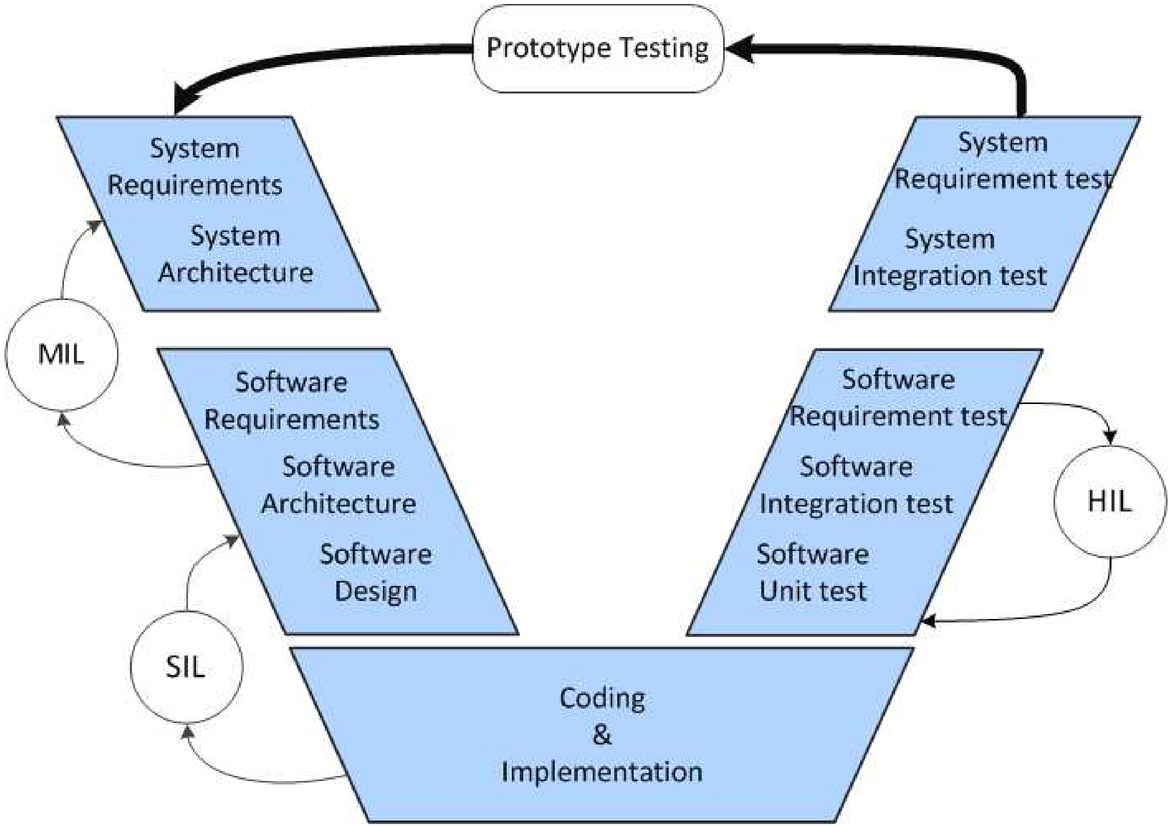
What is MORSE Project?

Model-based Real-time Systems Engineering



- High fidelity physical models for software verification & validation.
- Models capable of generating results ***before*** prototype parts are available.
- Automated tools to remove the overhead of model reuse.
- Automated parameter management and optimisation.
- Automated model optimisation for real-time implementation.
- Driveability analysis in SIL/HIL environments with AVL DRIVE.
- More OBD fault paths in virtual validation.

MORSE Project aims to give engineers the capability to test and calibrate software features earlier in the development, reducing the amount of prototype testing and improving product development efficiency.

AVL CLAYTEX Ford Go Further

MORSE Project Partners & Funding

- Collaborative engineering project between:
  - Ford of Britain: Control & Calibration expertise, model integration.
  - AVL Powertrain UK: Driveability calibration analysis.
  - Claytex: Physical model and modelling tools development.
- Co-funded by Innovate UK, the UK's innovation agency, as part of the 'Towards Zero Prototyping' competition.
- Provides a platform to improve existing tools used by each company, with an emphasis on real-time hardware in the loop simulation.
- Development of new engineering technology within the UK engineering sector.

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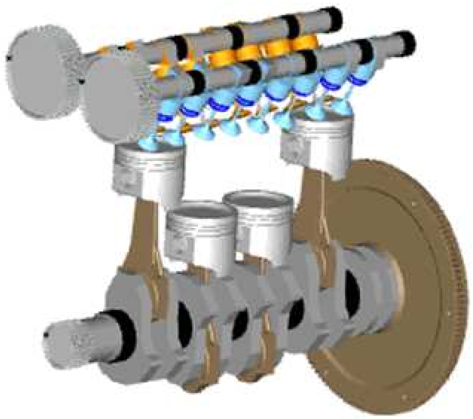
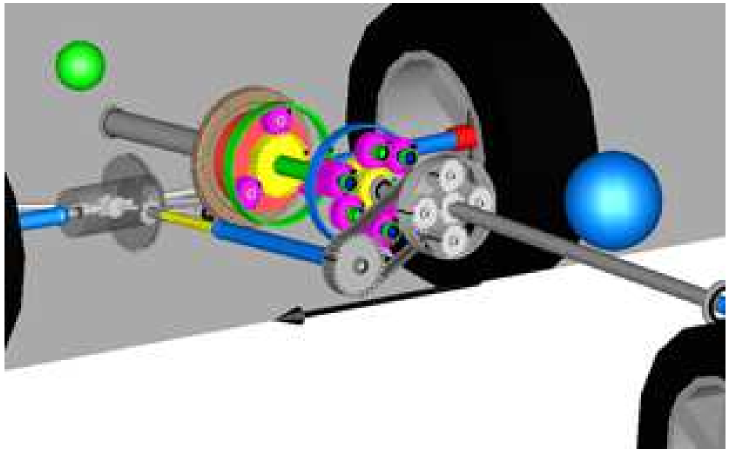
PROJECT OVERVIEW

Advanced Physical Models

Claytex Engine Library Enhancements:

- 0D Multi-zone combustion model[1]. An improvement on existing Wiebe function models.
- Addition of model components suitable for Ford control strategy, e.g. cylinder deactivation, high pressure fuel pump.
- Inclusion of models suitable for OBD fault path analysis, e.g. leaky pipe models, misfire simulation.
- Model optimisation for real time implementation.





Claytex PT Dynamics Library Enhancements:

- Thermal effects for gearbox warmup.
- Thermo-hydraulic models for driveline lubrication, actuators etc.
- Friction and viscosity temperature dependence.
- Driveline dynamics for driveability analysis.
- Tyre models for predictive acceleration performance.

1. "Combustion modelling for virtual SI engine calibration with the help of 0D/3D methods", Sebastian Grasreiner, TU Freiberg.

