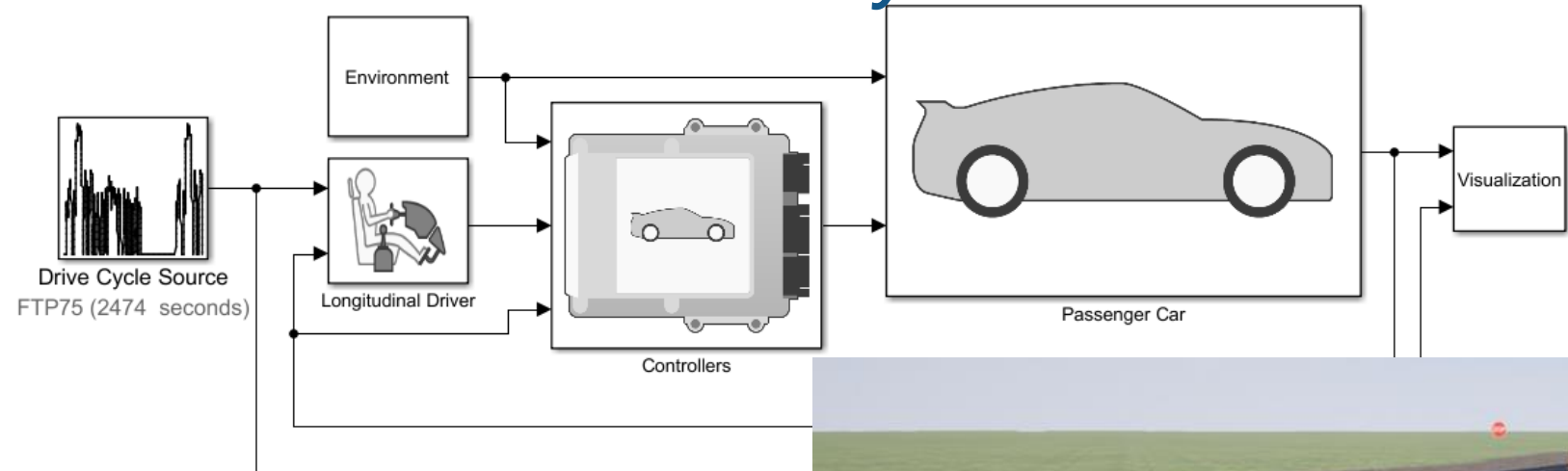
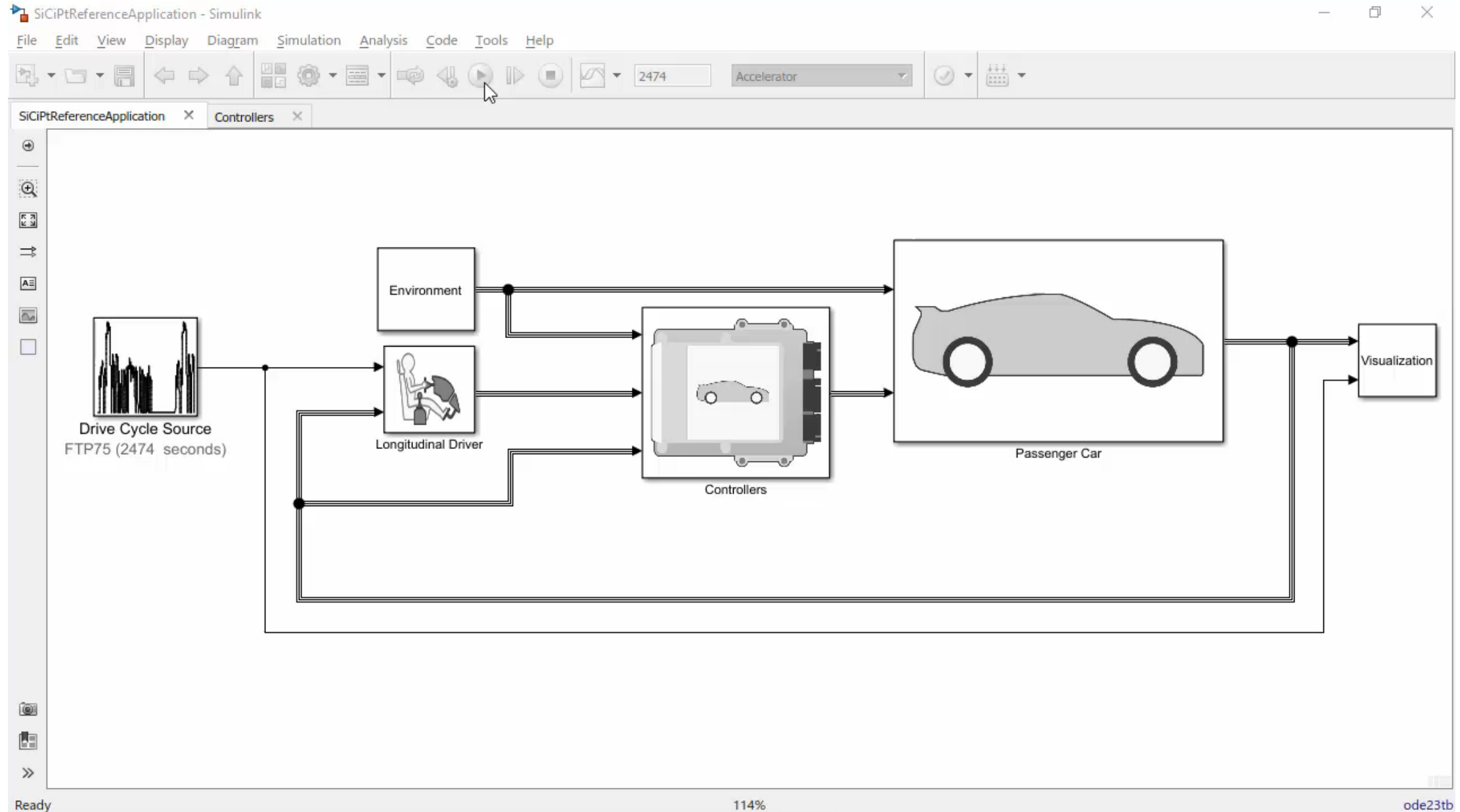


Five ~~Five~~ Six More Cool Things You Can Do With Powertrain Blockset *and Vehicle Dynamics Blockset*

Mike Sasena, PhD
Product Manager



Fuel Economy Simulation



Vehicle Dynamics Simulation



Ride & handling



Chassis controls









ADAS / AD

Agenda

- Product overview
 - Powertrain Blockset
 - Vehicle Dynamics Blockset

- Six Cool Things You Can Do

		Why are these cool?
– Automating engine model parameterization		– Reduce time tuning engine models
– Battery cooling circuit testing		– Account for complex thermal behavior
– Aftertreatment system testing		– Estimate tailpipe emissions accurately
– Ride and handling analysis		– Assess longitudinal / lateral dynamics
– Chassis controls development		– Perform closed-loop testing
– ADAS / AD testing		– Test in a virtual 3D environment

Agenda

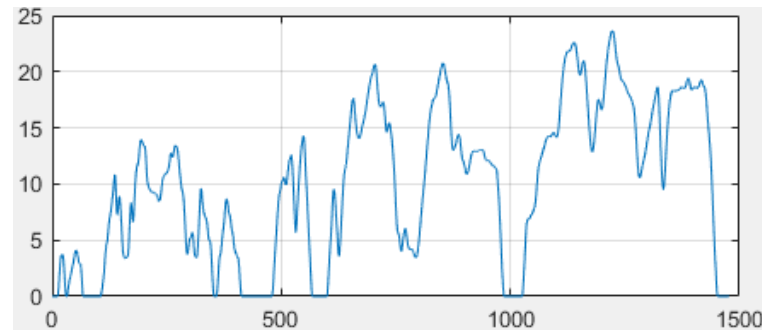
- Product overview
 - **Powertrain Blockset**
 - Vehicle Dynamics Blockset

- Six Cool Things You Can Do
 - Automating engine model parameterization
 - Battery cooling circuit testing
 - Aftertreatment system testing
 - Ride and handling analysis
 - Chassis controls development
 - ADAS / AD testing

Background

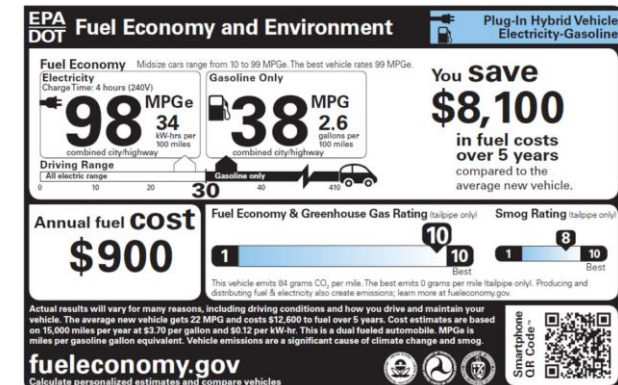
■ Context

- Automotive engineers need to evaluate powertrain systems as early as possible
 - What is the expected fuel economy, performance and emissions of my vehicle?
 - What is the impact of my controller on system efficiency?
 - Which electrification strategy should we develop?
- **Model-Based Design** has become an important methodology for answering these questions and accelerating the development process



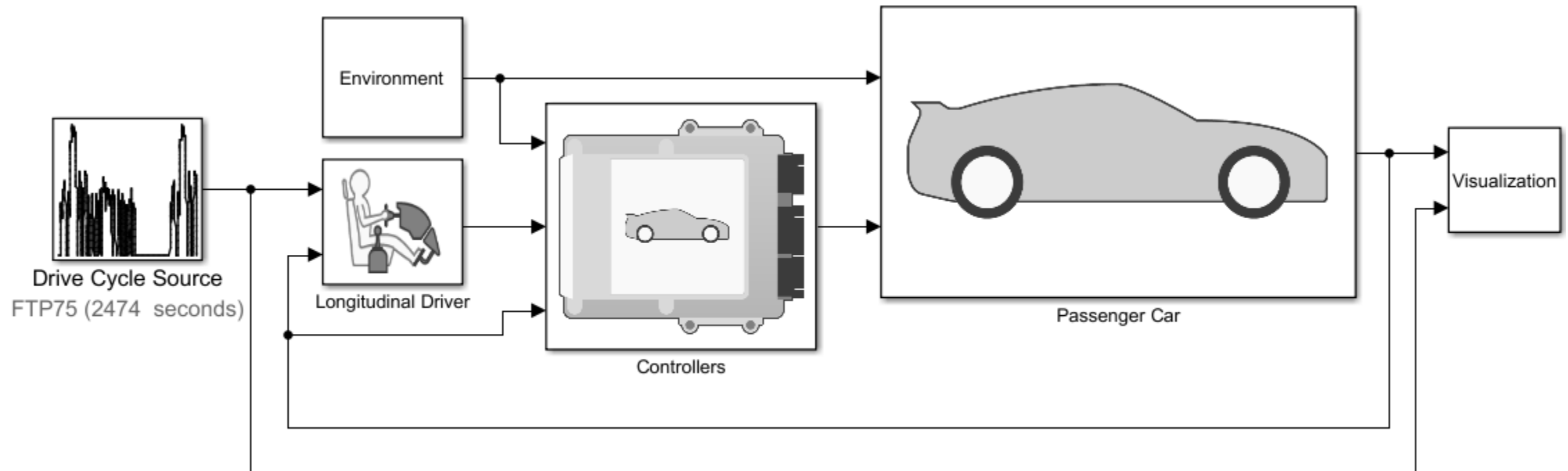
■ Challenges

- It's hard to do good Model-Based Design without good models



Powertrain Blockset

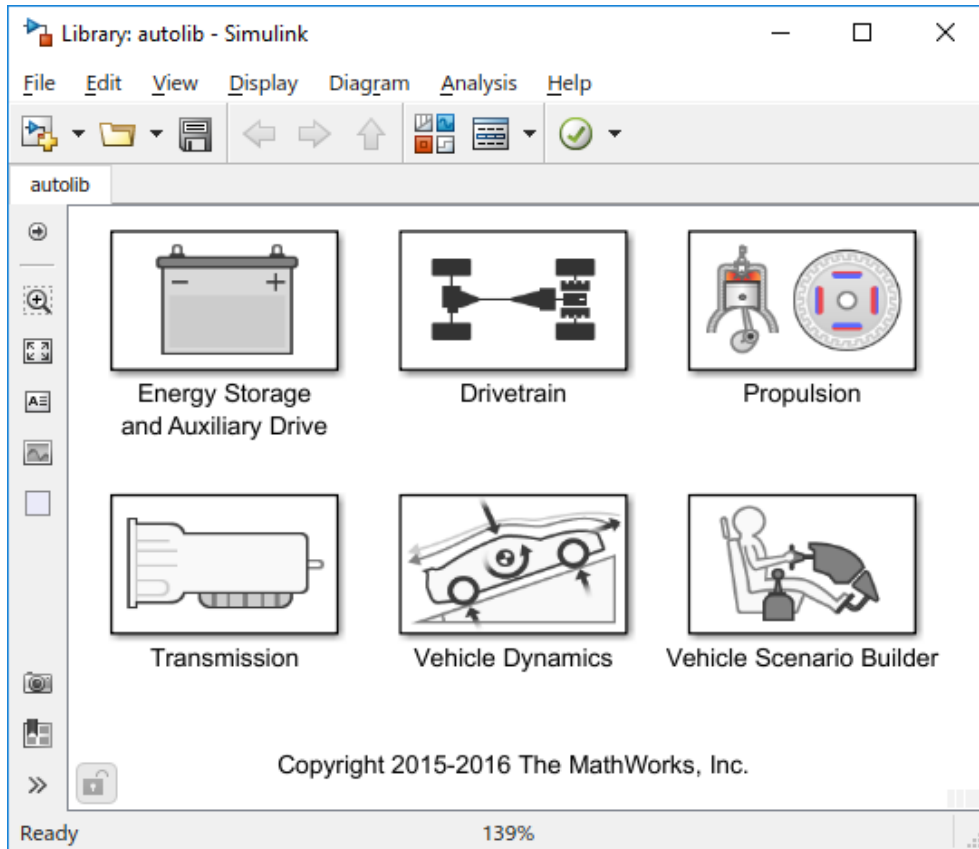
- Goals:
 - Provide starting point for engineers to build **good plant / controller models**
 - Provide **open** and documented models
 - Provide very **fast**-running models that work with popular HIL systems



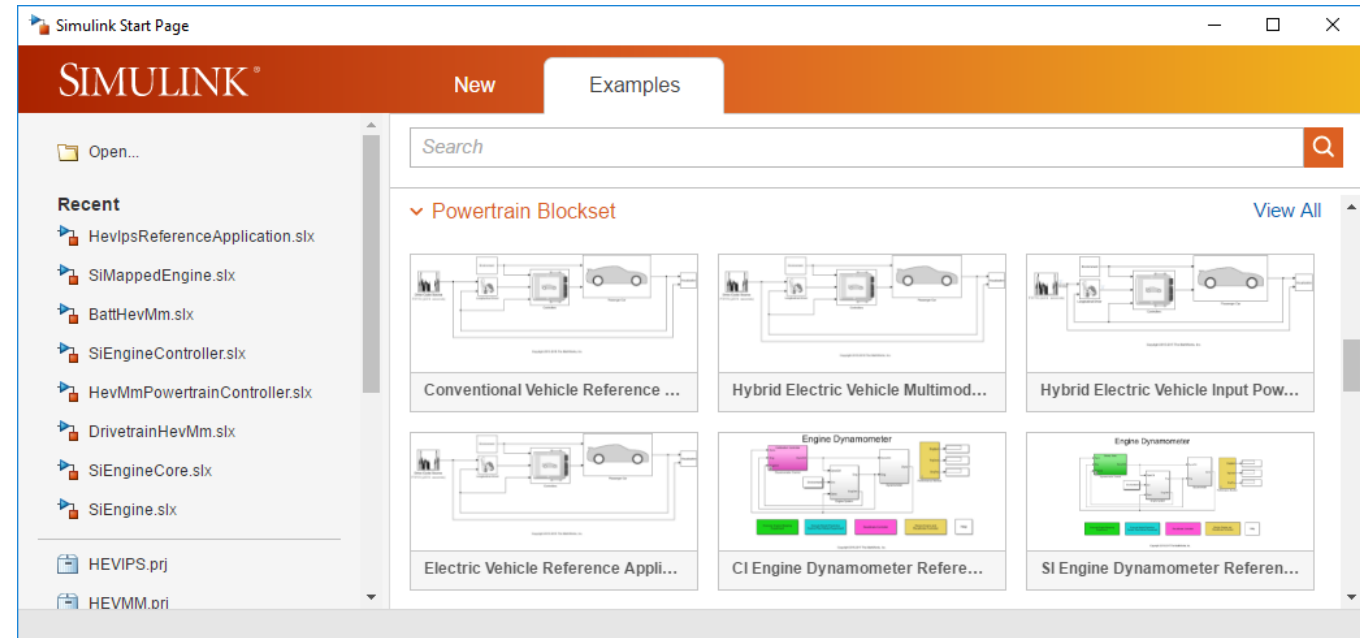
Lower the barrier to entry for Model-Based Design

