Driving Simulation for the Development of Electrified Powertrains

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McMaster Automotive Resource Centre (MARC)

Transportation Electrification and Smart Mobility @ Mac

- One of the largest in academia in North America
- 400+ researchers
- $250+ million in programs & initiatives
- Unique relationships with major OEMs & Tier 1/2 suppliers
- Collaborations with private & public sector organizations

McMaster Automotive Resource Centre (MARC)

- 4 world class research groups under one roof
- Located at McMaster Innovation Park (MIP)
- 80,000 ft^2 - unparalleled in North America
- 40,000 ft^2 expansion in Q1 2022

Research and Development Areas

- Electric & hybrid vehicles
- Autonomous vehicles
- Electrified powertrains
- Electric machines
- Motor drives/inverters
- Motor controls
- Power electronic DC/DC converters
- Chargers & V2X systems
- Embedded software & controls
- Functional safety
- Energy storage systems
- Energy management systems
- Advanced driver-assistance systems (ADAS)
- Artificial intelligence & machine learning
- Thermal management
- Modeling & simulations
- **Driving simulation**
- Vehicle dynamics

Associated Departments

McMaster Institute of Transportation and Logistics

- Transportation systems level applied research
- Goods (in-port, distribution networks, B2B)
- People (private/public, TaaS/MaaS vs vehicle ownership)

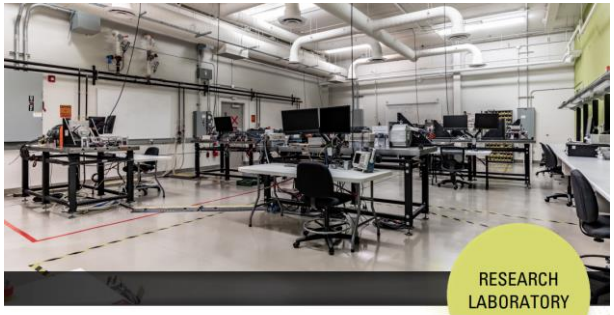
Health, Aging, and Inclusion

- Health monitoring, smart systems, and mobility
- Aging and mobility
- Inclusive design principles and practices
- Critical design thinking

Department of Computing and Software (CAS)

- McMaster Centre for Software Certification / Software Certification Consortium
- Leaders in safety, dependability, and certification of safety-critical software systems (e.g. automotive, nuclear power plant shutdown systems, medical devices, V2X) for 20+ years
- Led a national network ($22M over 5 years, >20 projects) focused on software engineering for automotive sector – key industry partners GM and IBM