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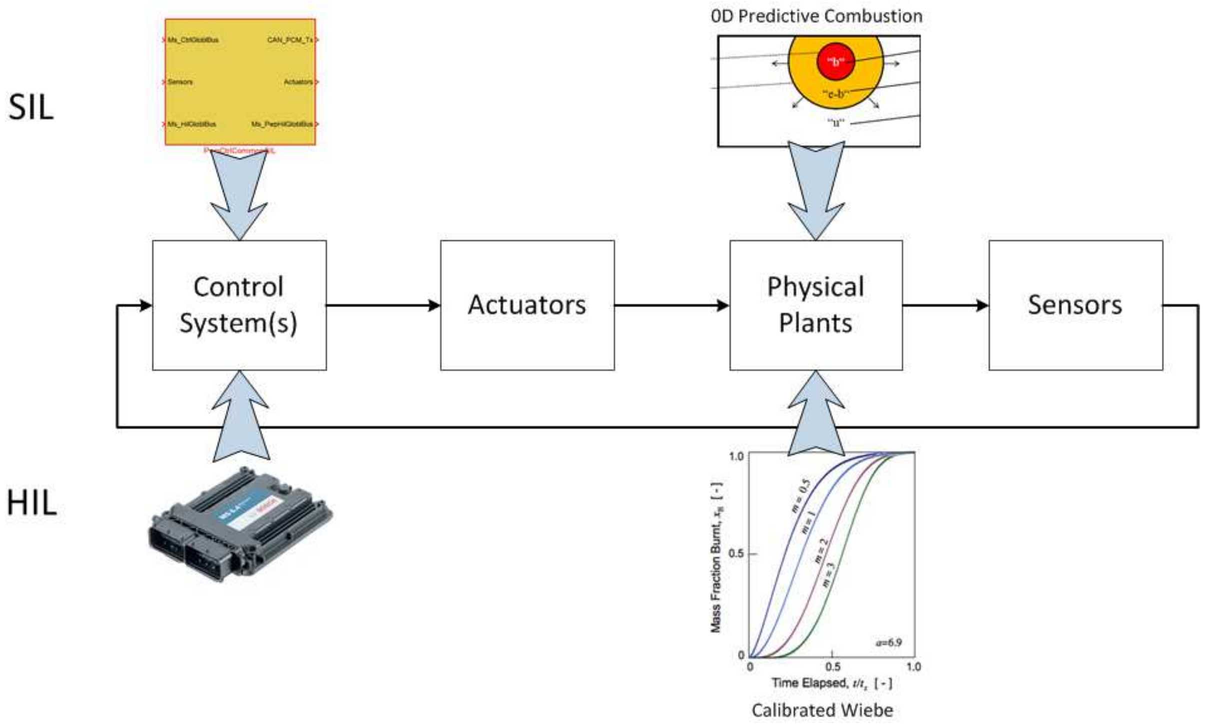
SIL/HIL Model Integration



- Many sources for models within Ford using different environments: Simulink, Dymola, AMESim etc.
- Modularity is key, and integration of different components within a single model environment enables model reuse throughout different stages of development.
- Current tools supply a single ‘model solution’ package specific to a vehicle programme. There is a large overhead associated with re-parameterising and reintegrating different model components.
- MORSE project aims to embrace modularity, and enable models to come from anywhere and integrate into a common interface, using recognised tools and processes within Ford.

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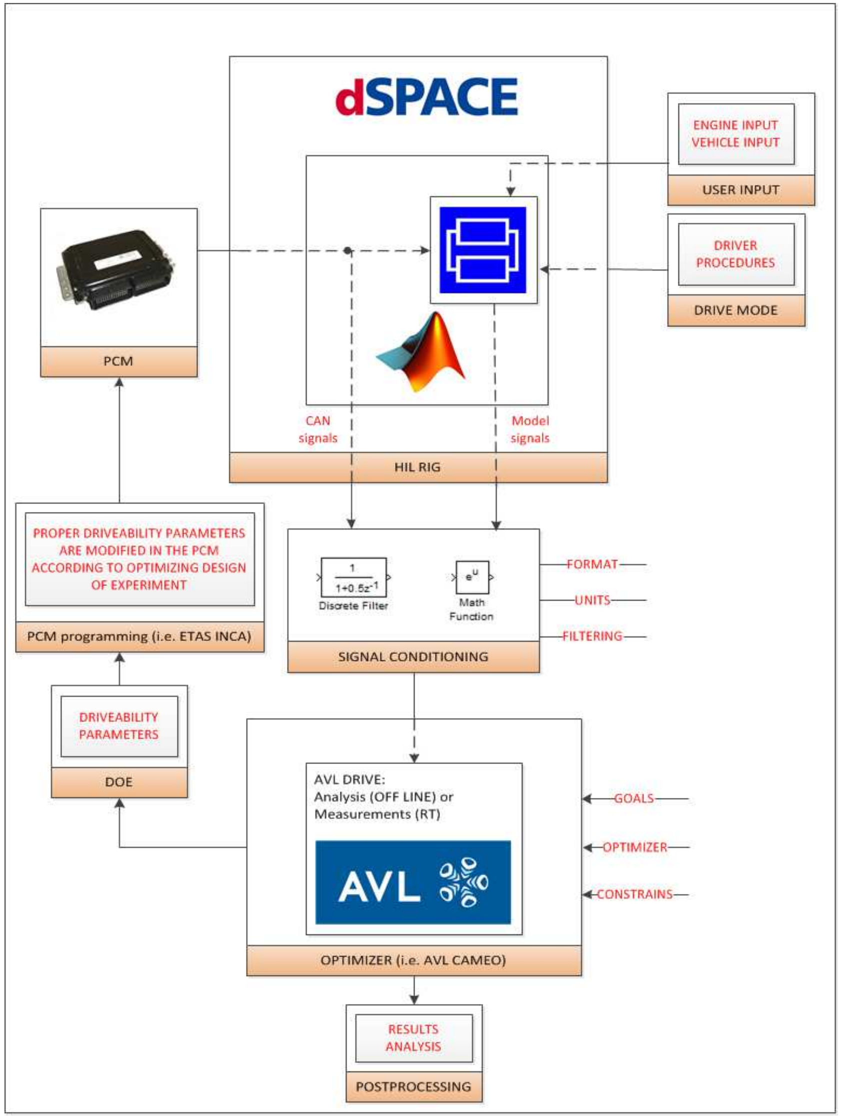
Automated Virtual Driveability Calibration Optimisation

