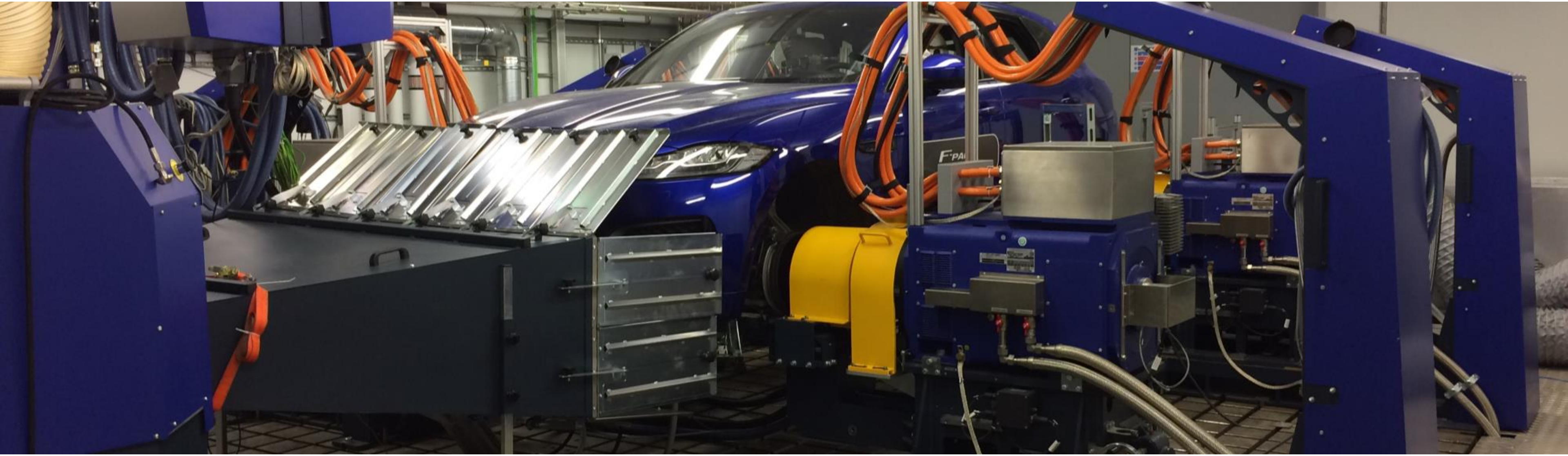


VEHICLE IN LOOP TESTING

HIGHLY EFFECTIVE VEHICLE INTEGRATION AND VALIDATION

Sulabh Dhingra, Paul Quinney
27rd April 2019

Key Agenda Topics

- Introduction to Vehicle-In-Loop Testing : The concept
- Modern Development Strategy : Left Shifting & Integrated Powerpack Approach
- Test Data Visualisation and Logging : MultiSync of Testbed & Vehicle BUS Networks
- Use Cases on a Typical Development Program
  - Example Use Case 1 : Emissions Development and Validation Testing
  - Example Use Case 2 : Eco-Stop, SOTM & Change of Mind Validation Testing
  - Example Use Case 3 : OBD Robustness Testing
  - Example Use Case 4 : Driveability Sign-off Testing
  - Example Use Case 5 : Driveline and Brake Drag Loss Measurement
- Summary

Introduction to Vehicle-In-Loop Testing : Testing Effectiveness

Vehicle in loop (ViL) testing involves testing key powertrain and non-powertrain vehicle functions by replacing all the wheels/tyres with hub dynos.

Its called In-the-Loop testing because,

- ❑ Test bed software toolchains can
  - ❑ Demand the vehicle to perform a manoeuvre and other specific actions
  - ❑ Monitor the vehicle response to the demand
  - ❑ Very effectively control the vehicle behaviour in a closed loop
- ❑ Test noise factors can be controlled with a much higher degree of fidelity compared with chassis dynos

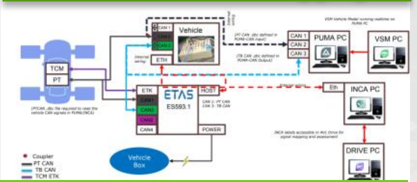
This test environment benefits from a high degree of test process and data - **R**epeatability & **R**eproducibility due to,