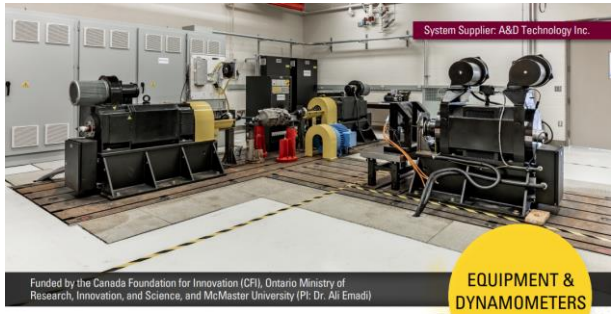
Labs and Equipment



RESEARCH LABORATORY

POWER ELECTRONICS & MOTOR DRIVES LABORATORY

MACHINES & ELECTRONICS



EQUIPMENT & DYNAMOMETERS

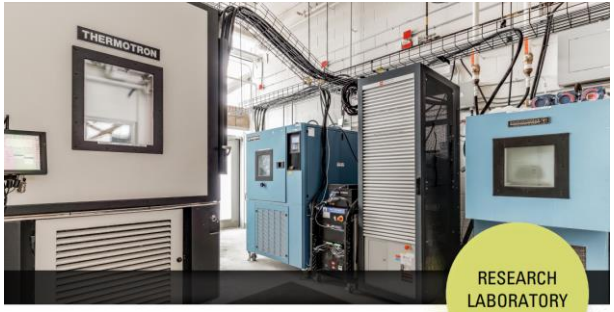
POWERTRAIN TESTER THREE MACHINE

POWERTRAIN DYNO

EQUIPMENT & DYNAMOMETERS

HIGH SPEED ELECTRIC MACHINE DYNO

ELECTRIC MACHINE DYNO



RESEARCH LABORATORY

ENERGY STORAGE LABORATORY

BATTERIES & ULTRACAPS

EQUIPMENT & DYNAMOMETERS

CHASSIS DYNAMOMETER

VEHICLE DYNO

MACHINES & EQUIPMENT

DRIVING SIMULATOR

DRIVER-IN-THE-LOOP

MARCdrive

A driving simulation lab at the McMaster Automotive Resource Centre

MARCdrive

McMaster University | ENGINEERING

BRIGHTER WORLD | CERC@MARC

MARCdrive Lab

A driving simulation lab at the McMaster Automotive Resource Centre

- Immersive environment
  - Full vehicle cabin
  - Active seat and seatbelts
  - Steering force feedback
  - Complete brake system hydraulics
  - 210 deg of field of view / 3 projectors
  - 3D surround sound system
- State-of-the art models
  - VICRT + Matlab/Simulink
  - VI-WorldSim & VI-GraphSim
  - VI-SimSound

MARCdrive Lab

A driving simulation lab at the McMaster Automotive Resource Centre

- Artificial Intelligence and Machine Learning
- Virtual Proving Grounds
- Multi-modal Transportation Systems
- Powertrain System Development
- Hardware-in-the-loop

Powertrain System Development

Powertrain System Development

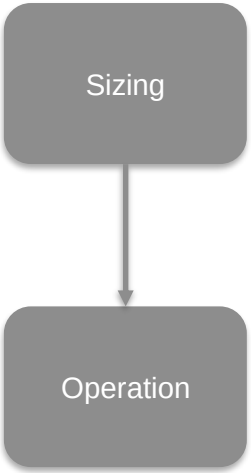
Current scenario in Industry

- Development of new models represents high investment of resources
- Design is highly dependent on prototyping and testing which is costly
- Development activities that relies on physical testing include calibration of different systems such as ECM, AWD, TSM, ABS, EPS, ECS, etc.
- Most level-1 prototypes (“mules”) are completely scraped after their use

Powertrain System Development

Traditional Approach: Virtual Development

- Forward simulation
  - Model-in-the-loop
  - Software-in-the-loop
- Design of control strategies (operation)
- Initial performance assessment (e.g., consumption)
- Component sizing (motor, final drive, battery, etc.)
- Resources
  - Matlab Simulink
  - Ansys
  - …

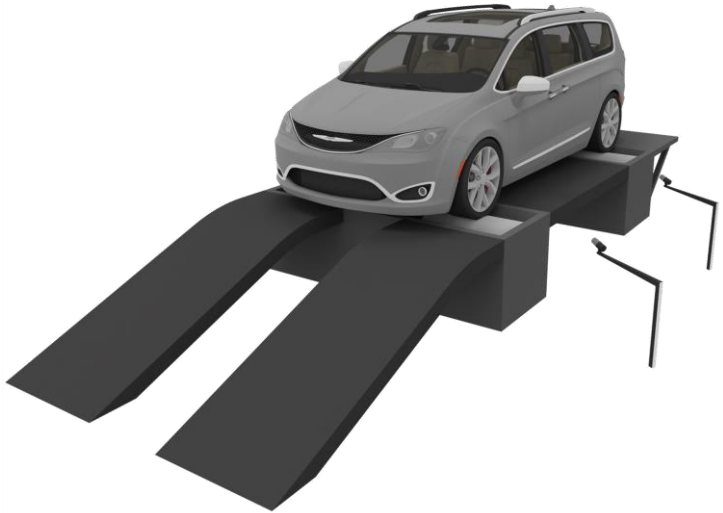


Virtual Development

Powertrain System Development

Traditional Approach: Physical Development

- Physical Experiments
  - In-lab testing
  - Road testing
- System Integration
- User Experience
- Homologation
- NVH
- Resources
  - Vehicle prototype
  - Chassis dyno
  - …