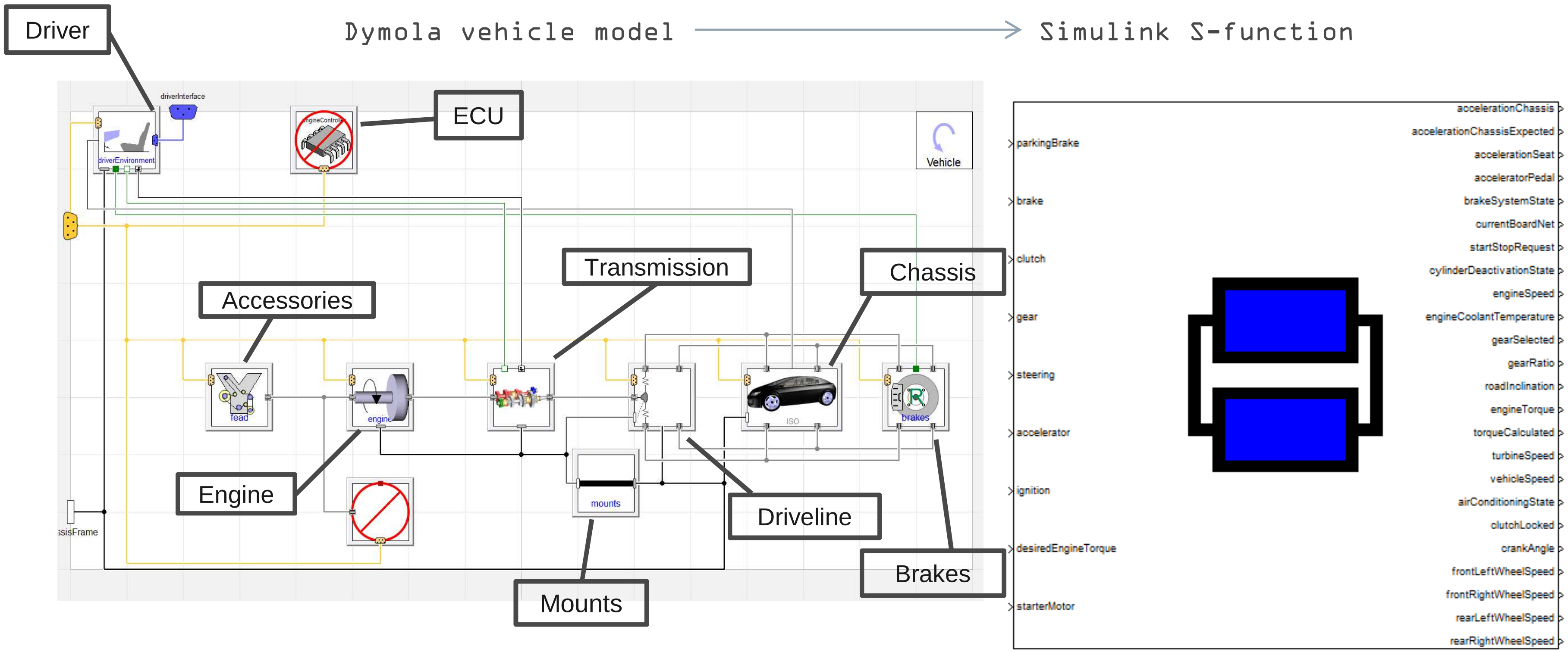


- MORSE Project aims to develop tools to enable automated simulation of drive cycles and manoeuvres.
- It also aims to create tools to handle the driveability analysis process, using AVL Drive.
- Automated tools will be created to analyse the driveability results and optimise a specific targeted parameter.
- These tools will carry over between SIL and HIL.
- Allows driveability engineer an upfront analysis of a particular software or calibration before in vehicle testing.
- Can aid in early identification of problems, or production of a base calibration.
- Can help to streamline in vehicle testing for targeted improvements in driveability.
- Simulation can take more testing out of physical prototypes and into the virtual domain.

Go Further

CURRENT PROGRESS

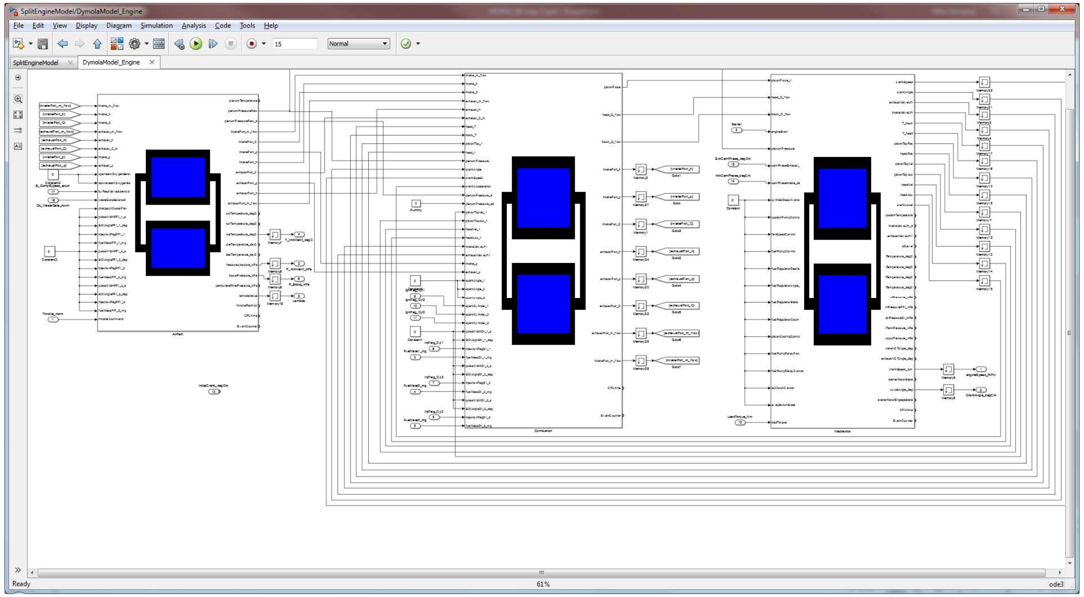
Vehicle model



- Claytex PT Dynamics vehicle models have been adapted to meet interface requirements for PCM in SIL/HIL environments.
- Engine subsystem replaced with torque actuator to allow splitting of the engine model to a separate S-function in Simulink.
- Models are used to create an S-function for use in SIL model and for compiling to HIL processor.

Split Engine Model

- Model architecture in Dymola has been modified to allow the model to be split into 3 S-functions in Simulink
  - This then enables dSPACE to run each s-function on a different core in HiL
- Air path
  - Contains intake and exhaust systems
  - Slowest part of the model and will need to run at a slower rate than the combustion model to achieve real-time



- Combustion
  - Contains the intake and exhaust valves and combustion chamber
  - Needs to run at the fastest rate possible to maintain accuracy in the combustion calculations
- Mechanics
  - Contains the mechanics, cooling system and fuel systems
- Air path and combustion models are split by replacing the intake and exhaust runners with a transmission line element
  - This is a numerically stable approach to replace the volume model with an approximation of the dynamics
  - Well established method for decoupling fluid models for multi-core simulation
- Successfully running with Engine Test Harness in Dymola and Simulink

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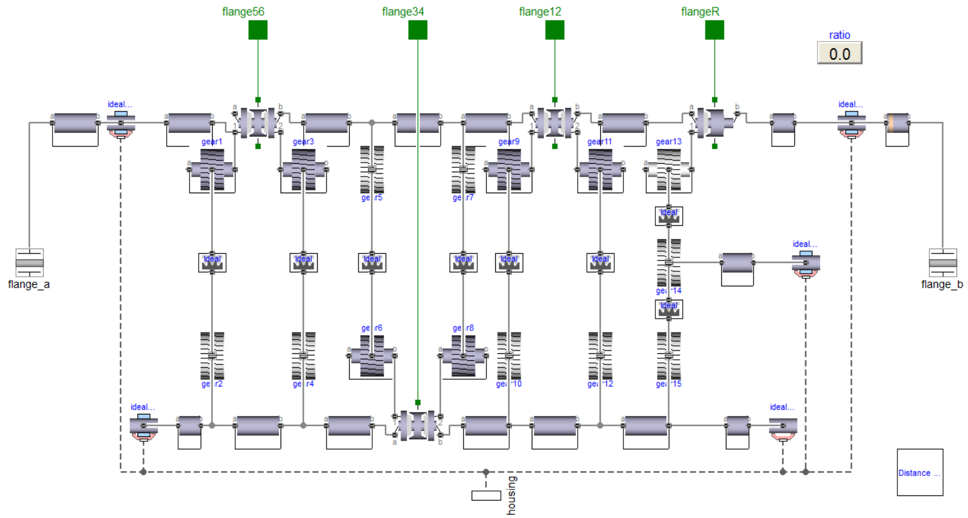
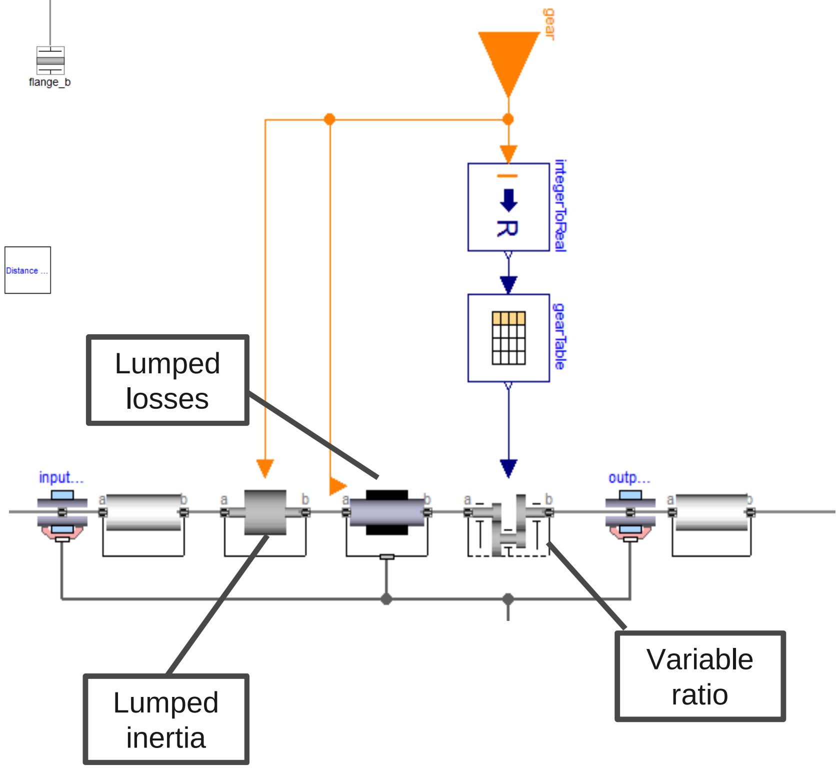
Simple gear set model obtained by model reduction