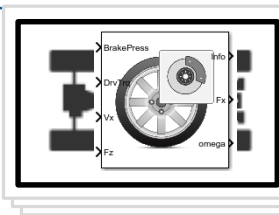
Powertrain Blockset Features

Library of blocks

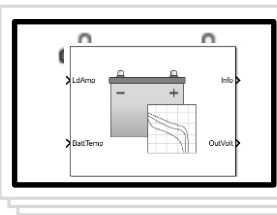


Pre-built reference applications

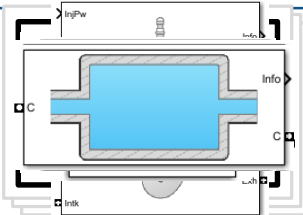




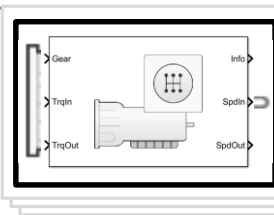
Drivetrain



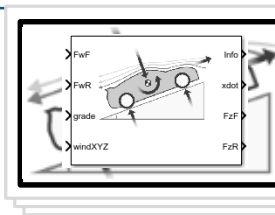
Energy Storage
and Auxiliary Drive



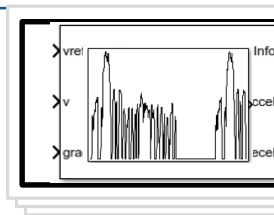
Propulsion



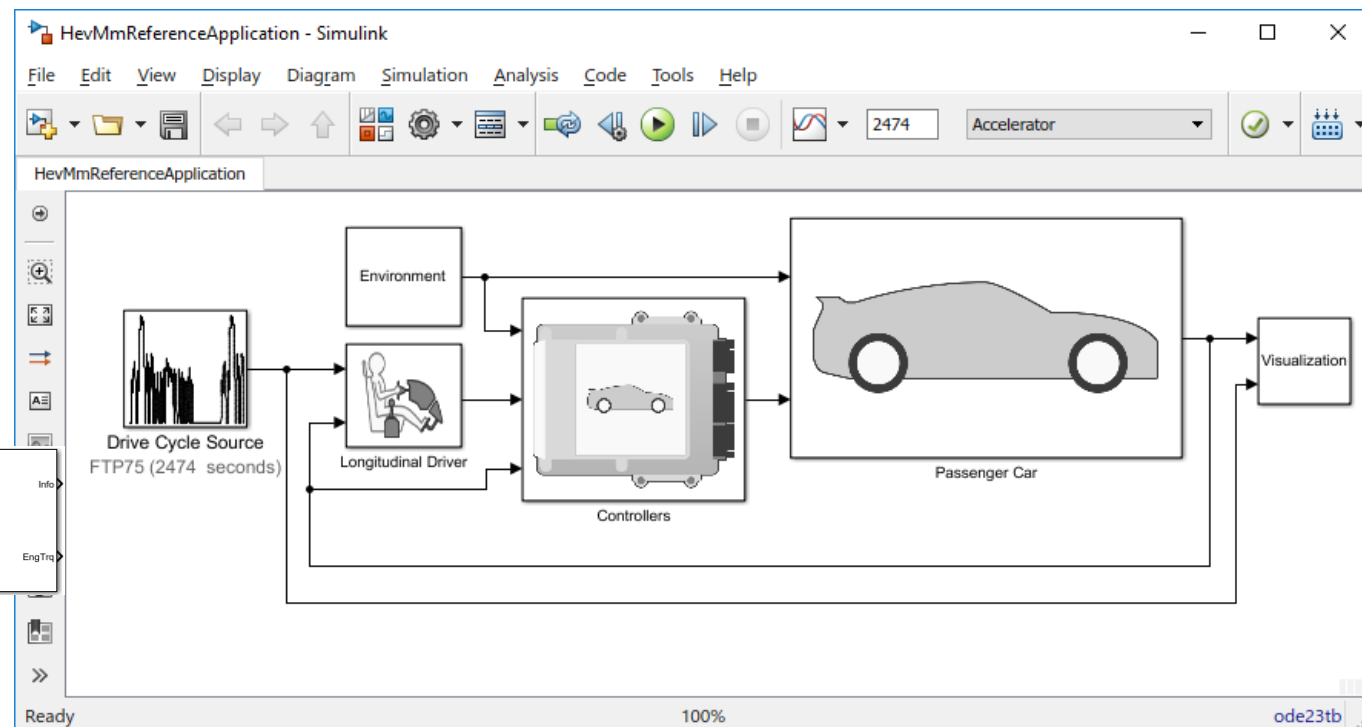
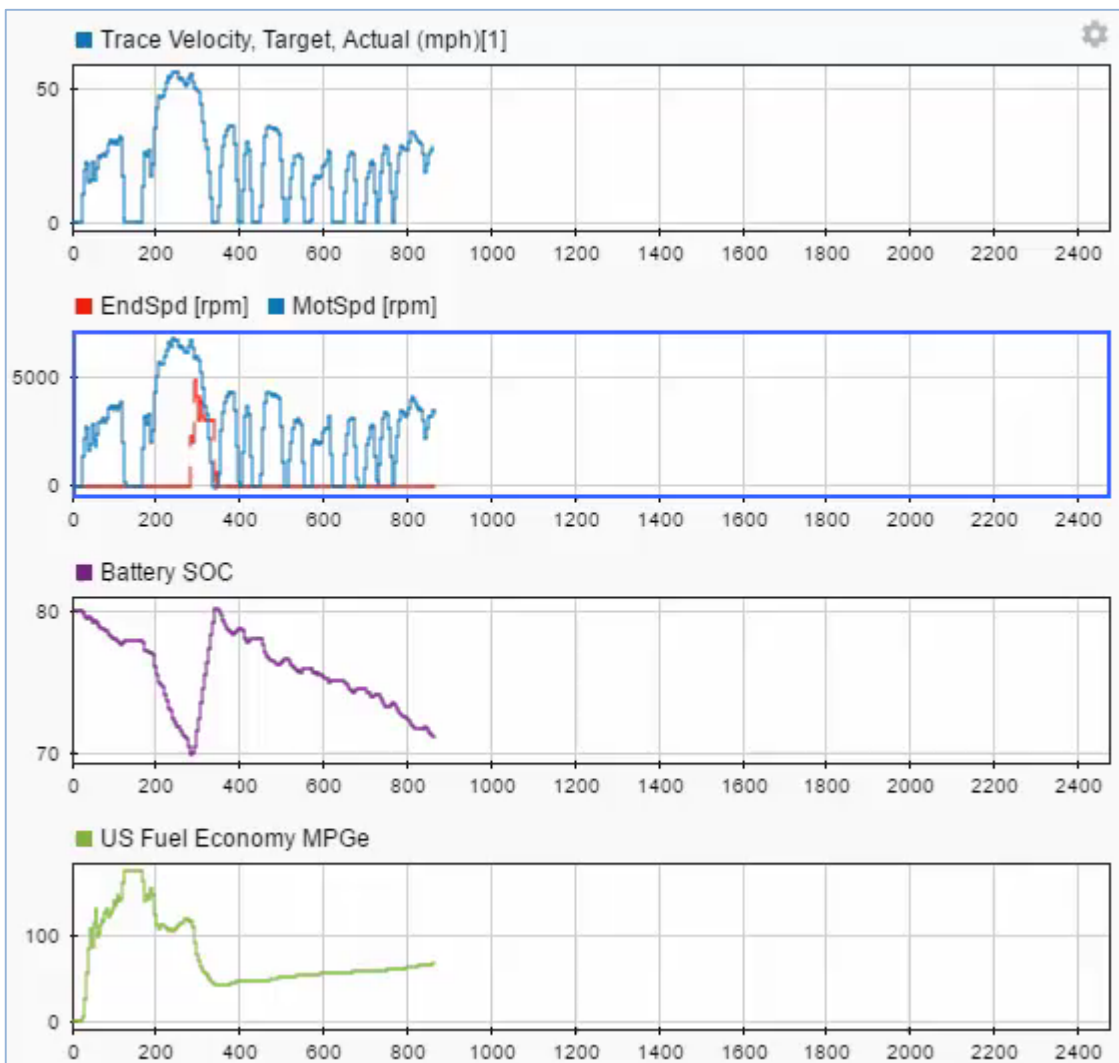
Transmission



Vehicle Dynamics

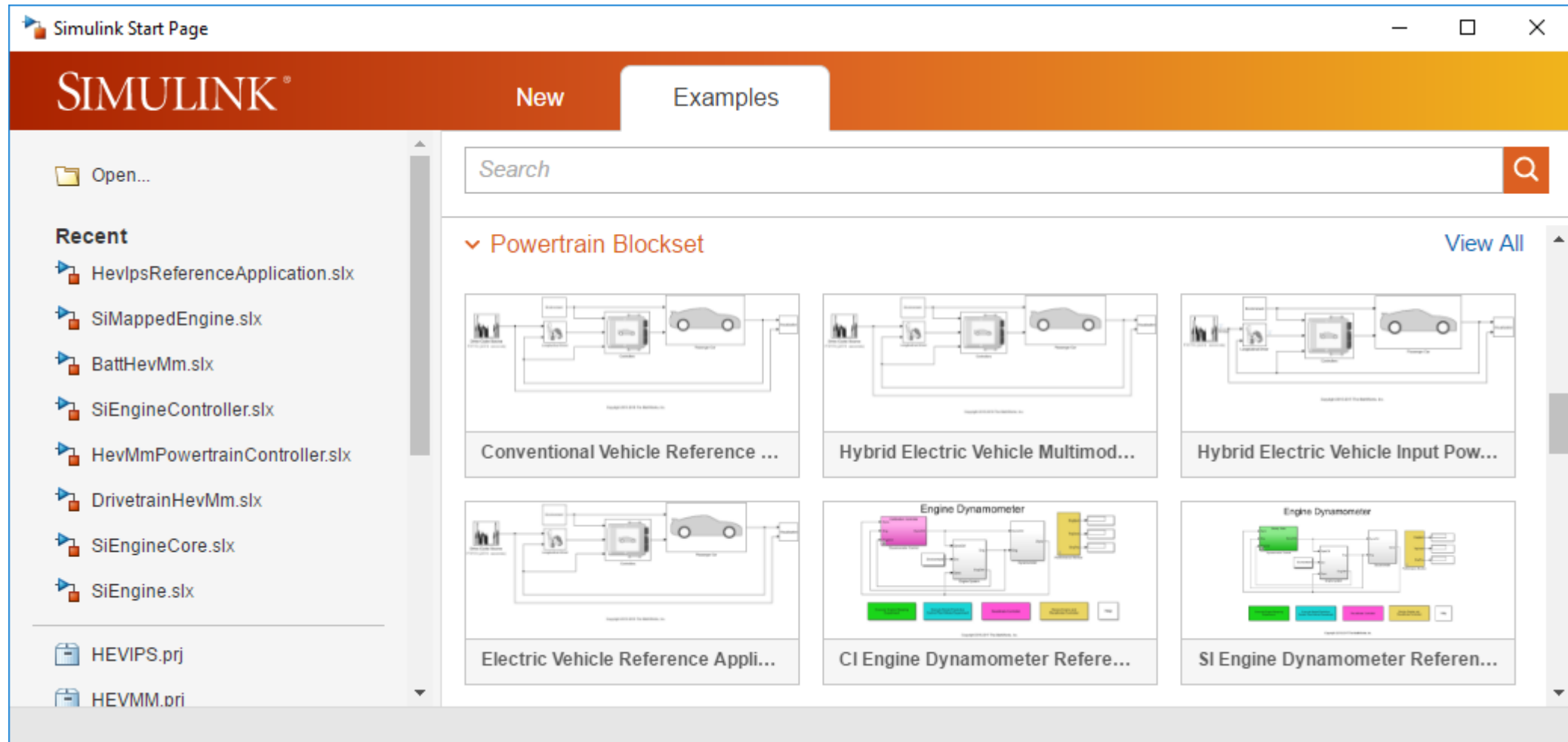


Vehicle Scenario Builder

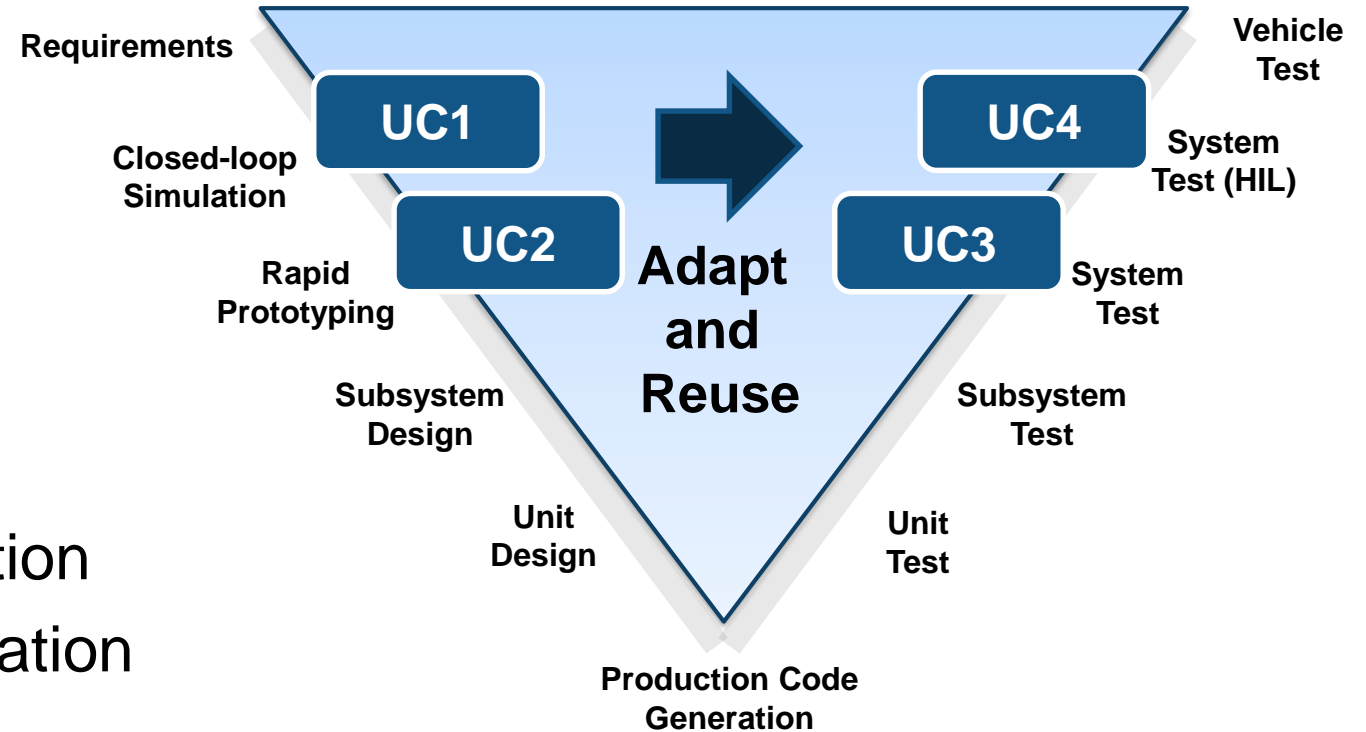


Reference Applications

- Full vehicle models (conventional, EV, multi-mode HEV, input power-split HEV)
- Virtual engine dynamometers (compression ignition, spark ignition)



Four Use Cases. One Framework.