Automated Actuation

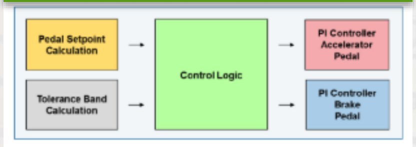
By-Wire Controls

Automated Conditioning

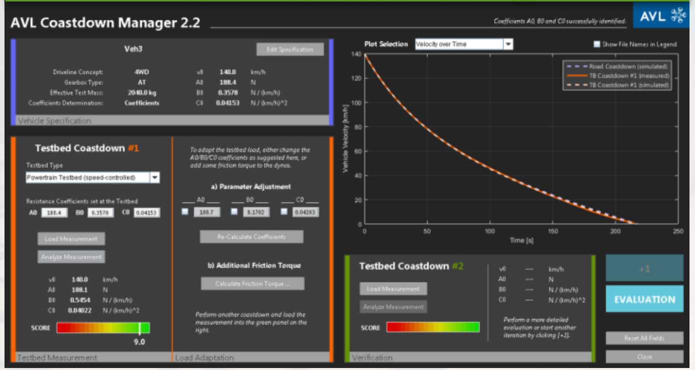
Automated BUS Logging



Robust Software Driver



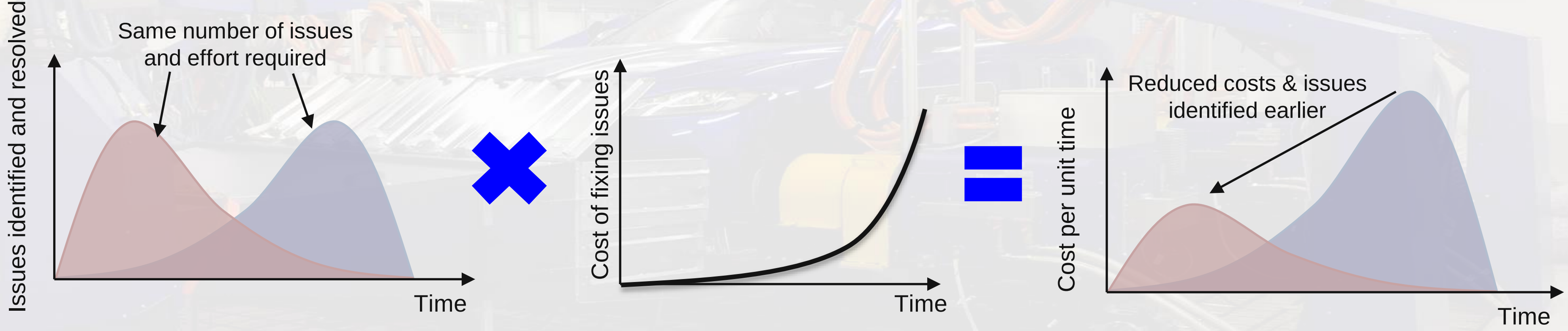
Robust Road Load Matching



& More…

Modern Development Strategy : Left Shifting & Integrated Powerpack Approach

- More complex programmes with shorter timelines require a new approach
- Left shift refers to pulling ahead calibration tasks using new testing methods and environments



- Vehicle in the loop powertrain test beds provide an environment where vehicle utilisation is much higher than on a test track or chassis dyno
- High levels of instrumentation allow for more data to be captured in a single location and shared between teams

Modern Development Strategy : Left Shifting & Integrated Powerpack Approach

- **Vehicle in the Loop allows for precise and targeted validation of powertrain performance testing in a repeatable controlled environment**
  - Engine calibration
    - Emissions – RDE and Certification Cycles
    - Transient Performance
    - Robustness / OBD
  - Transmission & Driveability calibration
  - Full powertrain integration validation
    - MHEV to IC Interactions
    - Targeted stress-testing of HEV functions
  - Full driveline analysis

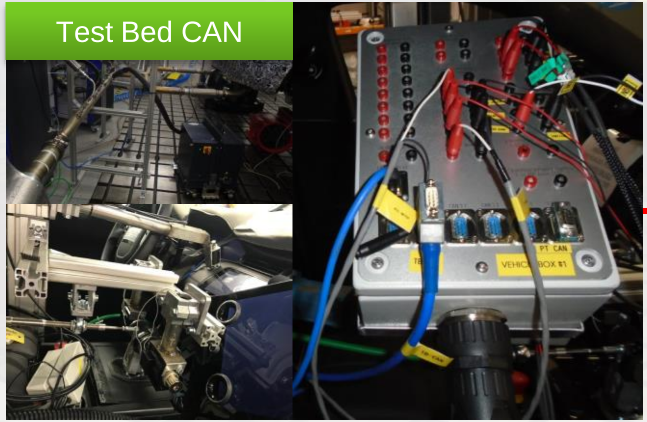
Data Visualisation and Logging : MultiSync of Testbed & Vehicle BUS Networks