- A model reduction method was developed for the PT Dynamics library
- Starting from a detailed transmission model (above diagram), the model reduction function lumps the individual component inertias and losses for each gear
- Represents a potential 30 – 60% saving in CPU time



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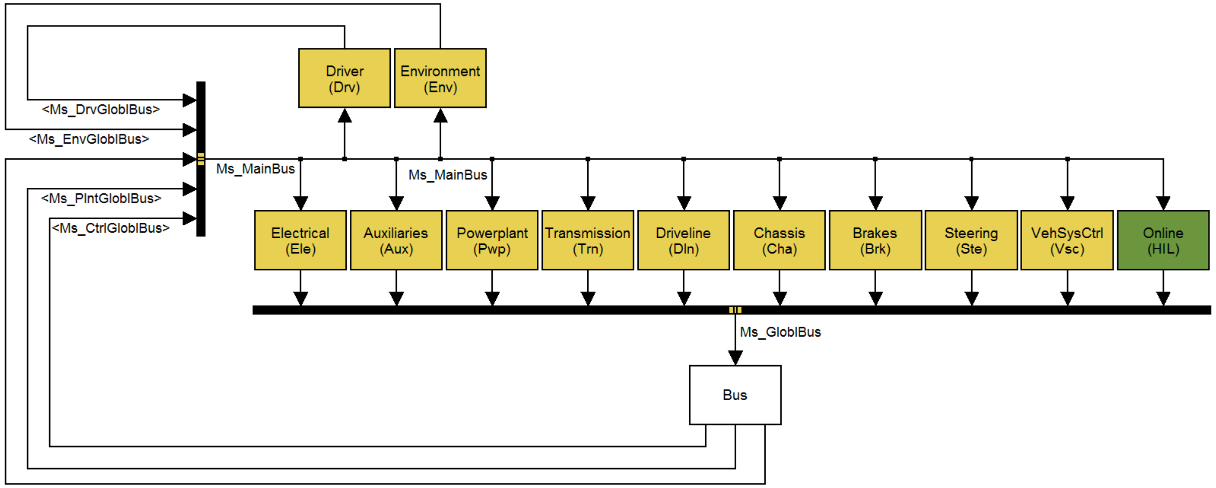
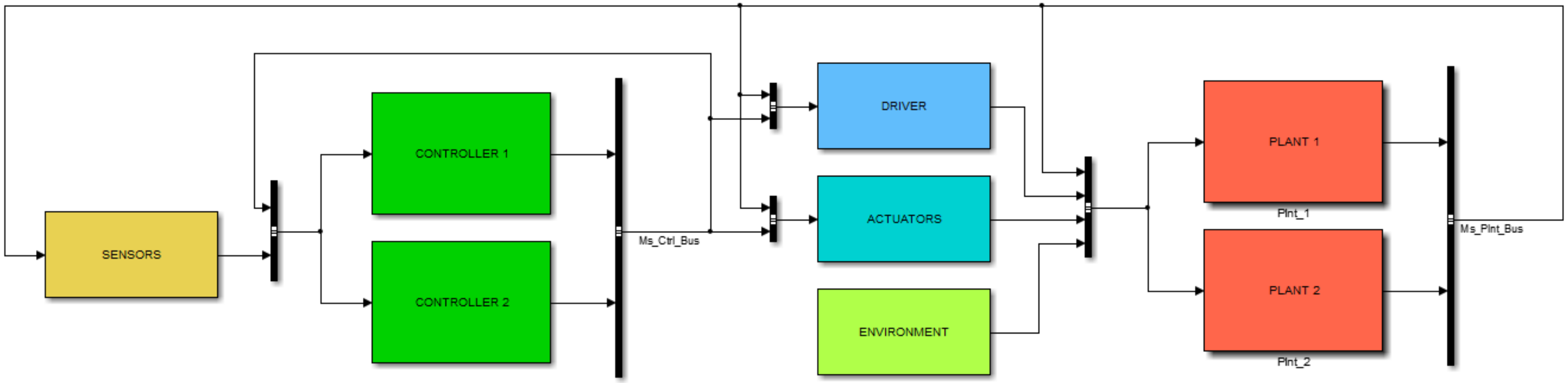
Model Interface and New Architecture



- The VMA[1] layout combines a plant and a controller to a specific vehicle subsystem, e.g. “Pwp – Powerplant”
- This creates challenges in the interface when a particular controller spans more than one system, e.g. PCM includes ECU and TCU. Where should this controller go? Pwp, or Trn subsystem?
- Use of dSPACE multiprocessor capability requires that inter-processor communication take place between a single subsystem at the top level of the Simulink model. VMA makes it difficult to separate control and plant to separate processors.
- New architecture allows ‘n’ controller subsystems and ‘m’ plant subsystems, giving extendibility.
- New architecture also considered SIL and HIL controllers in the same subsystem, hence giving them a common interface allow fast inter-change. VMA isolates HIL in a separate subsystem.
- New architecture combines sensor and actuator models at the top level. Many sensor and actuator models are common for SIL and HIL.
- Only subsystems that need communication have been connected, aiding signal traceability.

1. “A Vehicle Model Architecture for Vehicle System Control Design”, SAE International 2003