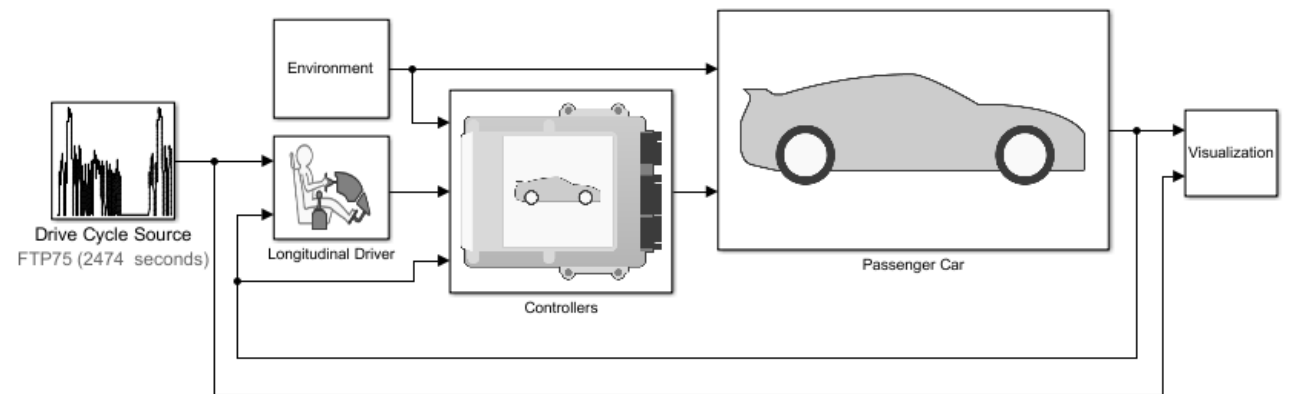
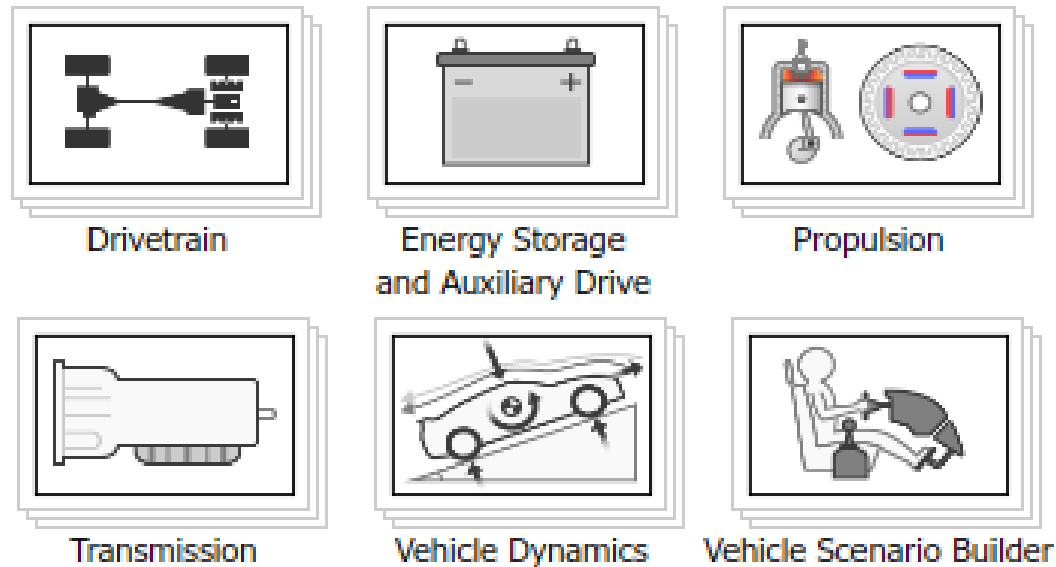


Use Cases:

1. System design and optimization
2. Controller parameter optimization
3. System integration test
4. Software-hardware integration test (HIL)

Powertrain Blockset Value Proposition

- **Open** and documented library of component and subsystem models
- Prebuilt vehicle models that you can parameterize and **customize**
- **Fast**-running models that are ready for HIL deployment



Agenda

- Product overview
 - Powertrain Blockset
 - **Vehicle Dynamics Blockset**
- Six Cool Things You Can Do
 - Automating engine model parameterization
 - Battery cooling circuit testing
 - Aftertreatment system testing
 - Ride and handling analysis
 - Chassis controls development
 - ADAS / AD testing

Background

■ Context

- Automotive OEM's and Tier 1 suppliers must assess vehicle's dynamic performance
 - Will the vehicle roll over?
 - What's the stopping distance of the vehicle?
 - Do the stability controls perform adequately?
- Answer questions by building prototypes and / or running simulations



■ Challenges

- Prototypes are expensive, so must achieve a good design as early as possible
- Specialized vehicle dynamics simulation software is quite expensive and difficult to use
- Integrating 3rd party vehicle dynamics software with Simulink controls is cumbersome

Vehicle Dynamics Blockset

New product (R2018a)

- Model and simulate vehicle dynamics in a virtual 3D environment
- Use Vehicle Dynamics Blockset for:
 - Ride & handling: characterize vehicle performance under standard driving maneuvers
 - Chassis controls: design and test chassis control systems
 - ADAS / AD: create virtual 3D test ground for ADAS and automated driving features



Ride & handling

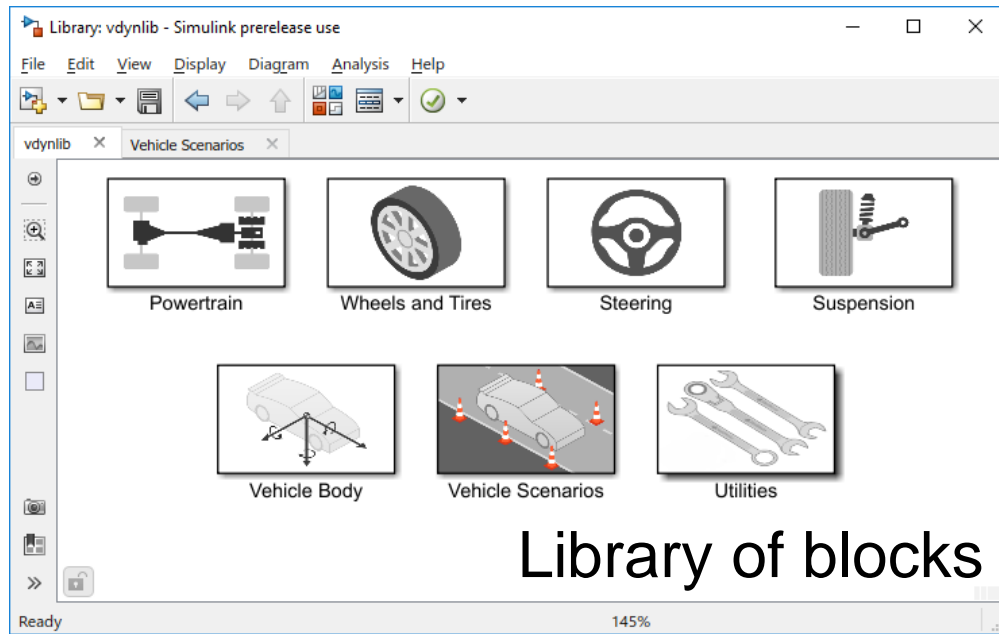


Chassis controls

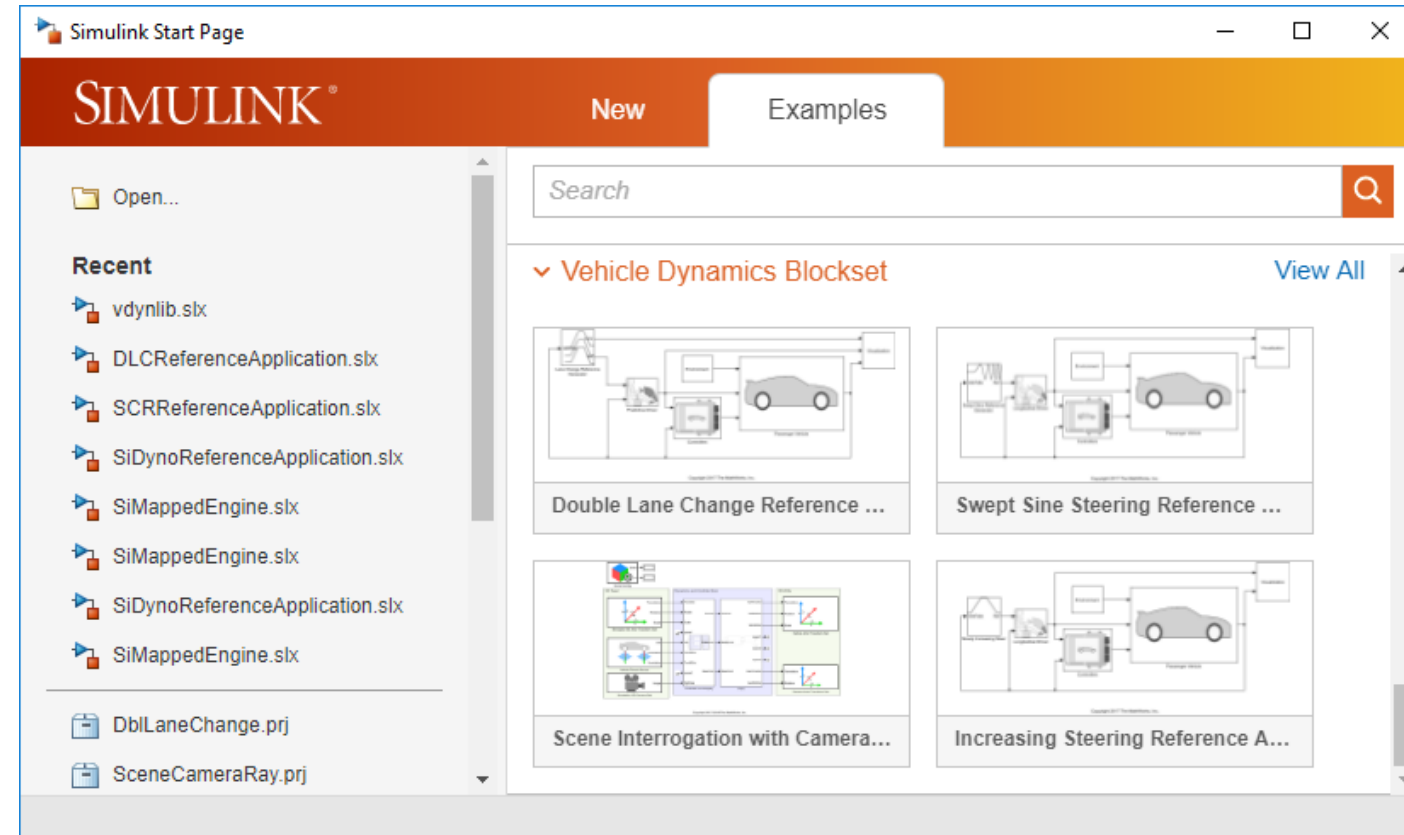


ADAS / AD

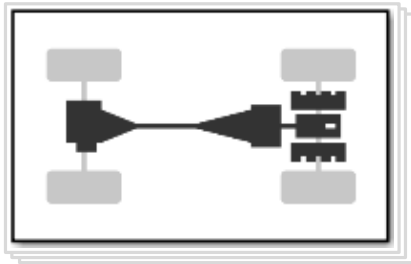
Vehicle Dynamics Blockset Features



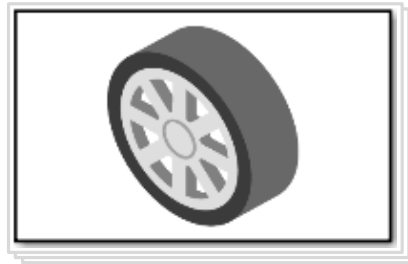
Pre-built reference applications



Block Library



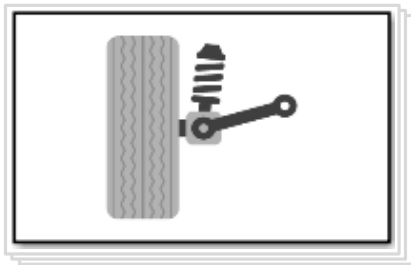
Powertrain



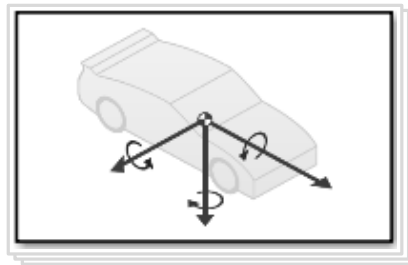
Wheels and Tires



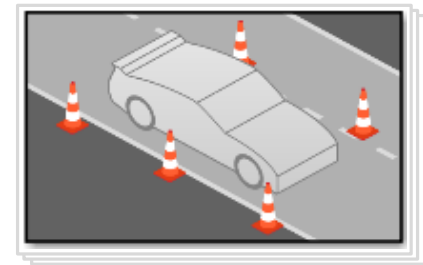
Steering



Suspension



Vehicle Body



Vehicle Scenarios

Game Engine Co-Simulation

Simulink

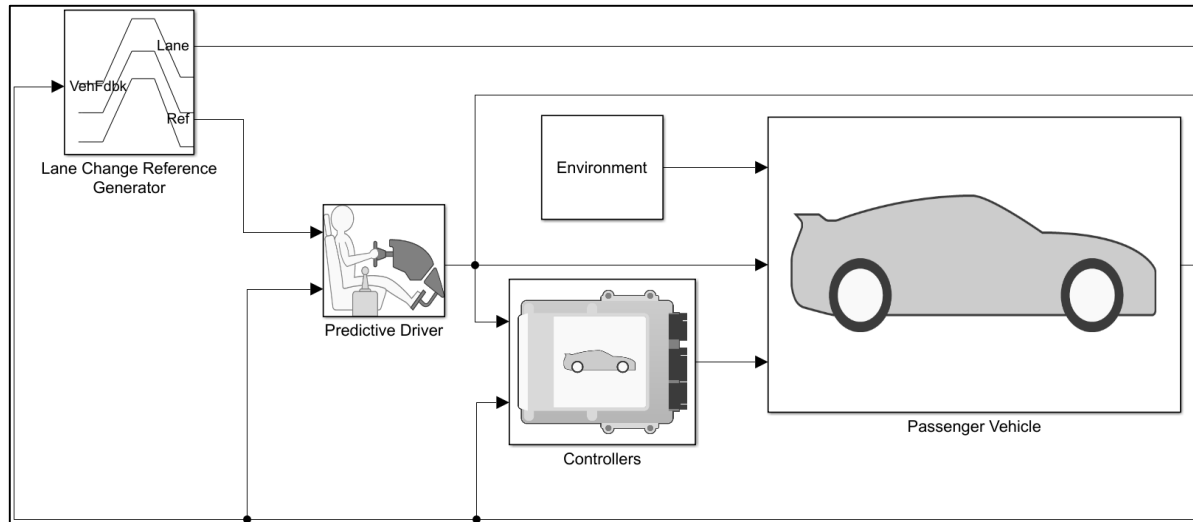
- Physics of vehicle
- Initialization of game engine camera

vehicle / camera location

Unreal Engine

- Rendering / lighting
- Physics of non-Simulink objects
- Collision detection

camera image, ground height, ...