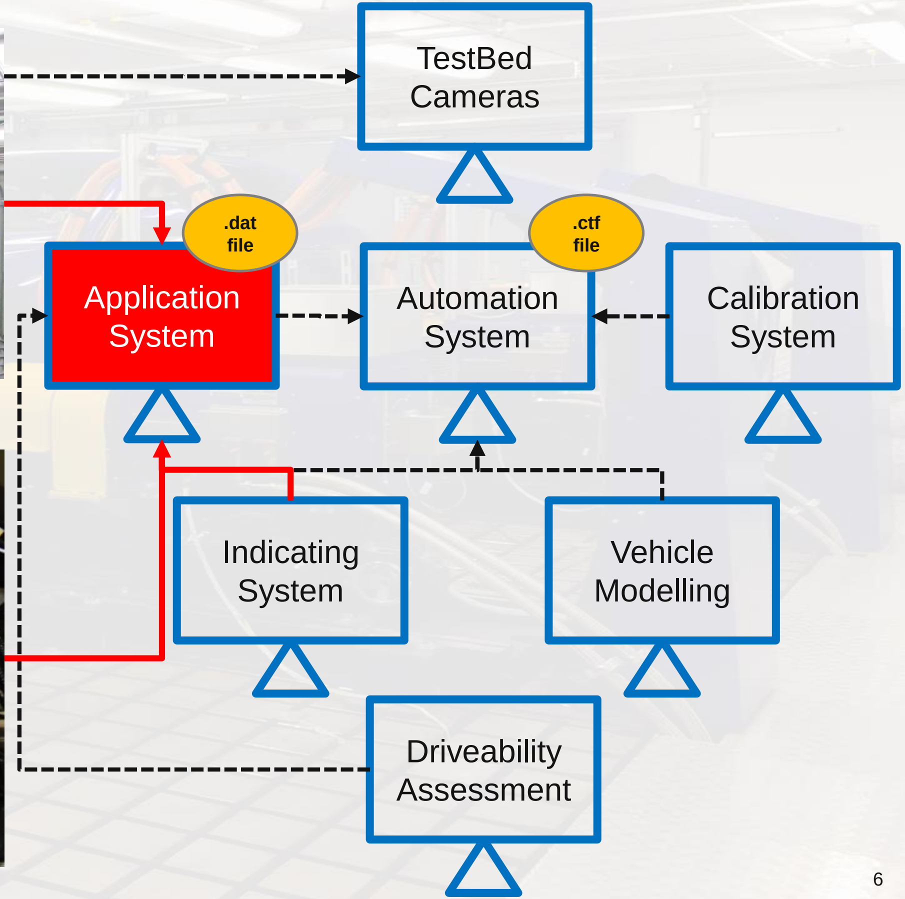
- PCM
- TCM
- Engg. Test Port
- Flexray
- Inst. CANs

Vehicle Modules

- Instrumentation
- Modal Emissions
- Dyno Controls
- Boundary Cond.
- Signal Emulation
- Vehicle Controls

Test Bed CAN





Example Use Case 1 : Emissions Development and Validation Testing

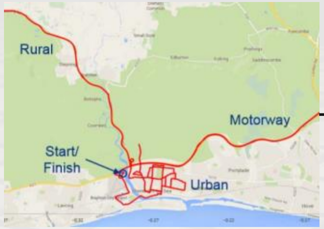
- ViL test beds can be used for emissions development and full calibration sign-off work.
- Typical test program involves calibrating vehicle after-treatment systems manually as well as using CAMEO.
- The developed calibrations are validated by running legislative, RDE and various city driving cycles.
- The developed test methodologies allow almost 100% automation of the testing process.