Model Interface and New Architecture



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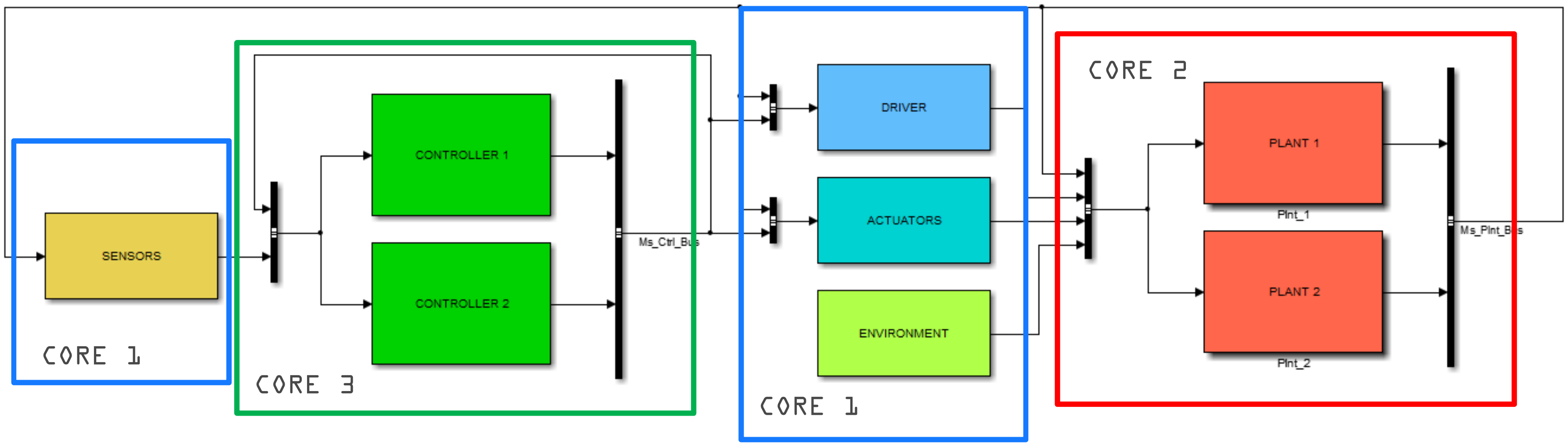
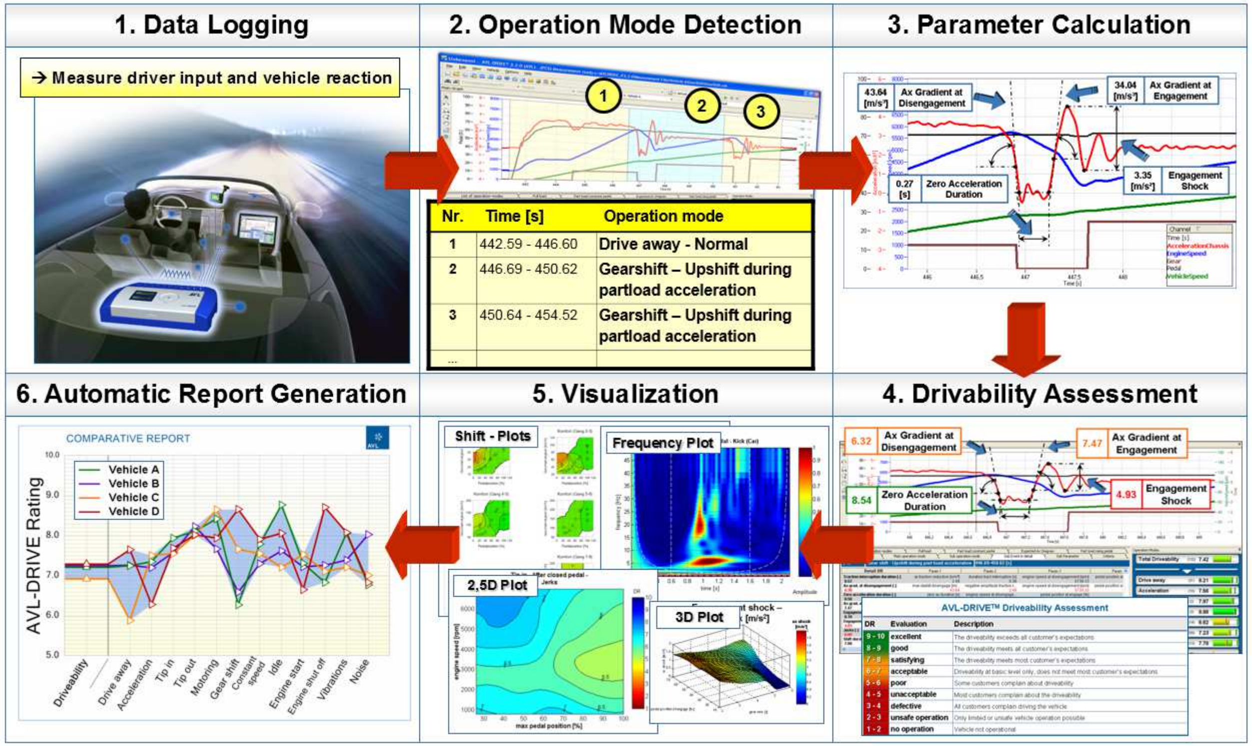
Use of Multiprocessor in HIL



- New architecture also aids use of dSPACE multiprocessor technology, as the model must be separated to each core at the top level of the Simulink interface. Each core gets a separate model.
- dSPACE multiprocessor interface is a move away from current implementation at Ford.
- Other groups have performed some testing, but so far it hasn't been used for full production controller testing.
- It gives the potential for more detailed models to be used on the HIL rig, by splitting the computation overhead amongst cores or processors.
- So far in MORSE project some initial tests have been carried out by splitting a vehicle model and dummy controller onto separate cores.
- The new model architecture has also been tested for multiprocessor implementation using simple blocks, no physical models.

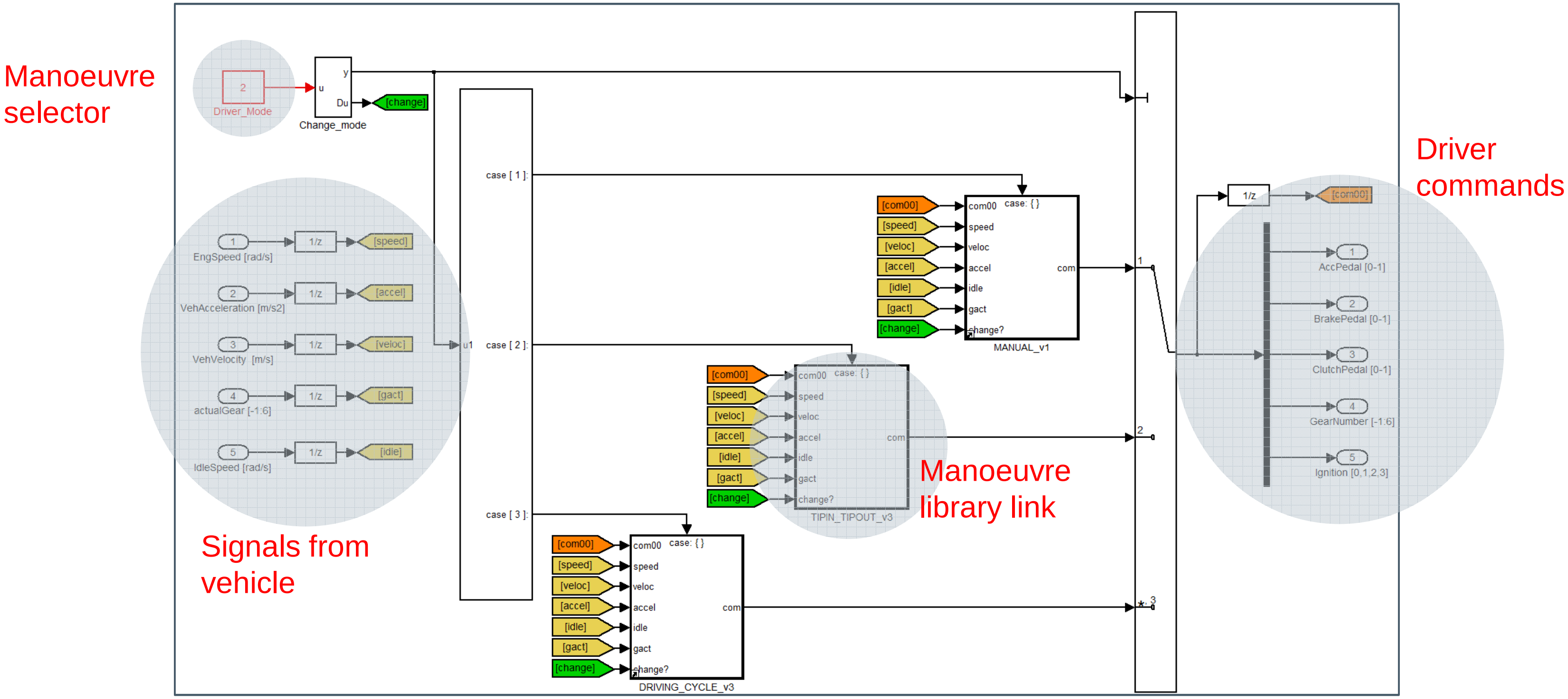
AVL-DRIVE™

- Driveability describes the qualitative assessment of the vehicle's response to the driver's input.
- AVL-DRIVE™ is a real-time tool to accelerate the process of establishing high quality vehicle driveability in an objective and standardised manner.