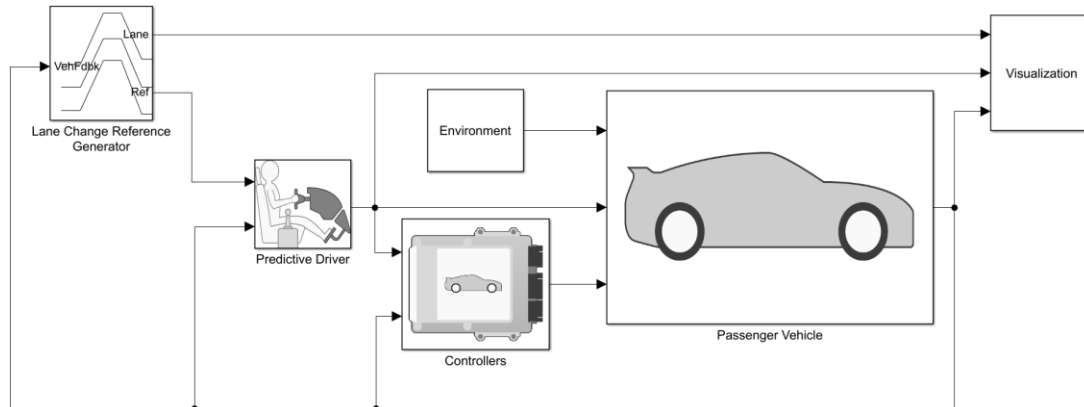


Reference Applications

Vehicle Maneuvers

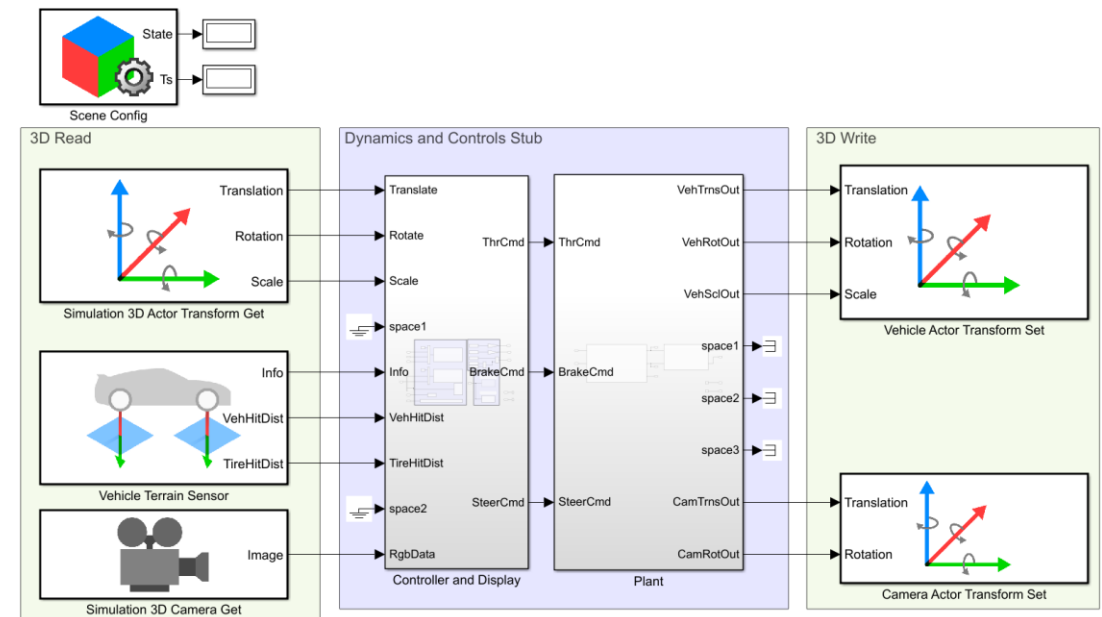
Analyze ride and handling on driving maneuvers such as:

- Double-lane change
- Swept sine steering
- Slowly increasing steering



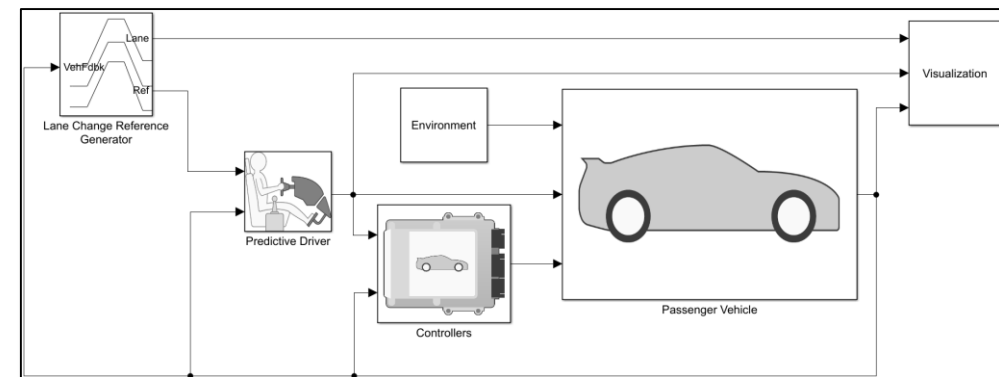
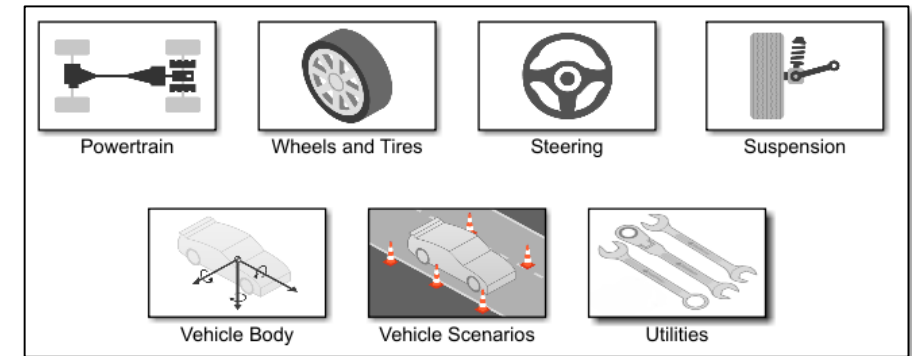
Scene Interrogation

Configure the interface to the 3D environment



Vehicle Dynamics Blockset Value Proposition

- **Open** and documented library of component and subsystem models
- Prebuilt vehicle models that you can parameterize and **customize**
- **Fast**-running models that are ready for HIL deployment
- Interface to **Unreal Engine**



Powertrain Blockset and Vehicle Dynamics Blockset:

Flexible Modeling Framework

1. Choose a vehicle configuration
 - Select a reference application as a starting point
2. Customize the plant model
 - Parameterize the components
 - Customize existing subsystems
 - Add your own subsystem variants
3. Customize the controllers
 - Parameterize the controllers
 - Customize supervisory control logic
 - Add your own controller variants
4. Perform closed-loop system testing
 - Design optimization
 - Sensitivity analyses
 - MIL / SIL / HIL testing






MAC 2017 Recap

Agenda

- Introduction to Powertrain Blockset


- Five cool things you can do with it:

Why are these cool?

- | | | |
|--|---|---|
| 1. Engine control design / calibration |  | Reduce time on HIL, dyno, vehicle testing |
| 2. Design optimization studies |  | Explore wider search space |
| 3. Multidomain simulation via Simscape |  | Integrate multidomain subsystem models |
| 4. Subsystem control design |  | Validate controller design via simulation |
| 5. Hardware-in-the-loop (HIL) testing |  | Validate controller virtually |

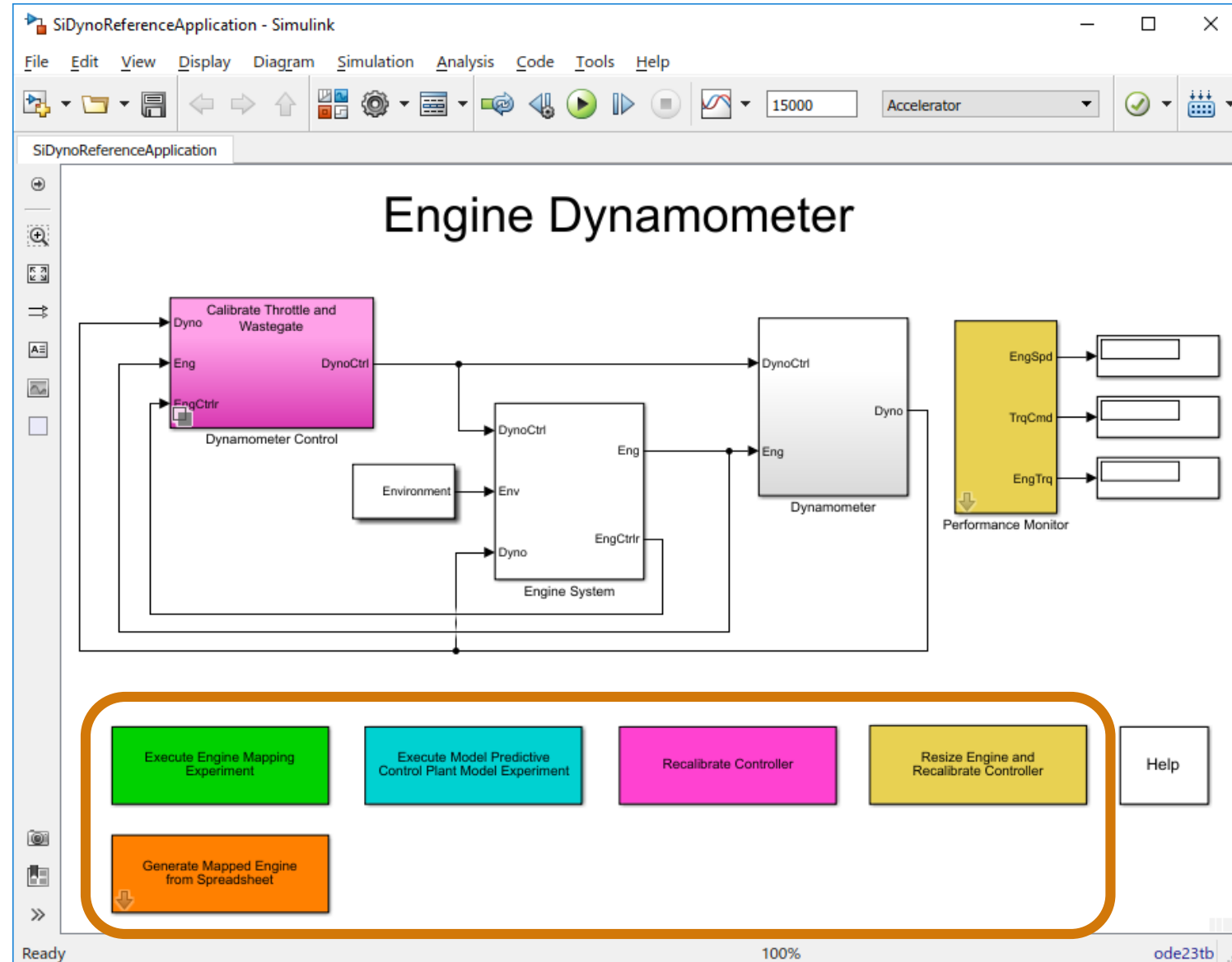
Agenda

- Product overview
 - Powertrain Blockset
 - Vehicle Dynamics Blockset

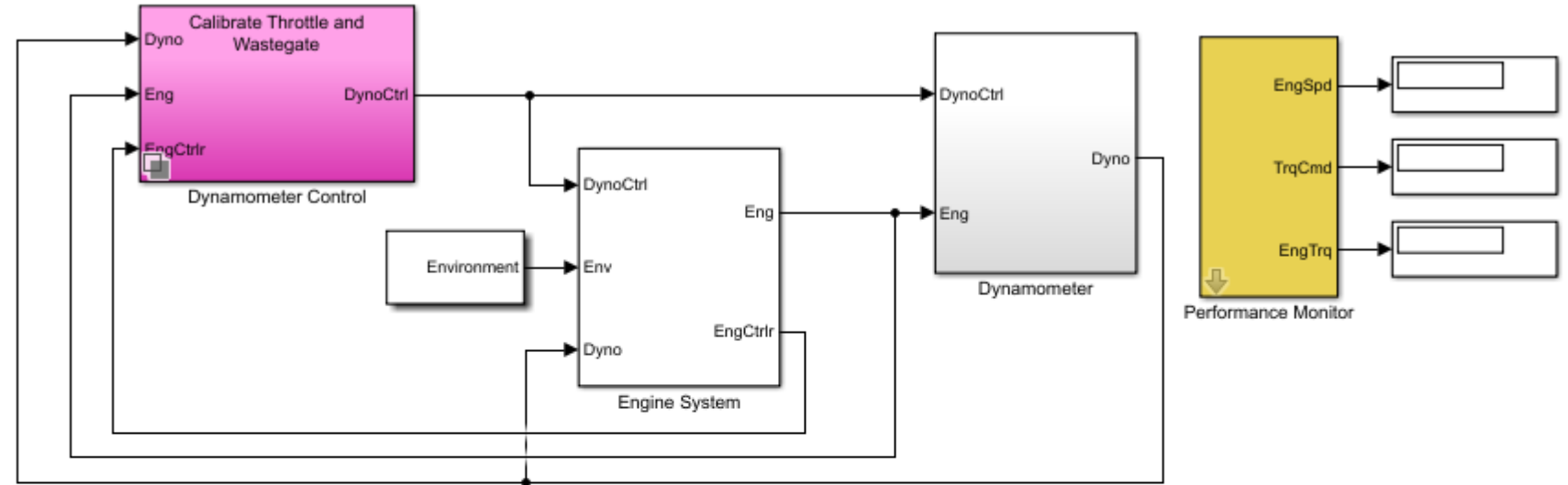
- Six Cool Things You Can Do
 - **Automating engine model parameterization**  – Reduce time tuning engine models
 - Battery cooling circuit testing
 - Aftertreatment system testing
 - Ride and handling analysis
 - Chassis controls development
 - ADAS / AD testing

Engine Dynamometer Reference Application

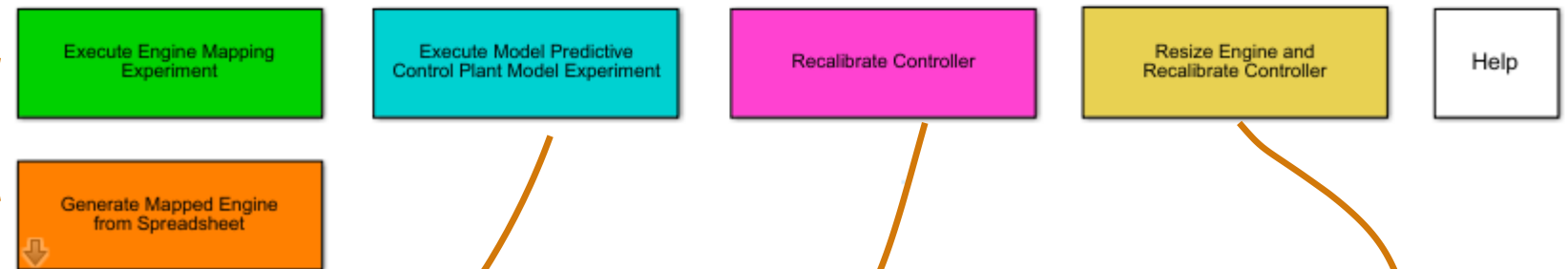
- Powertrain Blockset includes virtual engine dynamometer reference applications
- These can be used for a variety of engine controls development and calibration activities
- Includes several pre-defined experiments