Automation of Emissions Validation Cycles

- Cycle Selection
- Logging Experiment Selection
- Working Dataset Selection
- Cycle Start Temps
- Emissions Device Selection
- LV and HV SOC Conditioning
- DPF Regens/Cal Changes
- Wheel Speed, Gradient, Acc. Pedal & Brake

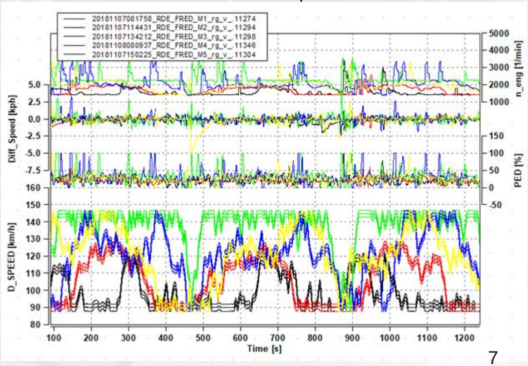
JLR Cycle Library

Legislative & Customised Cycles



Real Road Drive Traces

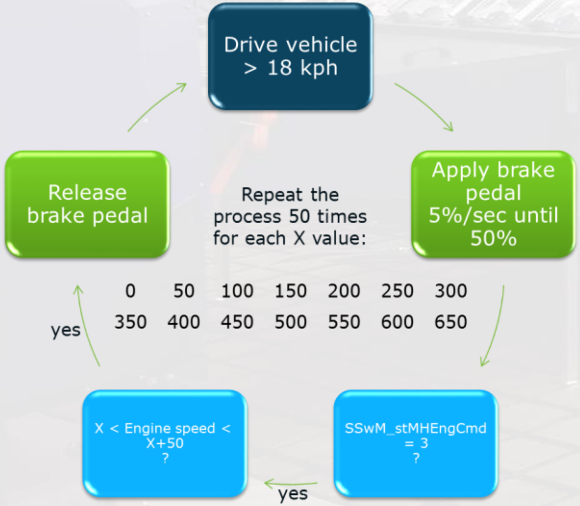
Typically 13-17 Cold WLTCs can be performed in 24hrs

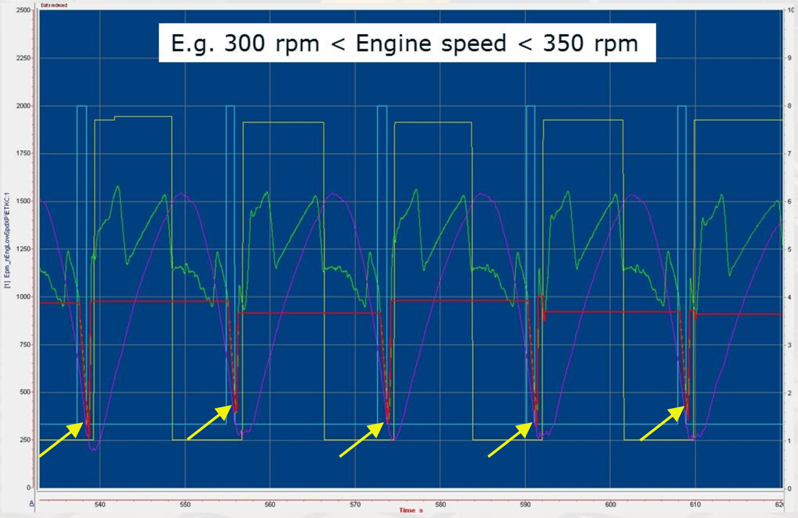


Example Use Case 2 : Eco-Stop, SOTM & Change of Mind Validation Testing

- Most modern cars with MHEV architecture allows vehicle to do an Eco-Stop as well as Stop-On-The-Move (SOTM)
- The system allows vehicles to achieve fuel economy gains and lower tailpipe emissions
- These functions are normally quite complex due to,
  - Multiple system inhibits – **At least 30**
  - Gradient and temperature dependence
  - Driver often changing his/her mind – **Anywhere between Idle to 0 engine rpm**

In Real World, replication is almost impossible !