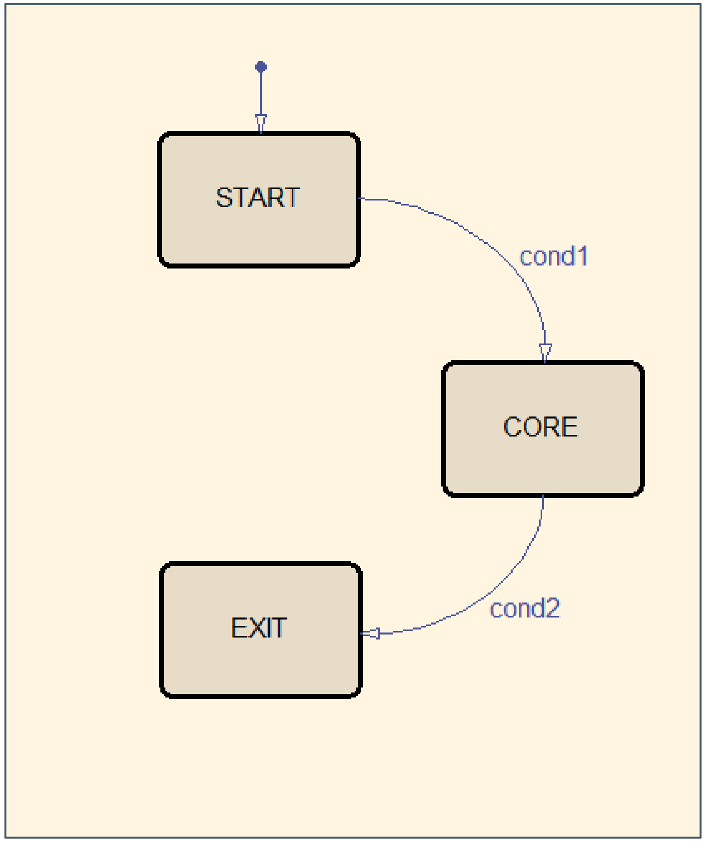
AVL Driver model (I)

- AVL Driver is a collection of manoeuvres (stored in library) that the user can perform through case selector.
- Feedback signals from vehicle model are used to allow the driver to work intelligently, modifying the pedal positions to perform the desired manoeuvre.



AVL Driver model (II)

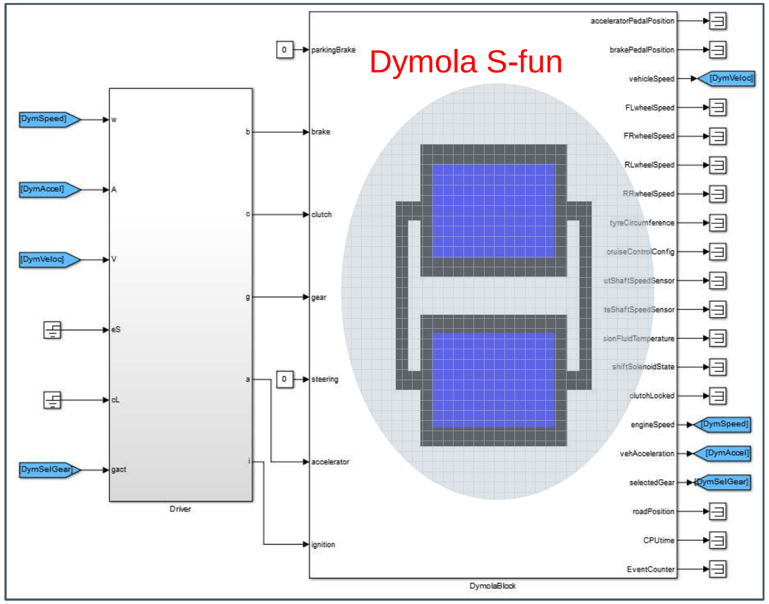
- Separate Simulink/Stateflow state-machines are used to implement the drive manoeuvres.
- Start procedure is to place the vehicle and engine into a suitable state to begin the desired test.
- Core procedure implements the logic of a predefined manoeuvre
- Exit procedure ensures the vehicle and engine are returned to a safe and steady state to allow smooth transition between manoeuvres.

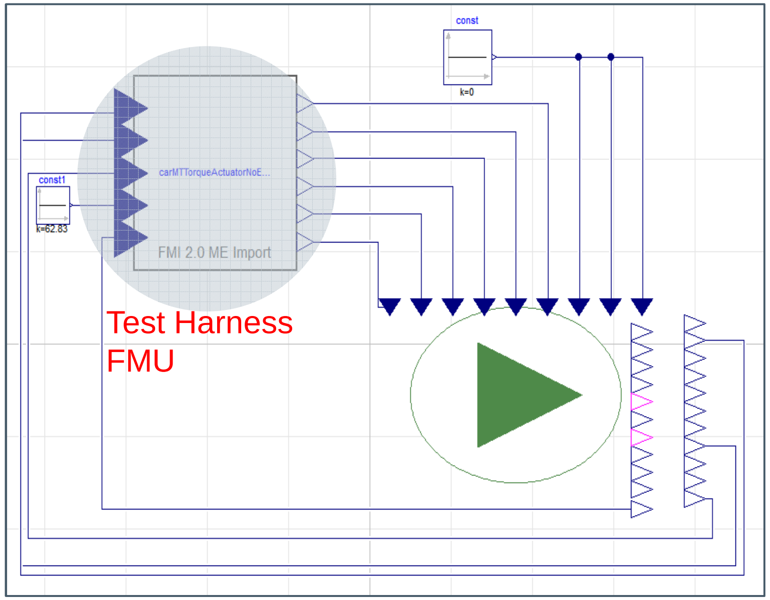


Engine/Vehicle Test Harness (I)

AVL has created test harness models in Simulink to perform sign-off tests for the Dymola models in two steps:

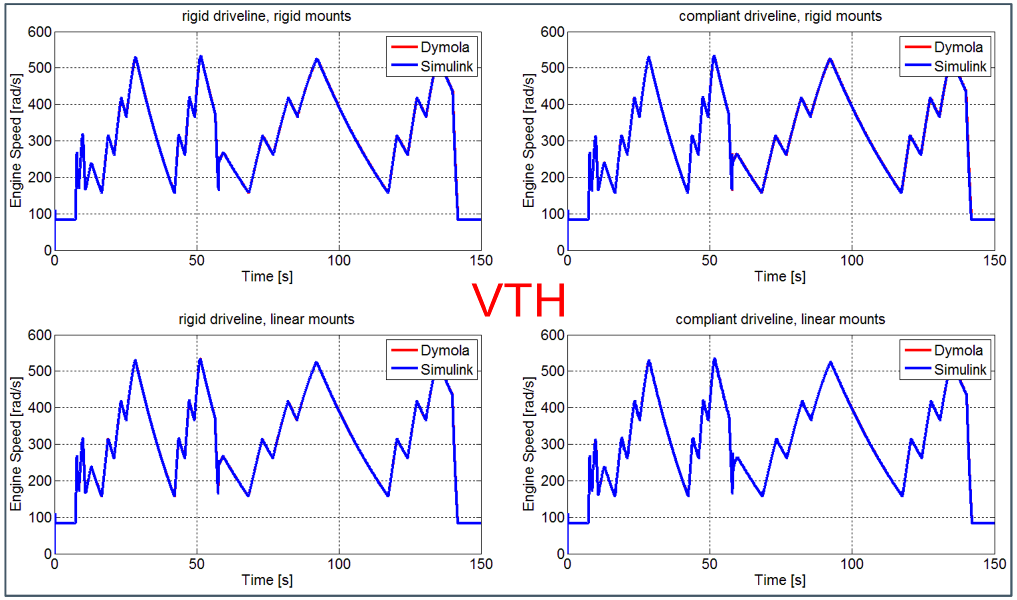
1. Test in **Simulink** with Dymola S-function
2. Build the FMU of Simulink test harness to be used directly in **Dymola**
3. Compare results from both simulation environments