Pre-defined Experiments for Automating Analyses



Simulate engine over
grid of **steady state**
operating points



Import engine
dynamometer **test data**

Follow **transient**
torque / speed profile

Calibrate controller to
match torque command

Scale engine and
recalibrate controller

Engine Test Data Import

SiDynoReferenceApplication - Simulink

File Edit View Display Diagram Simulation Analysis Code Tools Help

SiDynoReferenceApplication x Engine Plant x

Engine Dynamometer

Execute Engine Mapping Experiment

Execute Model Predictive Control Plant Model Experiment

Recalibrate Controller

Resize Engine and Recalibrate Controller

Help

Generate Mapped Engine from Spreadsheet

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Ready 80% ode23tb

SiEngineData.xlsx - Excel

File Home Insert Page Layout Formulas Data Review View

Clipboard Font Alignment Number

A5

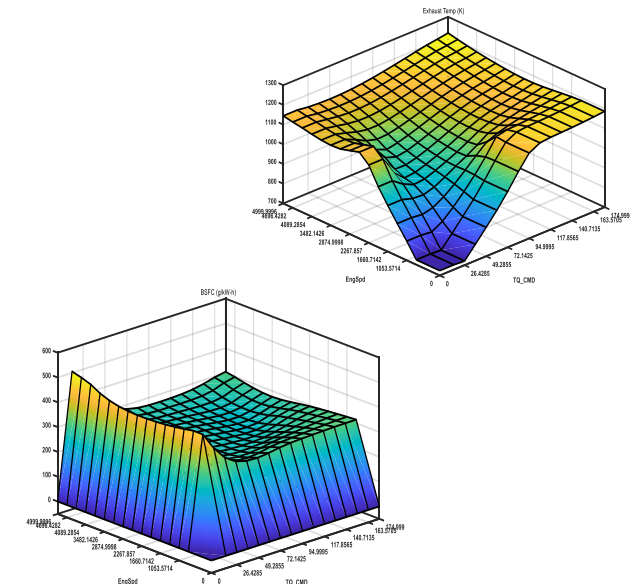
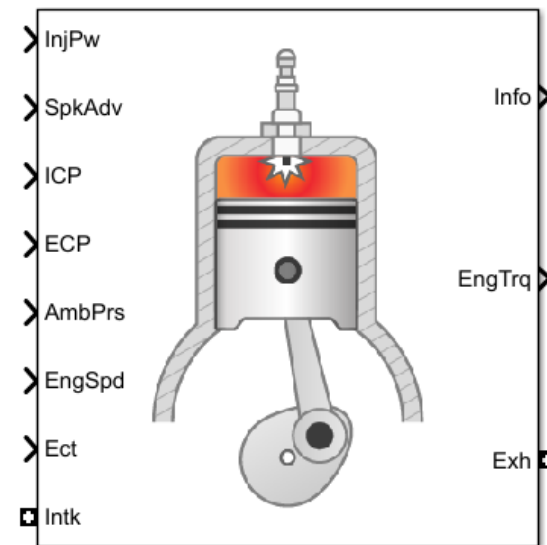
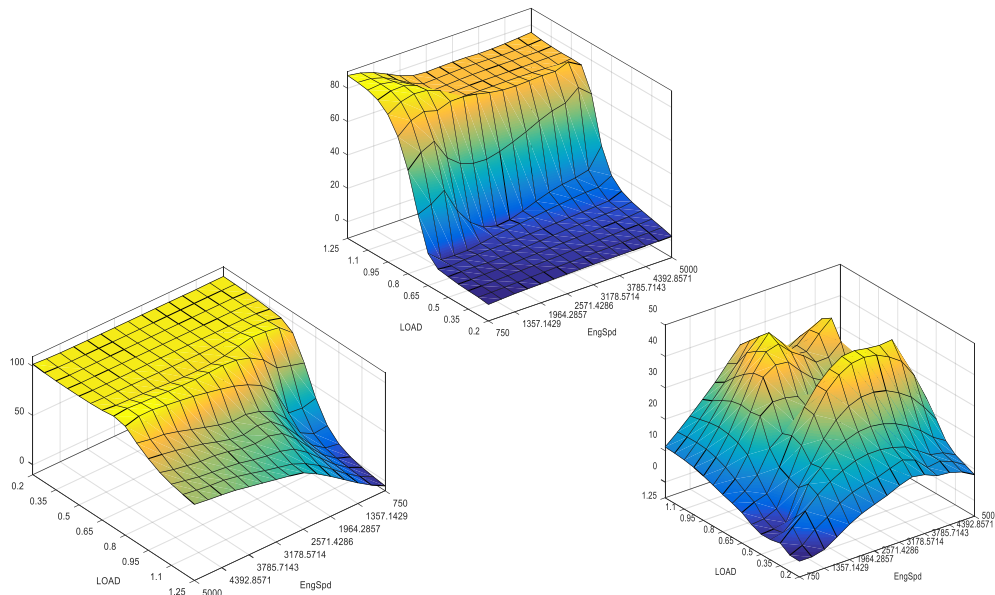
	A	B	C	D	E	F	G
1	Name:	Torque	EngSpd	AirMassFlwRate	FuelMassFlwRate	ExhTemp	BSFC
2	Unit:	N*m	rpm	kg/s	kg/s	K	g/(kW*h)
3	Data:	33.598	750				350.97314
4		45.847	750				318.76013
5		56.568	750				304.45778
6		68.245	750				296.26486
7		76.223	750				291.3998
8		76.223	750				291.39963
9		28.544	1053.6				393.66527
10		40.024	1053.6				329.91411
11		51.453	1053.6				299.89702
12		62.881	1053.6				286.35412
13		74.31	1053.6				277.26949
14		85.738	1053.6				275.16961
15		95.025	1053.6				283.46379
16		24.676	1357.1				413.12511
17		36.983	1357.1	0.007204383	0.000493451	921.4745	338.20039
18		48.412	1357.1	0.008373948	0.000573558	926.201	300.20794
19		59.84	1357.1	0.0097533	0.000668034	941.4953	282.79031
20		71.269	1357.1	0.011219721	0.000768474	955.8058	273.14525
21		82.697	1357.1	0.012688208	0.000869055	969.9667	266.19969
22		94.126	1357.1	0.014311804	0.000980261	1007.937	263.80194

Firing Data Nonfiring Data

Ready


Automating Engine Model Parameterization

- Calibrate engine control inputs to match torque command
- Define and simulate custom calibration procedures
- Generate engine maps from CAE models or engine dyno data



Agenda

- Product overview
 - Powertrain Blockset
 - Vehicle Dynamics Blockset

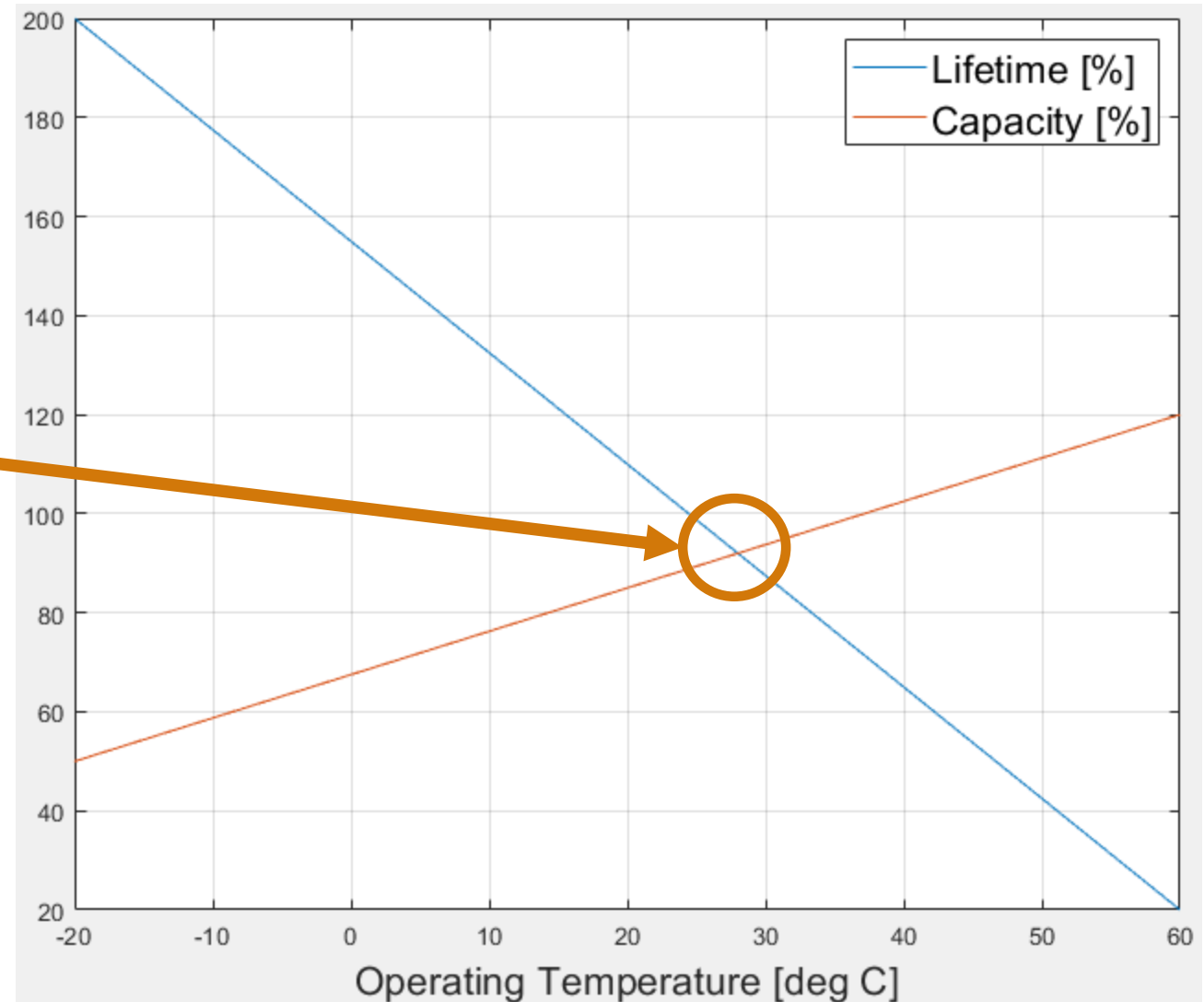
- Six Cool Things You Can Do
 - Automating engine model parameterization
 - **Battery cooling circuit testing**  – Account for complex thermal behavior
 - Aftertreatment system testing
 - Ride and handling analysis
 - Chassis controls development
 - ADAS / AD testing

Automotive Battery Cooling Considerations

- Effectiveness
 - Ensure enough cooling capacity
- Energy consumption
 - This should be minimal
- Weight
 - Lower weight → better performance
- Complexity
 - As simple as possible
- Technologies
 - Air cooled
 - Liquid cooled
- Questions to consider:
 - How long will my battery last?
 - Does it perform well?
 - Is the cooling system large enough?
 - What is the operating cost?
 - How can we minimize weight and cost?
 - What kind of controls will we use?

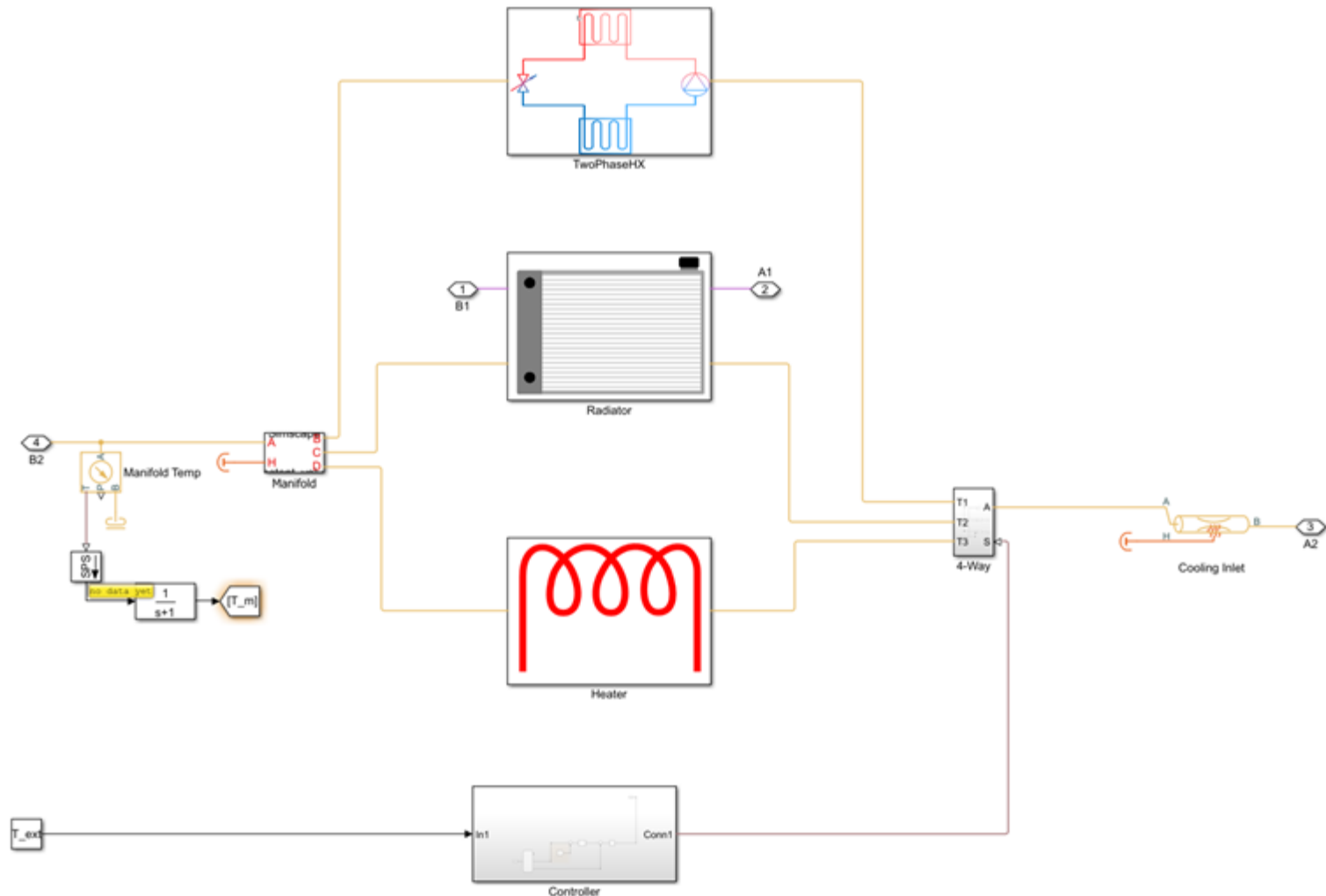
Why is Battery Thermal Management Important?

- Battery lifetime and performance depend on operating temperature
- Higher temperatures
 - Decreased lifetime
 - Increased capacity
- Potential tradeoff point



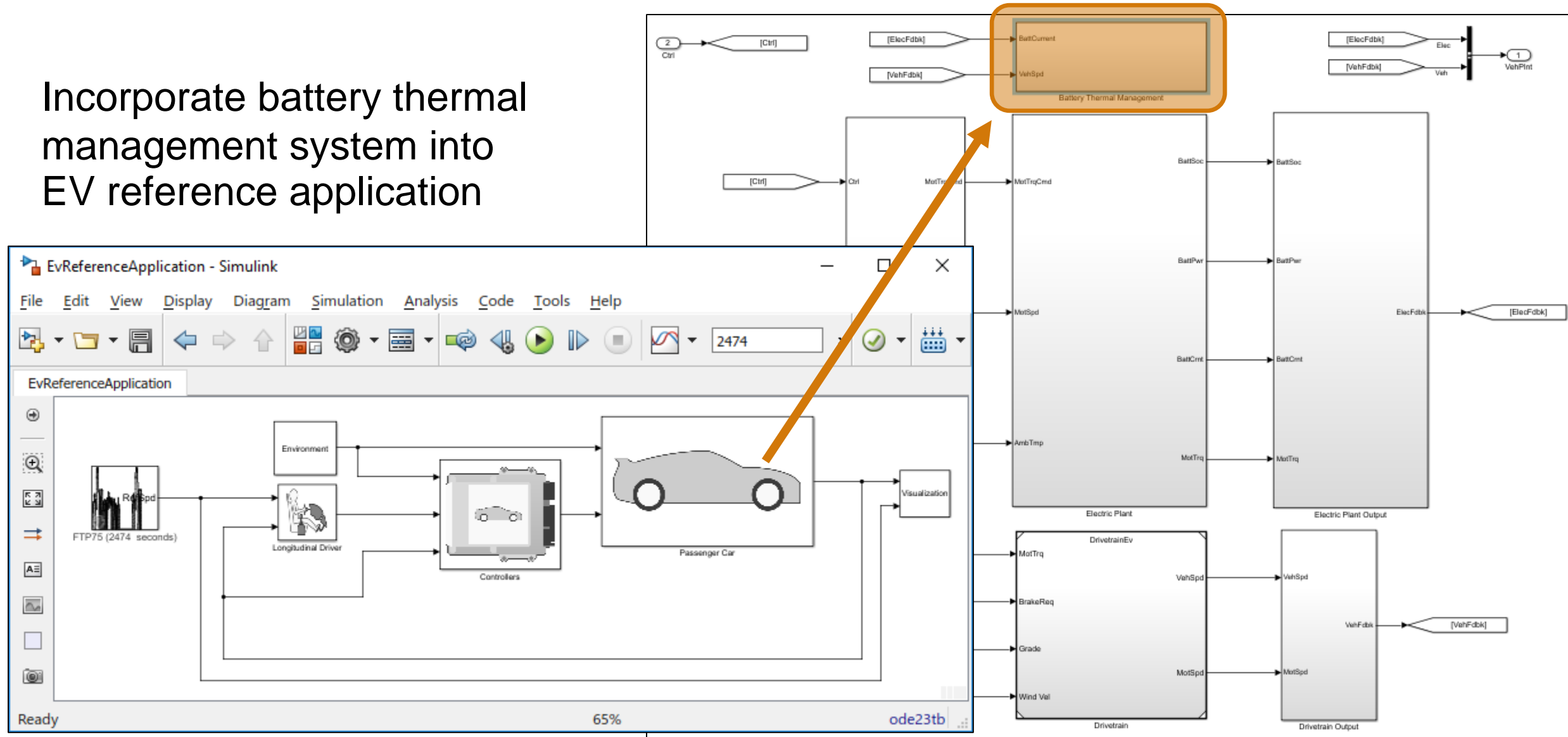
Battery Thermal Management Architecture

- Three modes to control coolant temperature
 - Heating
 - Ambient cooling (via radiator)
 - Two-phase cooling (via HVAC)
- Control strategies
 - Feedforward + PID
 - Minimize power usage