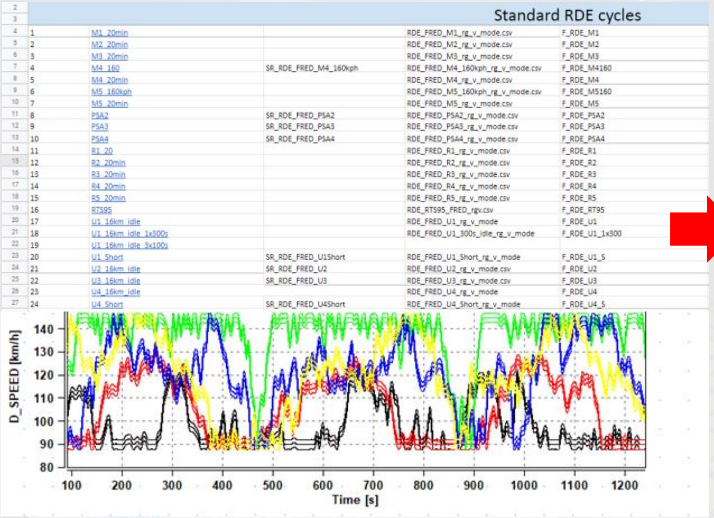
- Typically 3000 cycles/day
- +-12% gradient tested
- +14 to +40ºC tested
- BiSG and fuelling restarts can be replicated
- High repeatability
- High reproducibility
- Multiple calibrations can be tested

Example Use Case 3 : OBD Robustness Testing

- ViL test beds can be used for validating robustness of OBD monitors/functions.
- Use case involves validating the series production calibrations.
- A typical test program involves – running multiple transient cycles with forced inserted faults using DCMs.
- Method allows understanding of how the inserted fault effects the Engine Out & Tailpipe emissions.
- A typical test program also involves – replicating real road cycles to recreate DFCs seen during road testing
- The developed test methodologies allow almost 100% automation of the testing process.

Testing fully automated !

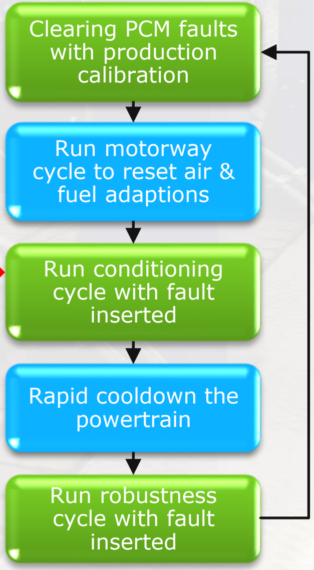
Comprehensive ViL Test Cycle Library



Typical OBD Use Case Program

- Fully automated clearing faults
- Fully automated dataset changes
- Fully automated soaks and rapid chills
- Fully automated cycle running

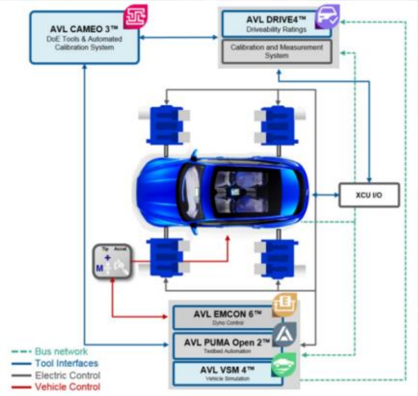
Test Methodology



Example Use Case 4 : Driveability Sign-off Testing

- Vehicle driveability on ViL test beds can be objectively assessed.
- A typical use case involves – A Road to Rig correlation of driveability KPIs via assessment of longitudinal acceleration signal.
- Once correlation is proven – ViL test beds open the world of opportunities for Performance and Driveability critical test work

Vehicle baselined on test track using driving robot → Vehicle Body and Chassis components modelled on ViL → Manoeuvres Replayed on ViL → Vehicle NGD model calibrated & validated → Run driveability sign-off manoeuvres



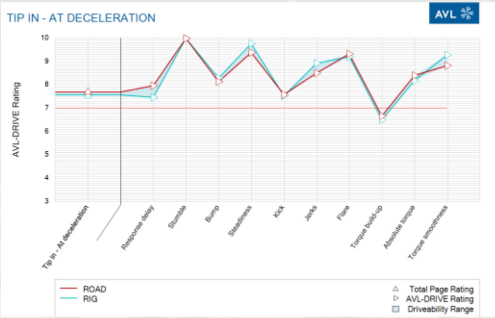
Manoeuvres driven on road and replayed on ViLs for correlation

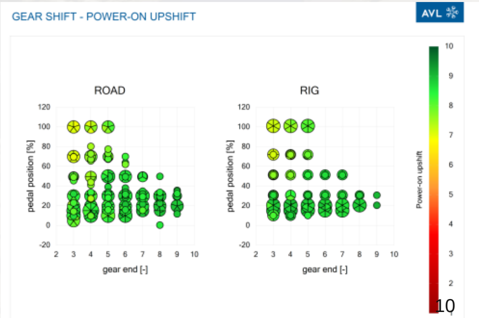
- Vehicle road load measurements
- Full Load Accelerations in D & S2/3
- Tip-Ins and Tip-Outs in S2/3

Manoeuvres driven on ViLs using vehicle model

- Full Load Accelerations
- Tip-Ins and Tip-Outs
- Power-On-Upshifts
- Coast Downshifts
- Tip-In Downshifts
- Tip-Out Upshifts
- Driveaways & many more….