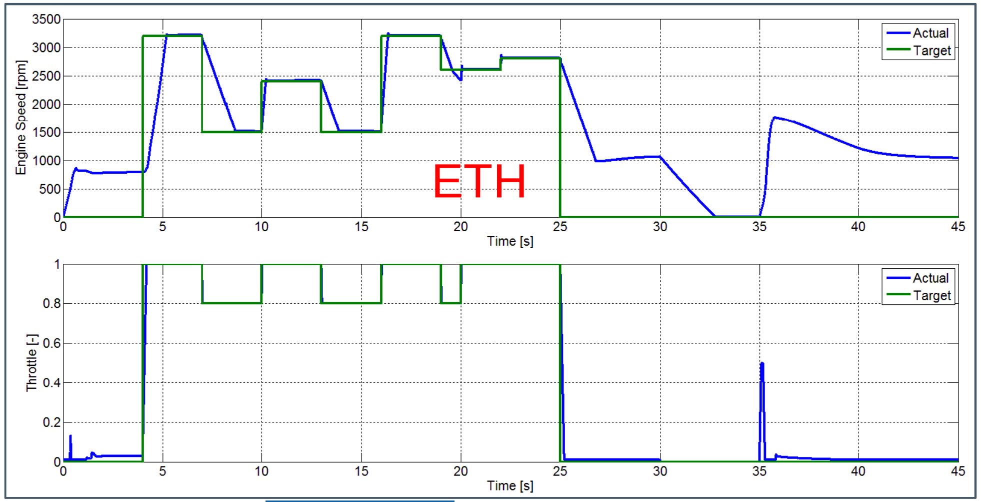




Engine/Vehicle Test Harness (II)

- Vehicle Test Harness (VTH) includes a driver model and a mapped engine
- The tested vehicle has a torque actuator to be interfaced with VTH engine
- Engine Test Harness (ETH) is a simplified controller fulfilling the Ford Engine Interface
- ETH is used to perform engine start, idle controller, dyno test, deceleration fuel shut-off, engine shut-off and engine re-start.





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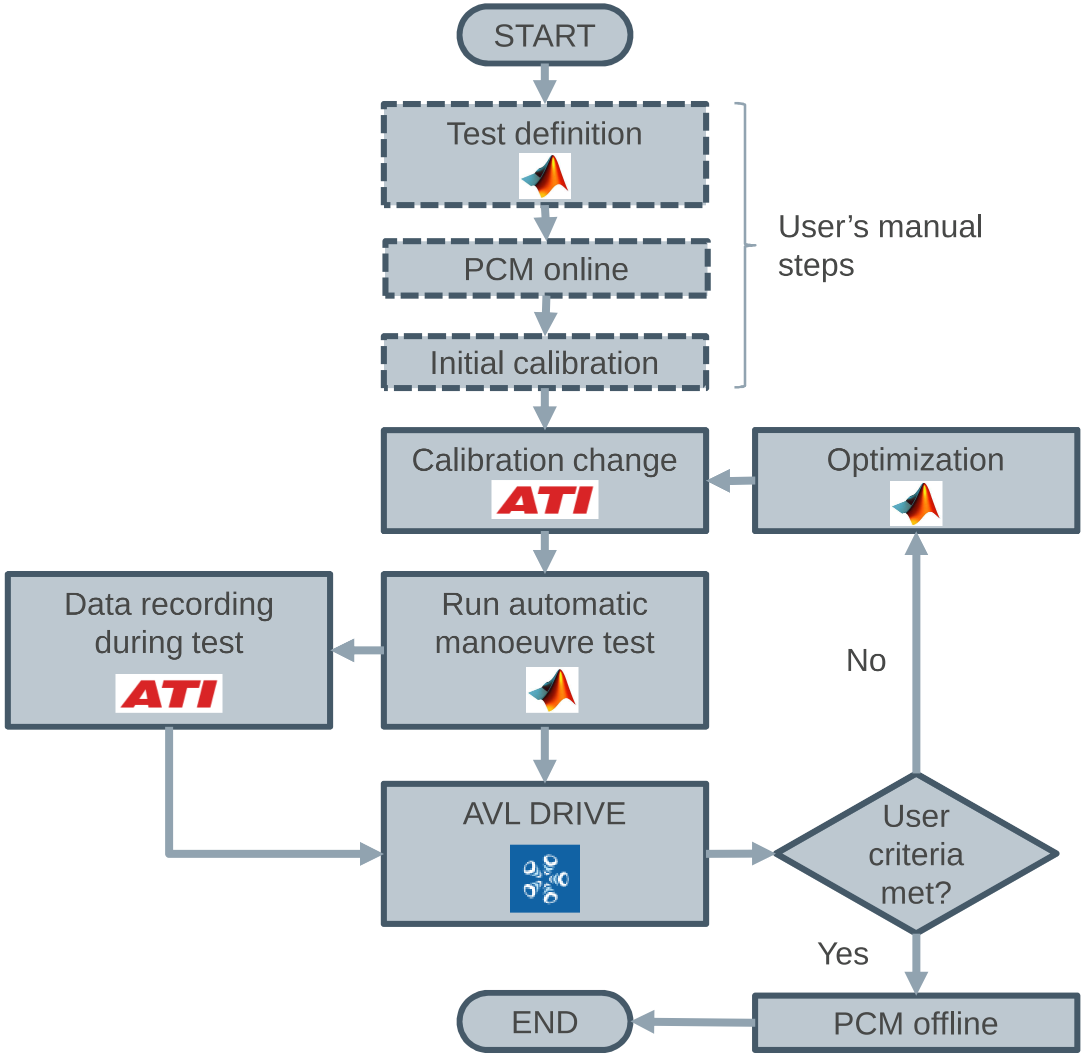
Automated driveability calibration optimization process – SIL (I)

Automated MATLAB routine to:

- Communicate with calibration software ATI Vision
- Run the SIL test of the model (controller, driver, Dymola vehicle)
- Call AVL DRIVE and import test recorded data to generate the objective driveability ratings
- Optimize driveability ratings and update the set of test parameters for the next iteration