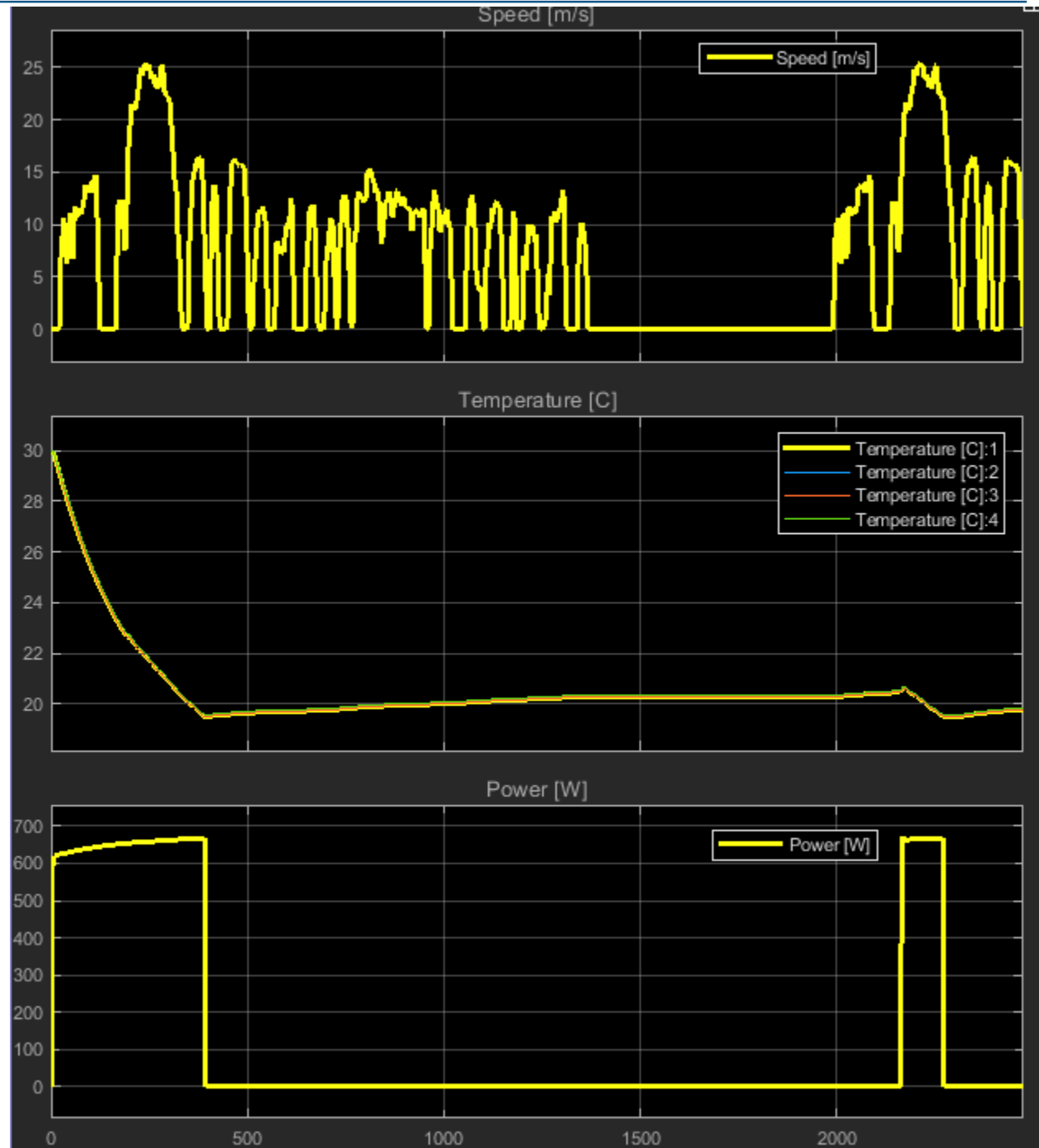
Battery Thermal Management System

Incorporate battery thermal management system into EV reference application



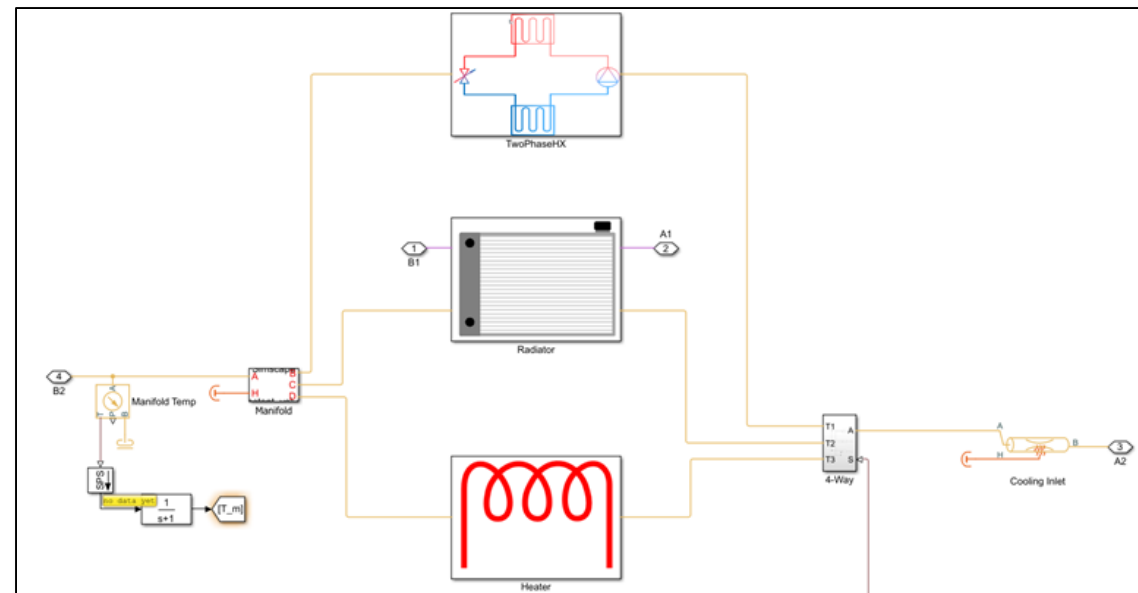
Results

- Given:
 - FTP75 drive cycle
 - $T_{\text{amb}} = 30^{\circ}\text{C}$
- Objective:
 - Regulate $T_{\text{batt}} = 20^{\circ}\text{C}$




Battery Cooling Circuit Testing

- Create detailed, multi-domain subsystem models with Simscape
- Incorporate them into system level vehicle models from Powertrain Blockset
- Validate subsystem performance with closed loop simulation



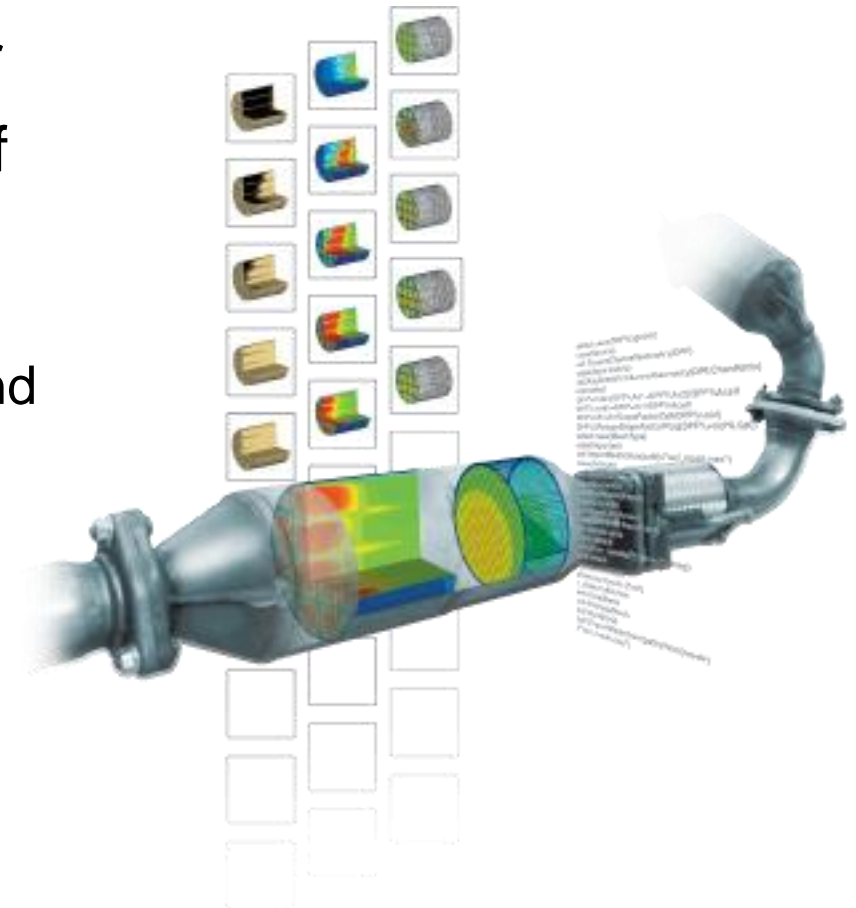
Agenda

- Product overview
 - Powertrain Blockset
 - Vehicle Dynamics Blockset

- Six Cool Things You Can Do
 - Automating engine model parameterization
 - Battery cooling circuit testing
 - **Aftertreatment system testing**  – Estimate tailpipe emissions accurately
 - Ride and handling analysis
 - Chassis controls development
 - ADAS / AD testing

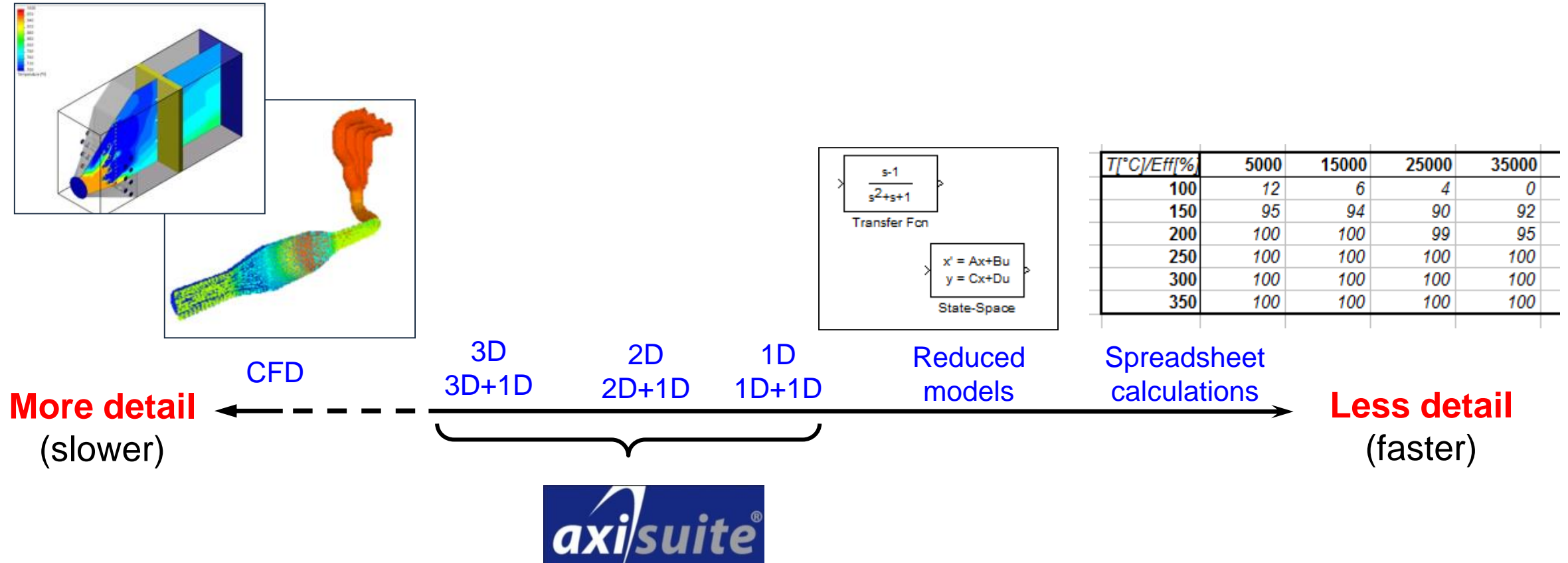
Exothermia

- *Exothermia* is a MathWorks Connections Partner
- **axisuite®**: modular software for the simulation of exhaust aftertreatment devices and systems
 - axitrap: for wall-flow particulate filters
 - axicat: for flow-through catalytic converters with any kind of catalytic coating
 - axifoam: for foam-based or fiber-based filters and catalysts, with any type of catalytic coating
 - axiheat: for connecting pipes
- Models can be exported as S-functions for coupling with Simulink-based software, e.g. **Powertrain Blockset**



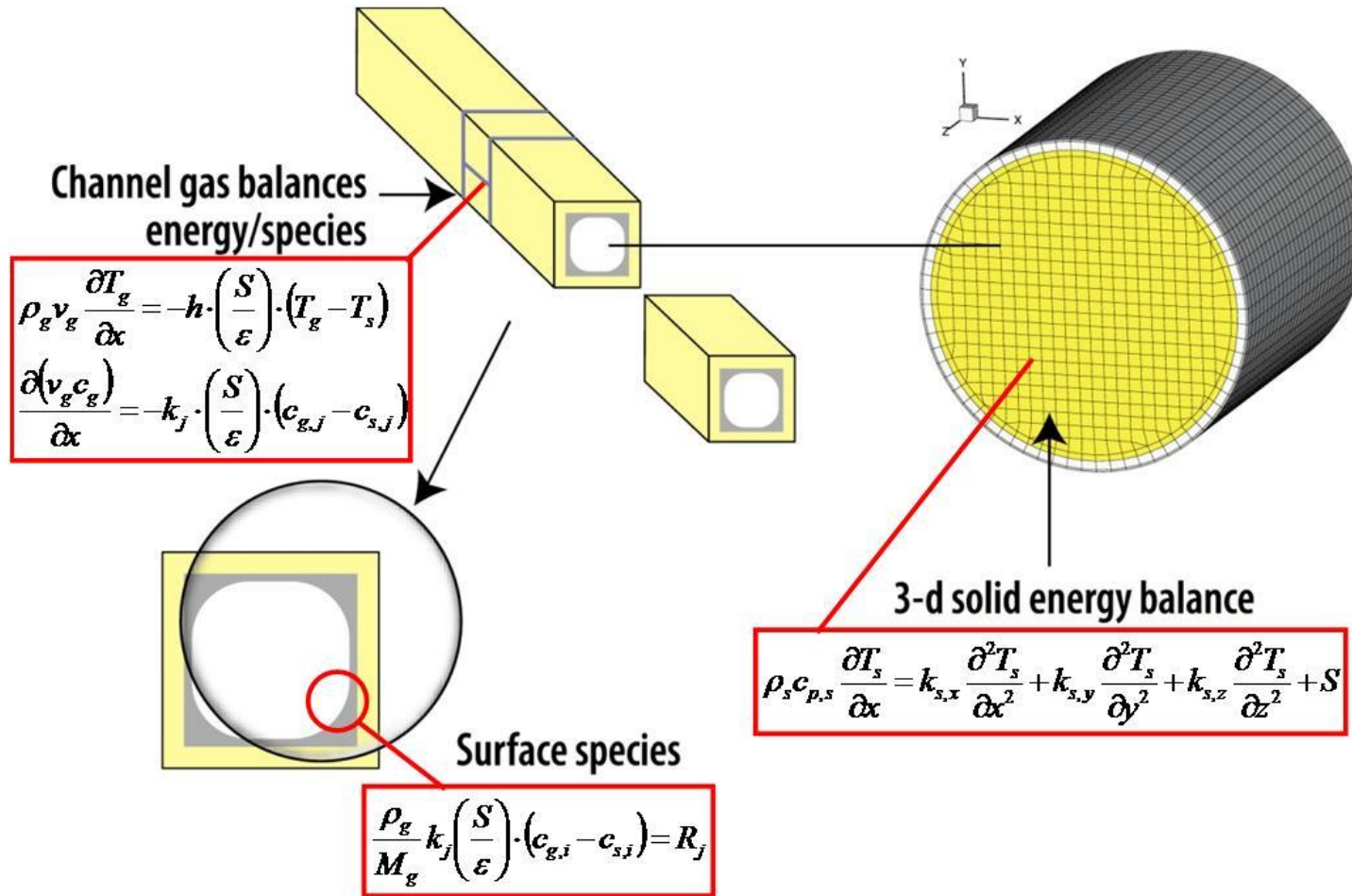
axisuite® is a trademark of Exothermia
www.exothermia.com