Physical (static)

Physical (dynamic)

Vehicle Testing

Physical Development

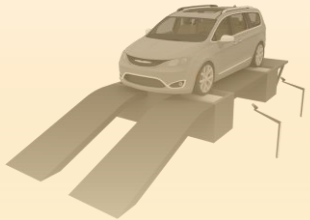
Powertrain System Development

Traditional Approach: Summary

- Simulation
  - Performance requirements
  - Architecture selection
  - Initial sizing
  - Offline optimizations

Virtual Development

- Experimental
  - In-lab experiments
    - Roller-bench, dynamometers
  - Drive cycles
    - Urban, highway, mixed
  - Off-lab experiments
    - Calibration, reliability

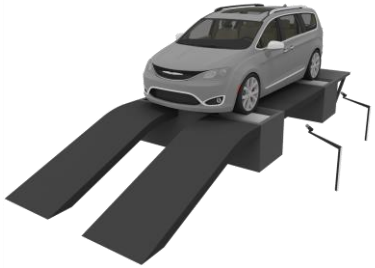


Physical Development

Powertrain System Development

Traditional Approach: MIL, SIL, DIL, HIL

Virtual Development



Physical Development

Model-in-the-loop

Software-in-the-loop

Software-in-the-loop

Driver-in-the-loop

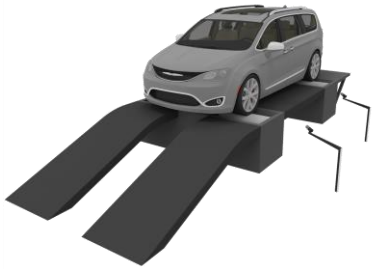
Hardware-in-the-loop

Powertrain System Development

Leveraging Driving Simulation: MIL, SIL, DIL, HIL

Virtual Development

Driving Simulation



Physical Development

Model-in-the-loop

Software-in-the-loop

Driver-in-the-loop

Hardware-in-the-loop

Powertrain System Development

Leveraging Driving Simulation

- Real-time simulation
  - Model-in-the-loop
  - Software-in-the-loop
  - Driver-in-the-loop
- Calibration of controls
- Model integration (HV, Thermal, Mech, Comm, Autonomous)
- User experience/interface (drivability, safety, comfort, HMI)
- NVH
- Resources
  - Static driving simulator
  - NVH driving simulator