The process can be easily adapted for HIL test

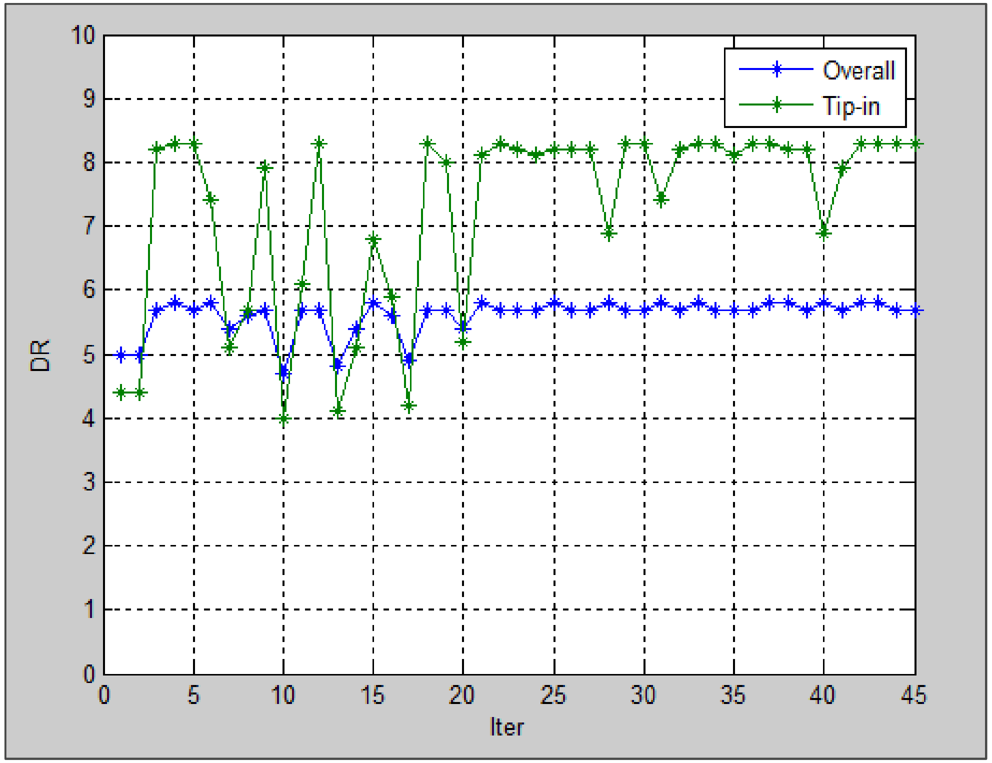


Automated driveability calibration optimization process – SIL (II)

Example of automated driveability calibration optimization

- To maximize drive ratings for both "overall" and "tip-in"
- By changing an entire column values of 2D Table within the a particular driveability PCM function
- During a tip-in/tip-out test for several engine speed and fixed throttle position

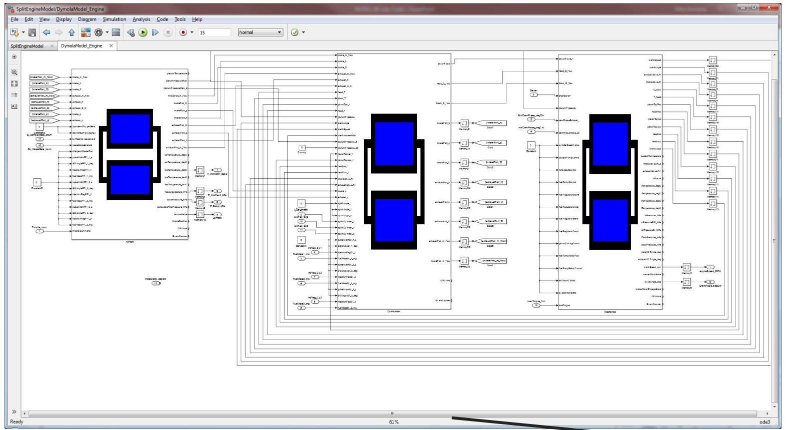
Driveability optimization process shows good convergence after 45 iterations.



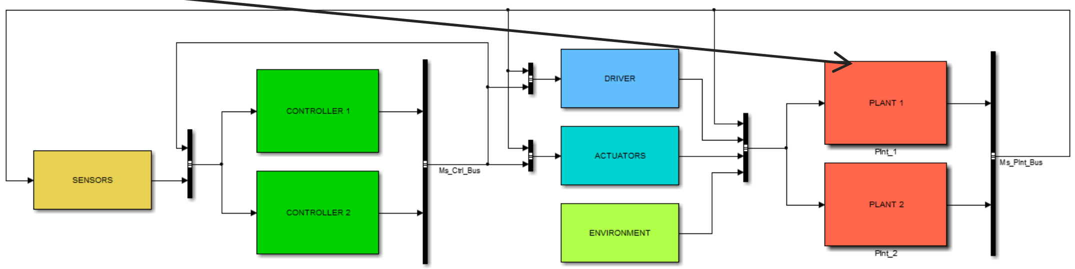
Go Further

FUTURE WORK & CONCLUSION

Future Development



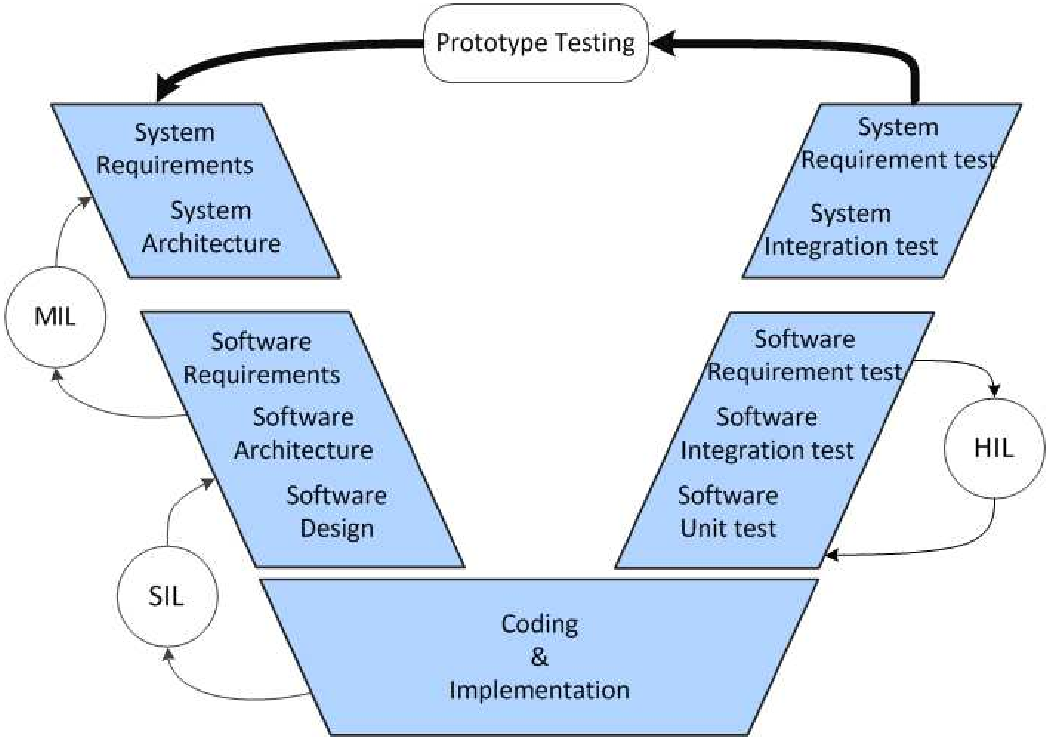
- Integration of Dymola Wiebe function model into Simulink model architecture.
- Testing of this in SIL and HIL environments with PCM.
- Extension to use the predictive combustion model.
- Use for driveability and OBD calibration.



Additional Work:

- Improvement of drivability optimization routine, validation against in-vehicle test data.
- Testing of OBD fault paths and extension of OBD tests using physical fault insertion (e.g. leaks, misfire).
- Testing of parameter and workflow utilities.

Conclusion



- Model modularity has been key to MORSE project, many different models have been integrated.
- Models come from increasingly many sources, so quick integration and use in SIL and HIL will aid model usability.
- There is no one perfect model solution, and many models will be needed for different tasks.
- Creating tools to enable carry over of engineers work to new models enables increased reuse of models, preventing costly ‘redesigns’ and duplication.
- Tools that can automatically take a model and reduce it to a simpler model, albeit with less bandwidth, can enable reuse of models where execution speed becomes a problem. e.g. SIL to HIL.
- MORSE project has addressed these issues and provided a framework to develop innovative solutions.

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THANK YOU FOR LISTENING

ANY QUESTIONS?