Catalyst Modeling Scales

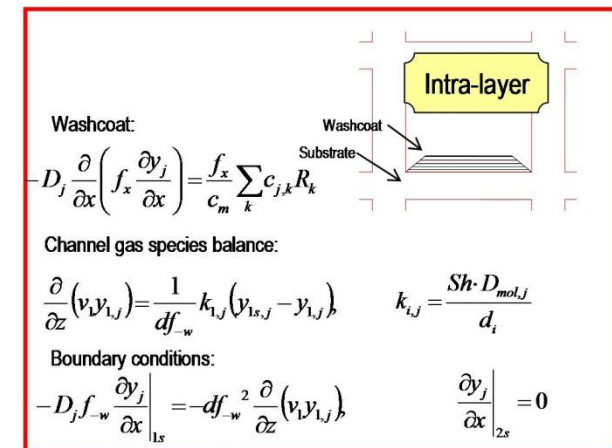


- Dedicated simulation software for catalytic exhaust aftertreatment
- Extensively validated and applied by most automotive OEMs and suppliers

Overview of Flow-through Catalyst Model Equations in axisuite

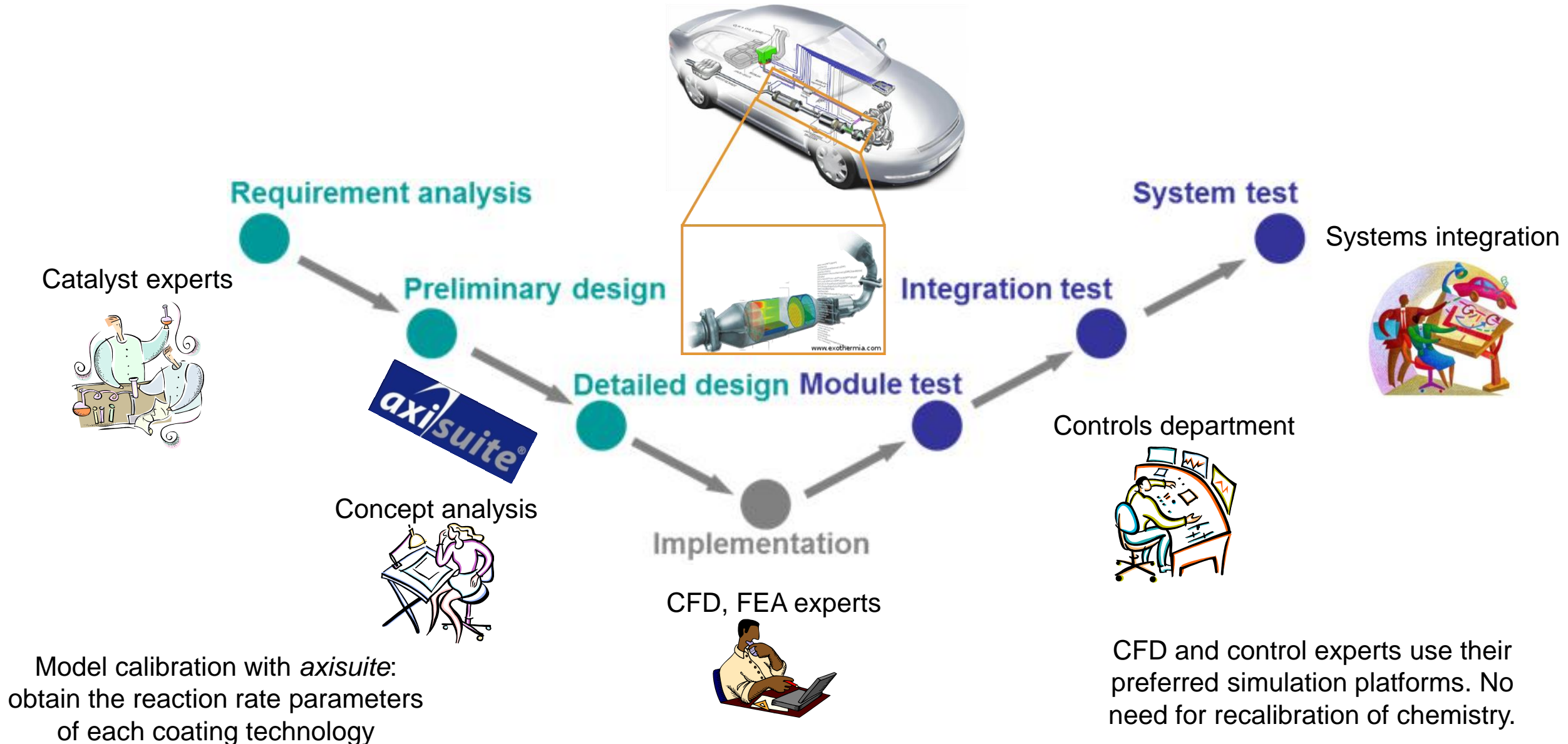


axisuite						
software module	functionality / reactor type	3-way catalyst	diesel oxidation catalyst	lean NO _x trap	selective catalytic reduction	diesel particulate filter
axi ^{cat}	flow-through	✓	✓	✓	✓	n/a
axi ^{trap}	wall-flow	n/a	✓	✓	✓	✓
axi ^{foam}	deep-bed	n/a	✓	✓	✓	✓
axi ^{heat}	exhaust pipe	single-wall	double-wall	insulating material	flanges	reacting flow



Koltsakis et al, Appl. Catal B., 1997.
 Pontikakis et al., Top. In Catal, 2001
 Tsinoglou & Koltsakis, Proc. IMechE, 2007

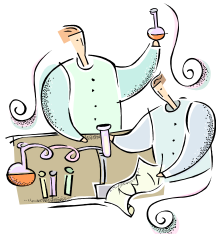
Catalyst simulation in the 'V-shape' development process



Use Cases: Aftertreatment System Design

- Use axisuite to design aftertreatment system
 - Determine required flow rates, thermal properties, etc.
 - Estimate conversion efficiency, O₂ storage dynamics, etc.
- Couple with Powertrain Blockset to evaluate at vehicle level
 - Test on different drive cycles, ambient conditions, etc.
 - Perform design studies, sensitivity analysis, etc.

Catalyst experts



Concept analysis



CFD, FEA experts



Use Cases: Aftertreatment Controls Development

- Closed-loop testing of controls features
 - Air Fuel Ratio (AFR) control - rear trim, Selective Catalytic Reduction (SCR) control, etc.
 - Catalyst light-off calibration, thermal management, etc.
- Diagnostics and predictive maintenance
 - On-Board Diagnostics (OBD) catalyst monitoring
 - Front / rear O₂ sensor feedback
 - Diesel Particulate Filter (DPF) regeneration feedback

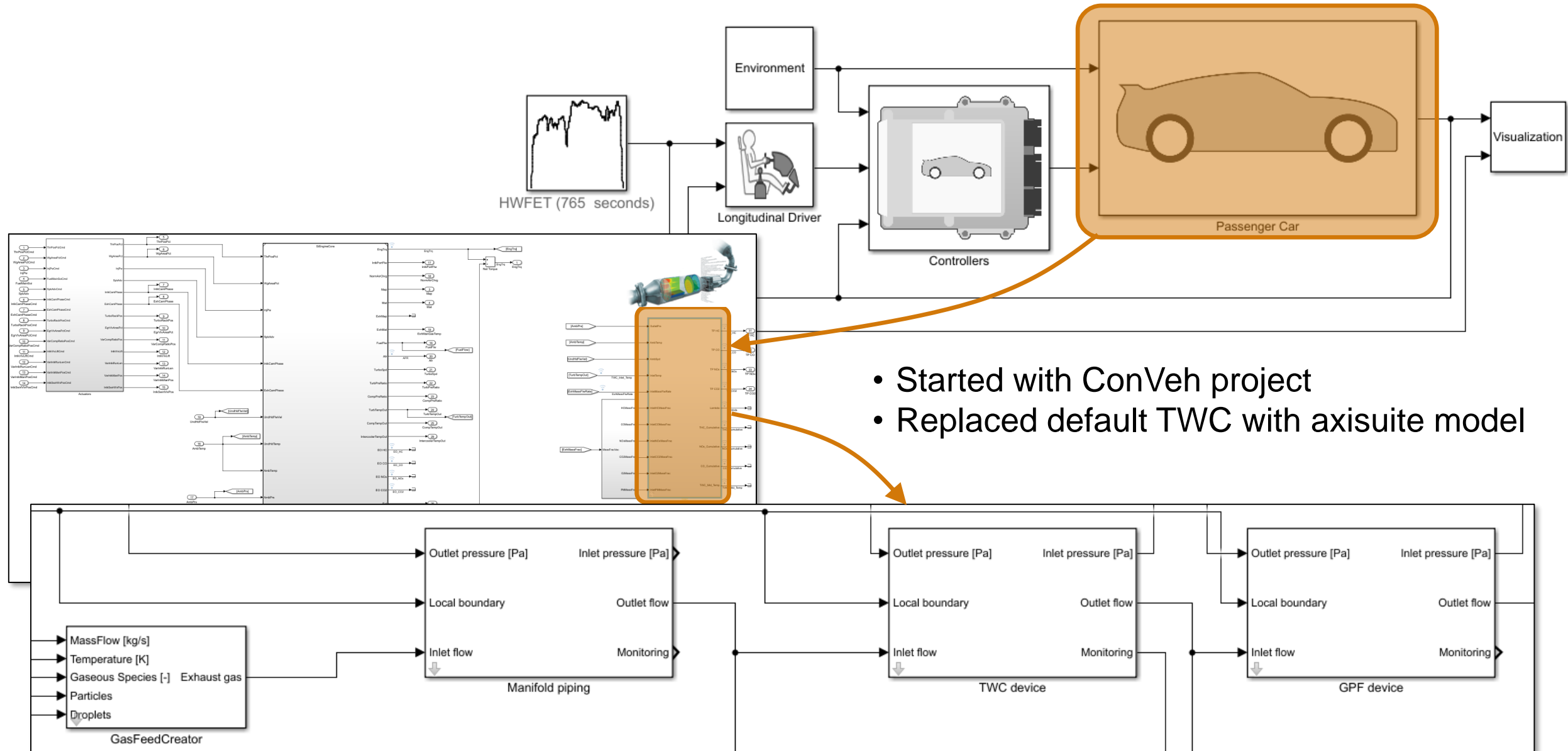
Controls department



Systems integration

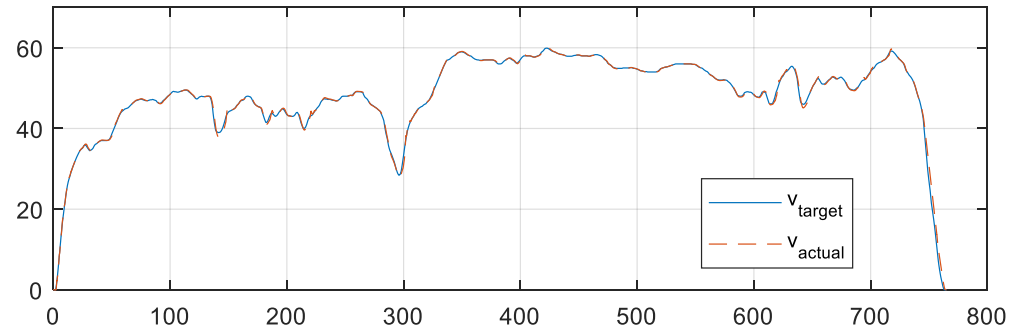


Example: Conventional Vehicle + TWC / GPF

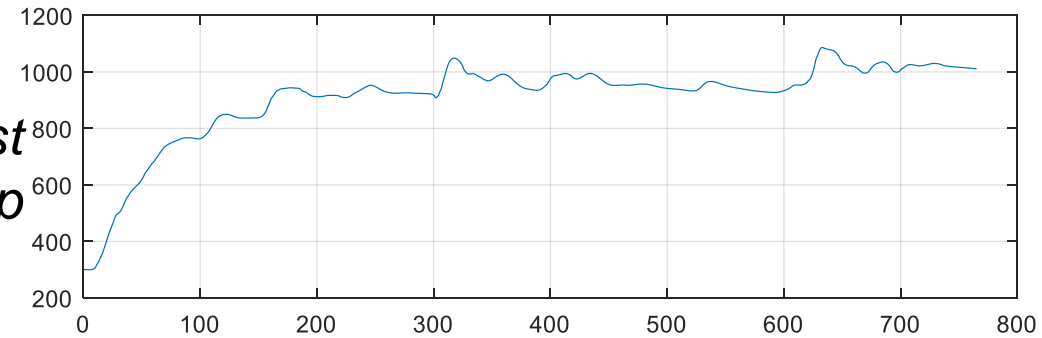


Results

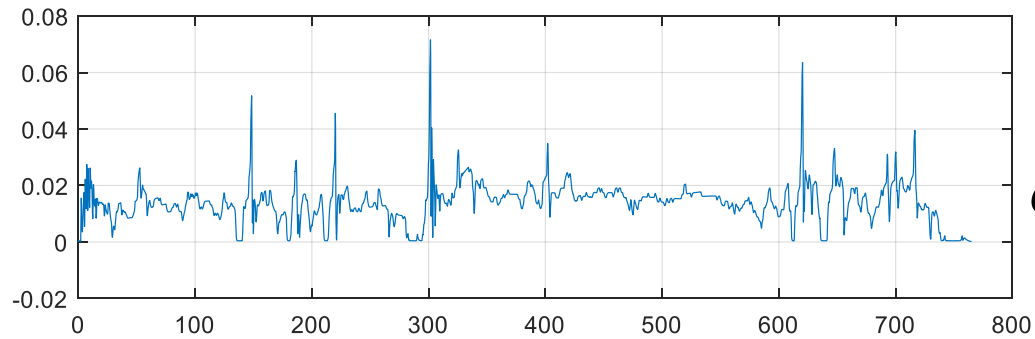
Vehicle speed



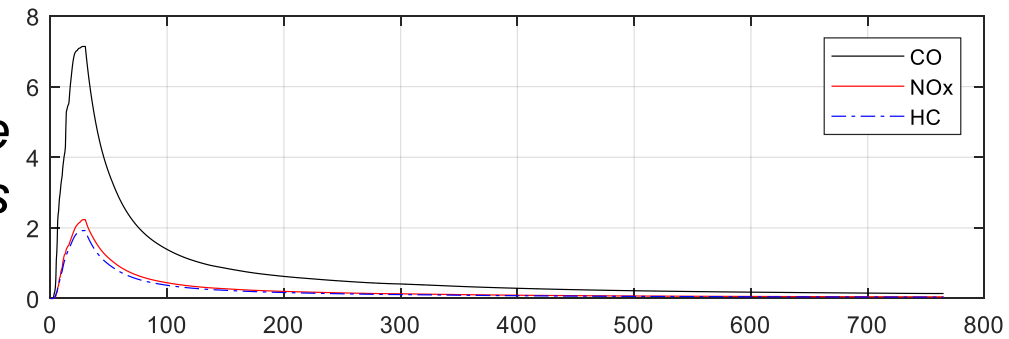
Catalyst temp



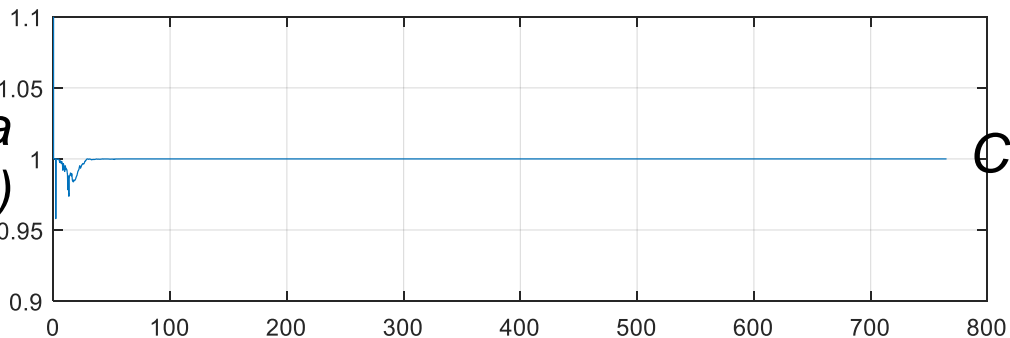
Exhaust gas flow rate



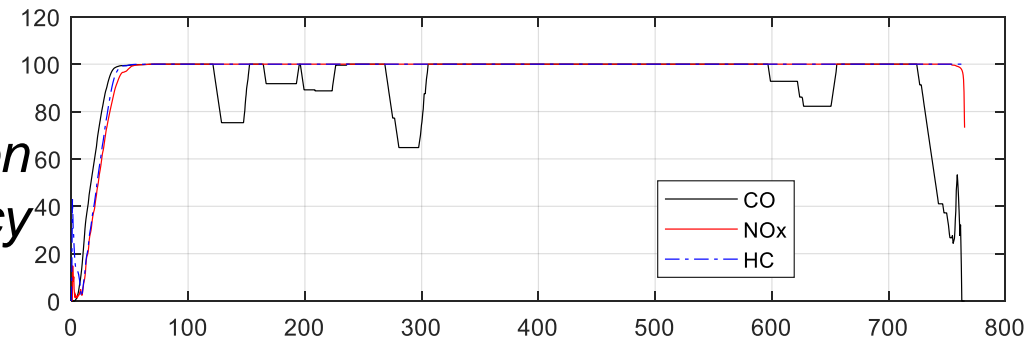
Tailpipe emissions



Lambda (post TWC)