Operation

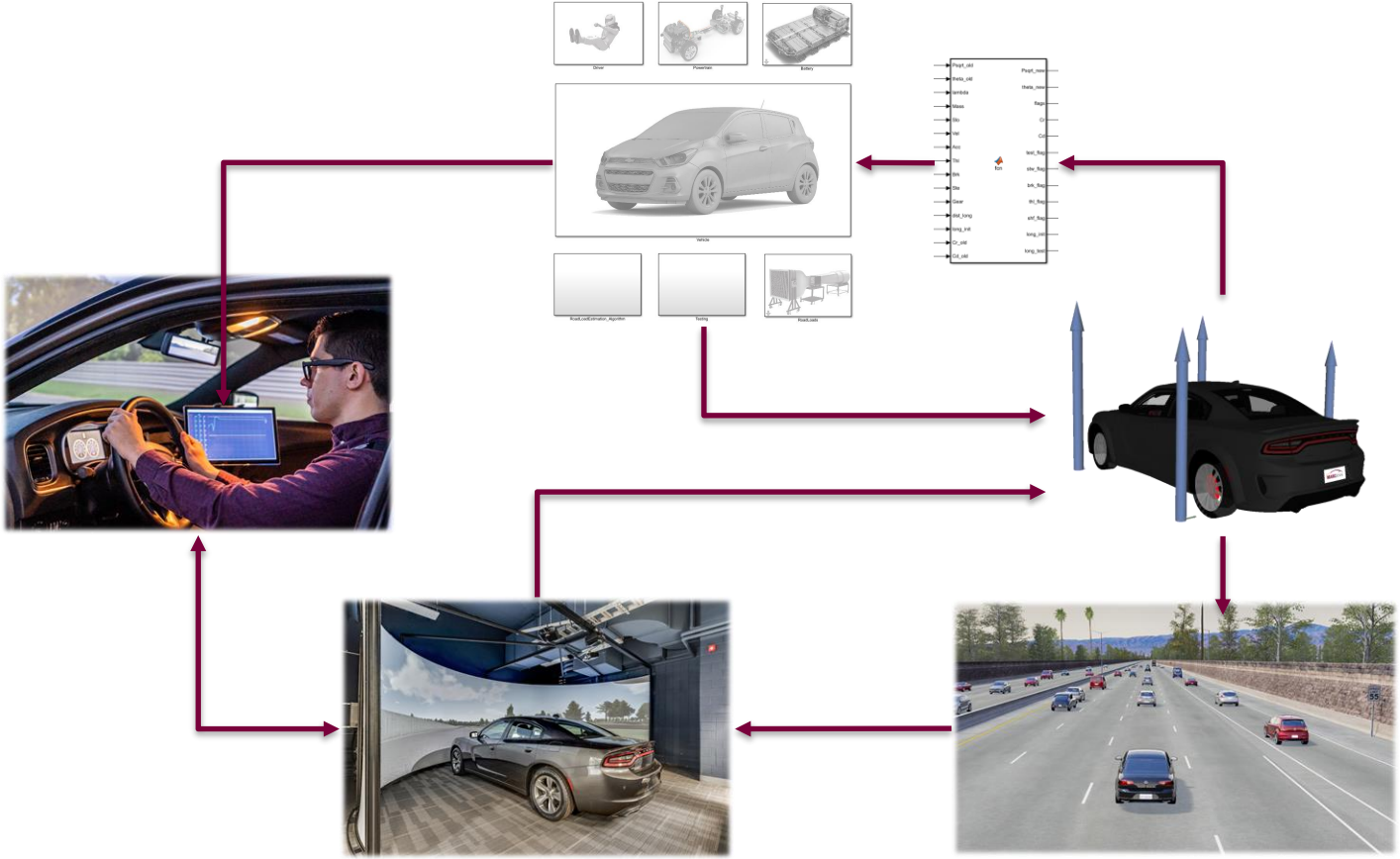
Integration/
Calibration

Driving Simulation

Powertrain System Development

Leveraging Driving Simulation: Methodology

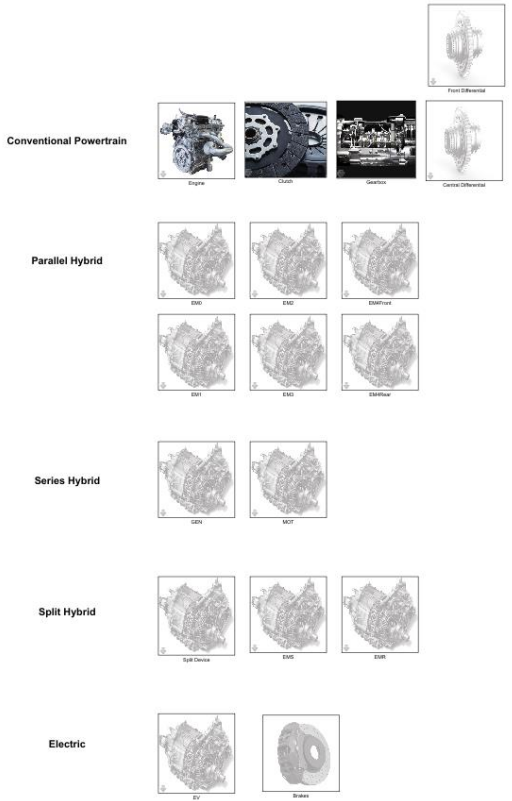
- Modelling of components and vehicle
- Architecture selection in the co-simulation model
- Interchangeable components in the co-simulation structure
- Model validation (experimental results)
- Model ready for testing proposals
- System development on digital twinned environments
  - Driver-in-the-loop
  - Software-in-the-loop
  - Model-in-the-loop
  - Hardware-in-the-loop