Up to 700 critical PED manuavers can be ran in a week of test bed time !





Example Use Case 5 : Driveline and Brake Drag Loss Measurement

- ViLs can be used to baseline vehicle Driveline Losses and Brake Drag Losses
- Aim is to capture and quantify the contribution to tailpipe CO_2 emissions
- DLT* have interest in both aspects where BDT* is mainly focused on brake drag...

Original vehicle setup — **Day 1, Shift 1**

↓

Driveline Loss Measurements with driveshafts ON & Brake Pads ON ⟷
- ✓ Different transient cycles
- ✓ With and Without driveshafts
- ✓ Hot and Cold driveline

↓

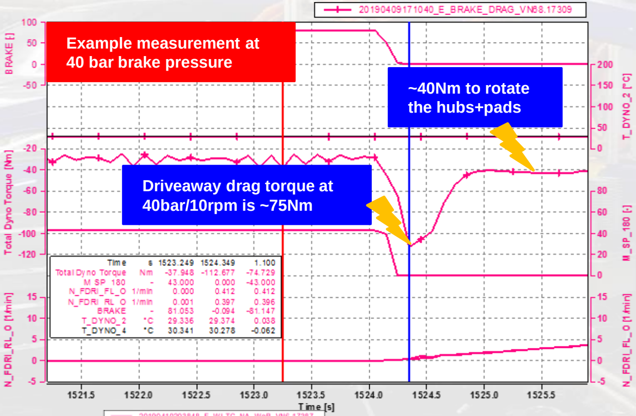
Vehicle modification

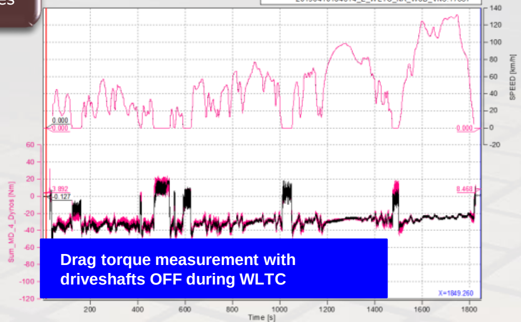
↓

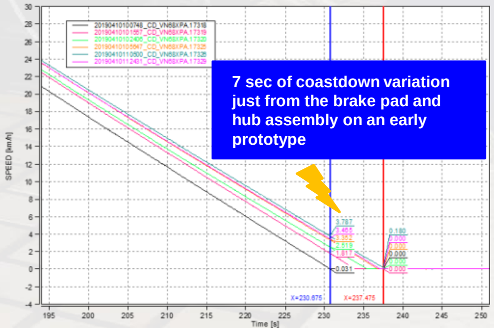
Driveline Loss Measurements with driveshafts OFF & Brake Pads ON ⟷
- ✓ Different brake pressures
- ✓ Different brake disc temperatures
- ✓ Measure drag and residual torques

↓

Brake drag measurements — **Day 2, Shift 6**







*DTL : Driveline Team
*BDT : Brake Drag Team

Summary

- Vehicle in the Loop testing has provided:
  - Opportunity for a repeatable, reproducible fully integrated powertrain test environment
  - High levels of instrumentation and synced data logging that allow issues to be captured and analysed faster
  - Wide breadth of use cases and cycles that can reproduce what is seen on the road
  - Intense and targeted validation of sub-system interactions
  - A highly automated test environment that allows for more data to be generated and for more in-depth high quality data analysis

THANK YOU

Sulabh Dhingra
Lead Engineer – Testing & Methodology Development
Powertrain TestBeds, Jaguar Land Rover
AVL Technical Center, Coventry

M +44(0)7341074325
sdhingra@jaguarlandrover.com

Paul Quinney
Lead Engineer – Calibration Methodology
Diesel Calibration
Jaguar Land Rover

M +44(0)7384 238 823
pquinney@jaguarlandrover.com

Jaguar Land Rover
W/1/26 Abbey Road, Whitley
Coventry CV3 4LF, UK

jaguarlandrover.com