Powertrain System Development

Powertrain Modelling

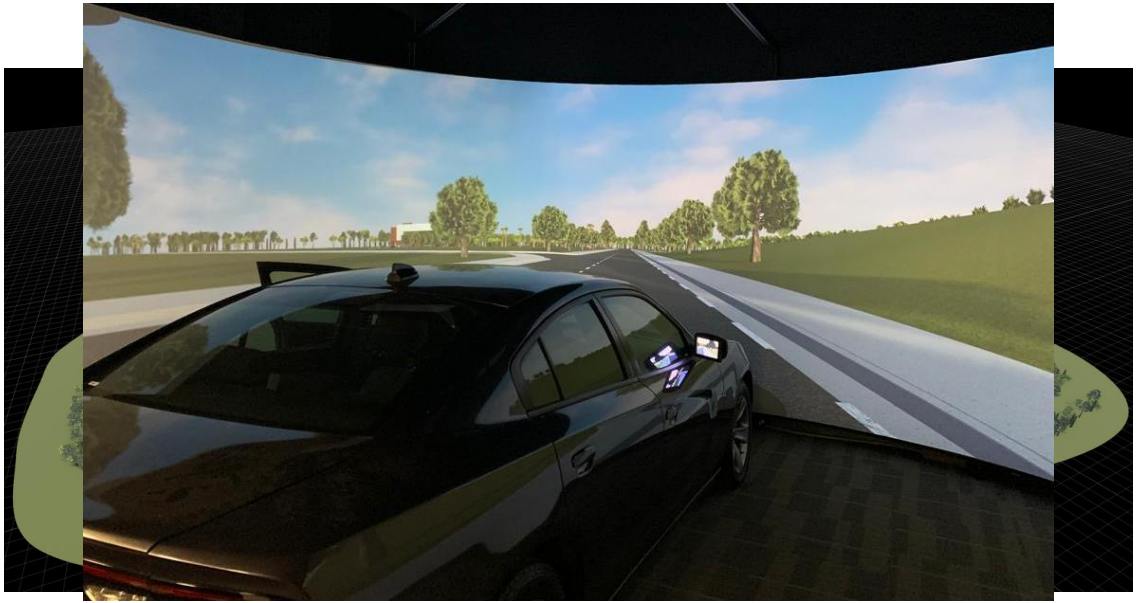
- High-fidelity battery models
  - Equivalent circuit models
  - Physics-based models
  - Thermal models
- Diverse Powertrain topologies
  - BEV, PHEV, SHEV, ICE-only
- Accurate Powertrain component models
  - E-PWT template
- Road load strategies
  - Rolling resistance, drag, grade
  - A, B, C
- Library of tests and drive cycles
- Real-time communication to driver inputs and VICRT model



Powertrain System Development

Virtual Environments: Drivability and Performance Tests

- Diverse scenarios created on VI-WorldSim
  - Proving ground
    - Hills
    - Straights
    - Circles
    - Mock-up city



Powertrain System Development

Virtual Environments: Consumption & Emission

- Diverse scenarios created on VI-WorldSim
  - Urban environments
  - Highway environments
  - Standard roads

Powertrain System Development

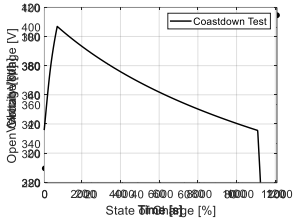
Human Machine Interface

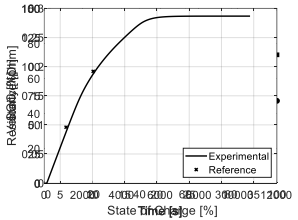
- Rapid model changes
- Real-time visualization of results
- Reduced number of people required
- Built-in consumption tests (drive cycles)
- Built-in performance tests (maneuvers)

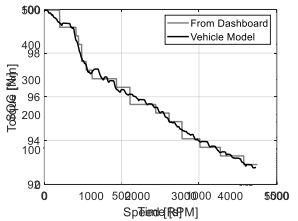
Powertrain System Development

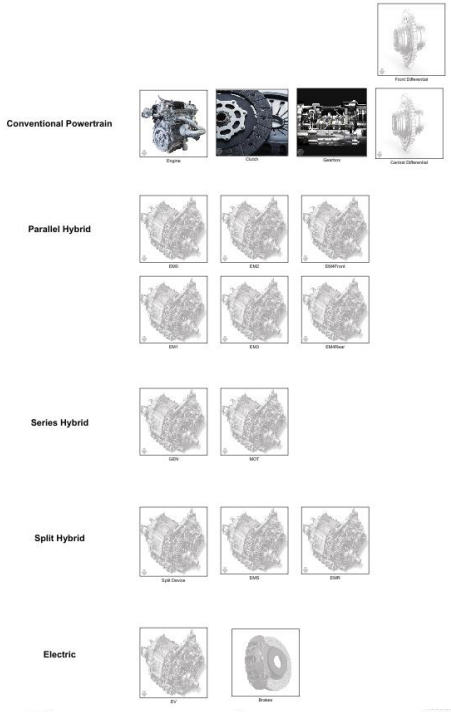
Example

- Modelling of a BEV
  - Powertrain architecture
  - Battery model
  - Powertrain model
- Validate energy consumption
- Validate road load resistance
- Validate powertrain performance
- Model is ready!





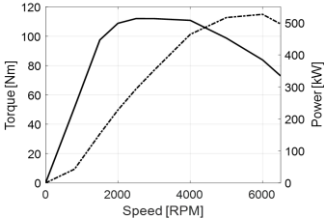


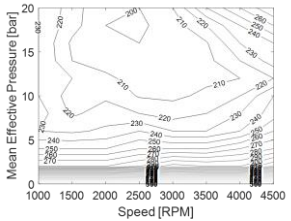


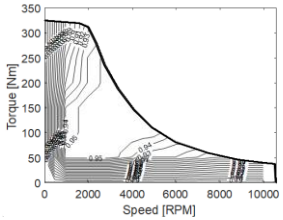
Powertrain System Development

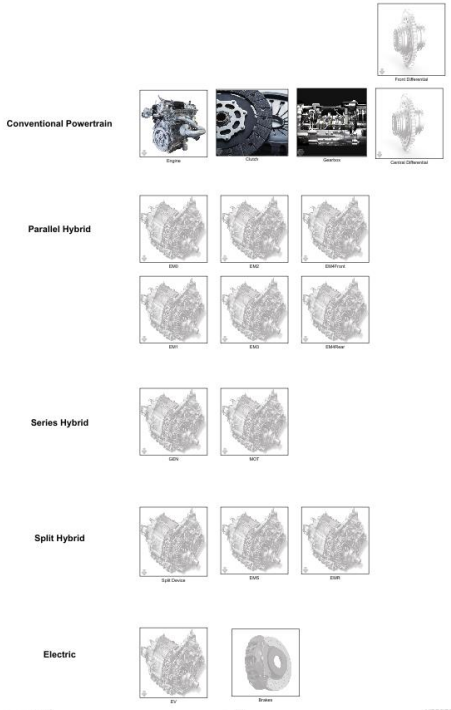
Example

- From BEV to SHEV!
- Assessment of new control strategies
- Fuel consumption
- Drivability
- Performance









“MARCDrive 2.0”

Multiple agents in the loop

(vehicles, pedestrians, bystanders)

MARCDrive

Passengers in autonomous driving simulator

Connect additional drivers in a shared real-time simulation environment

Safely run AI/ML simulations in a multi-agent real-time networked environment

Digital Twins

Vehicle DT on chassis dyno
DTs of real-world environments
Augmented with V2X, traffic management, etc.

Connect pedestrians and bystanders via **LIVELab**

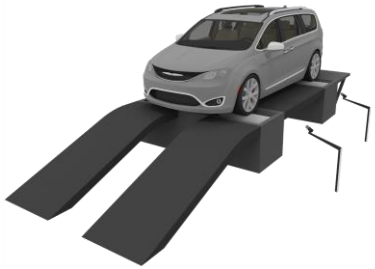
Powertrain Development Strategy

Moving Forward

Virtual Development

NVH Desktop Simulator

Driving Simulation



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