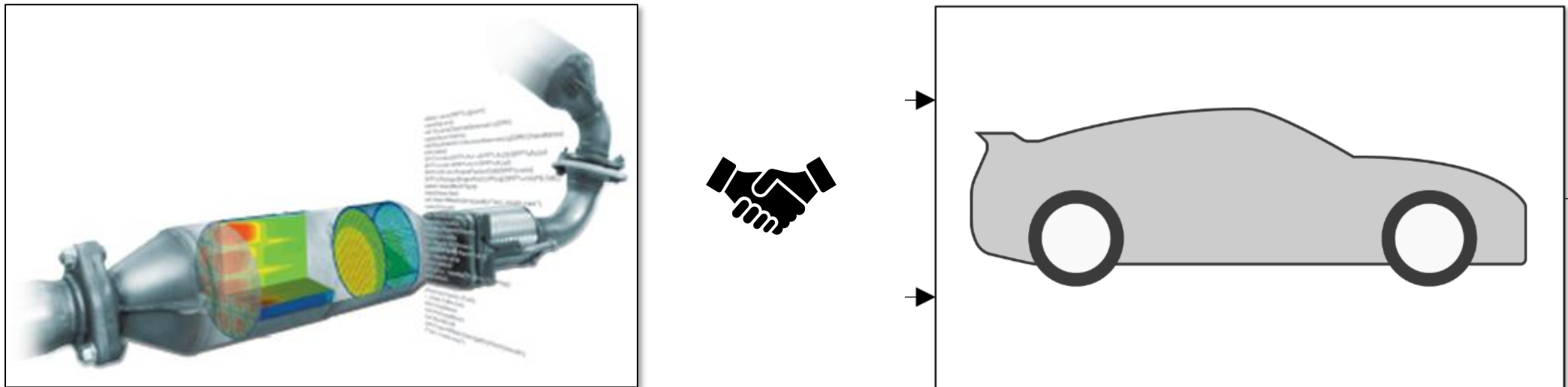


Conversion efficiency




Aftertreatment Modeling

- Account for system level interactions (driver, vehicle, engine, aftertreatment, etc.) in a single environment
- Study impact of design and control changes on overall vehicle performance
- Couple high-fidelity aftertreatment model with real driving conditions

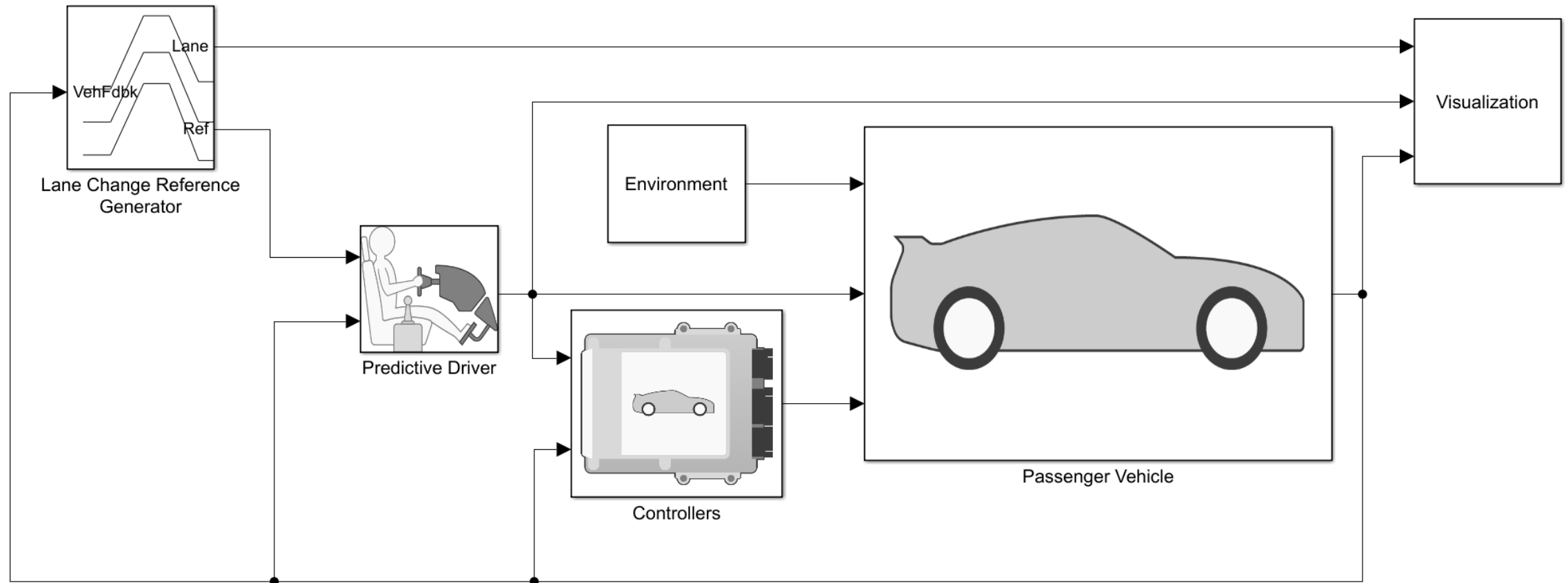


Agenda

- Product overview
 - Powertrain Blockset
 - Vehicle Dynamics Blockset

- Six Cool Things You Can Do
 - Automating engine model parameterization
 - Battery cooling circuit testing
 - Aftertreatment system testing
 - **Ride and handling analysis**  – Assess longitudinal / lateral dynamics
 - Chassis controls development
 - ADAS / AD testing

Reference Application: Double Lane Change



Ride and Handling Study: Double Lane Change at 30 mph



Ride and Handling Study: Double Lane Change at 50 mph




Ride and Handling

- Analyze ride and handling metric of interest
 - Lateral acceleration
 - Roll-over propensity
 - Understeer / oversteer
- Simulate the vehicle over various driving maneuvers
 - Double lane change
 - Slowly increasing steering
 - Swept sine steering
 - Customer maneuver

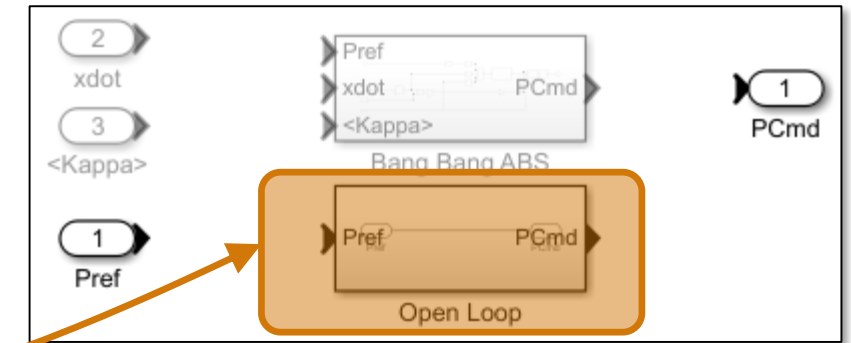
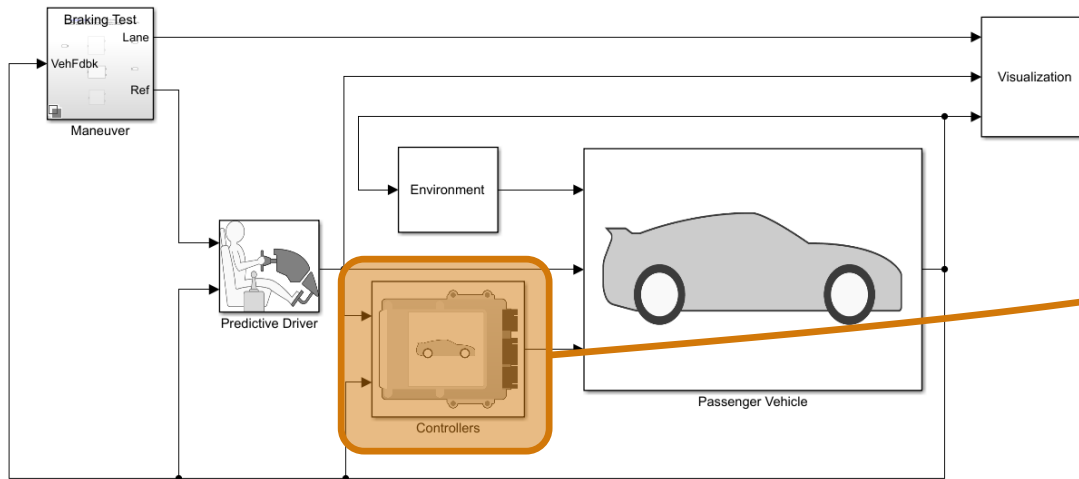


Agenda

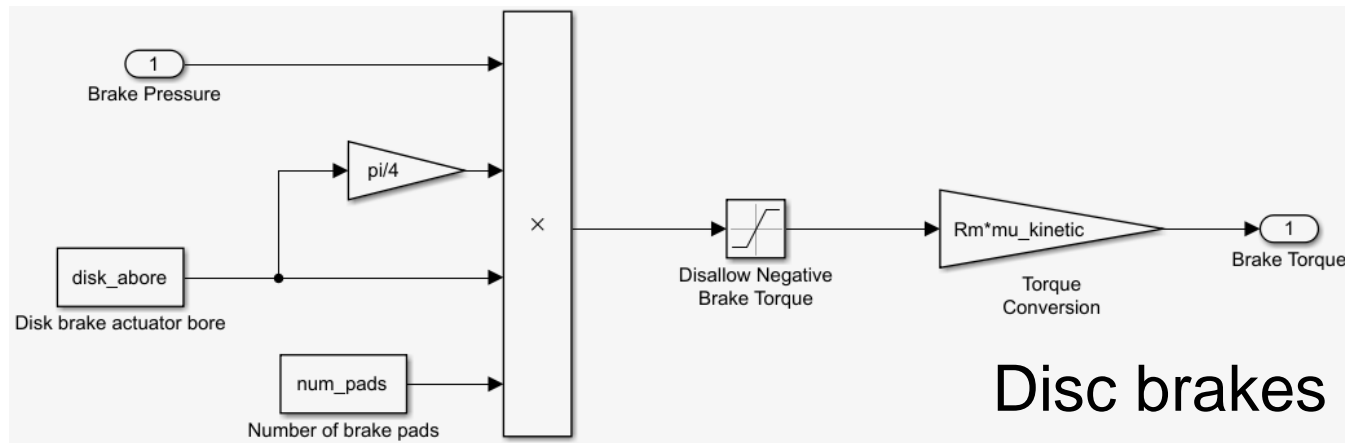
- Product overview
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 - **Chassis controls development**  – Perform closed-loop testing
 - ADAS / AD testing

Chassis Controls Study: Braking Test



Open loop brake controller simply passes through brake pressure command

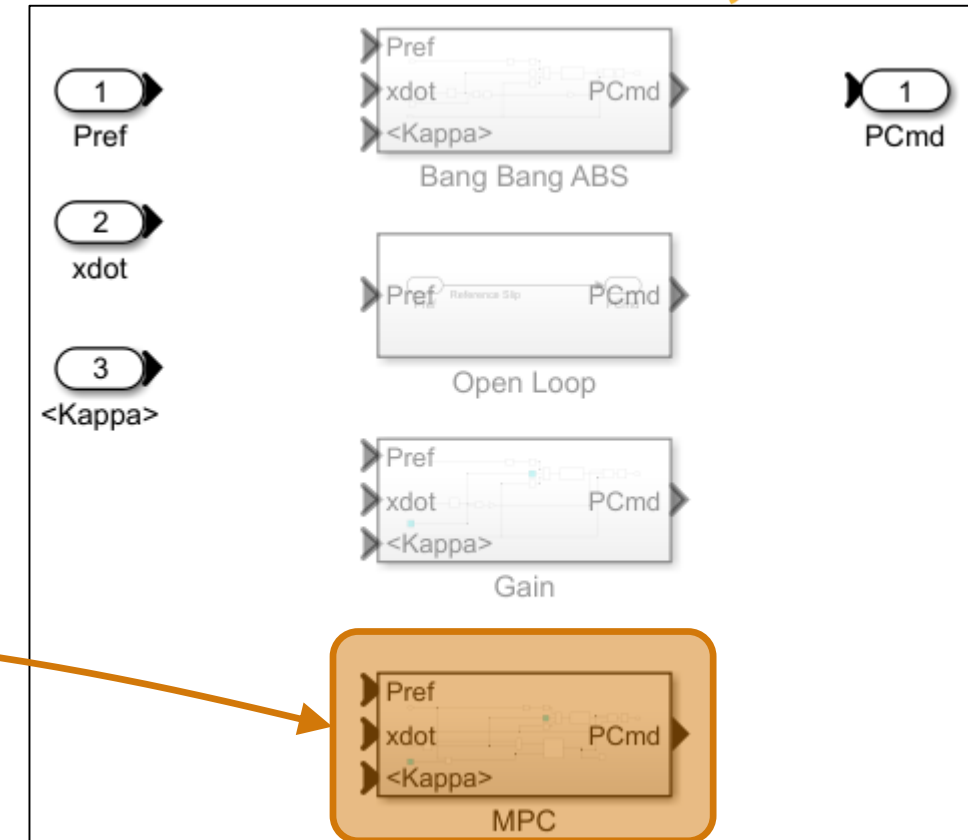
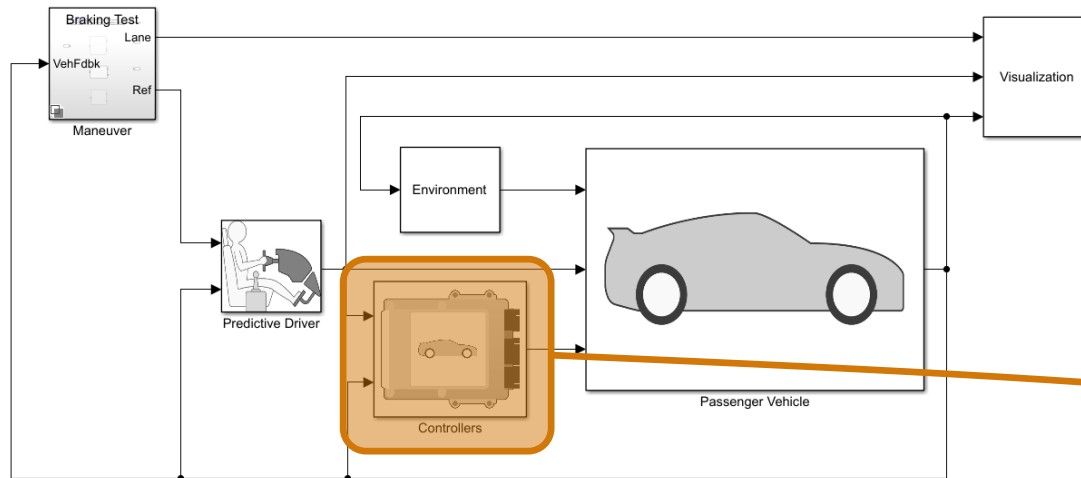


Disc brakes

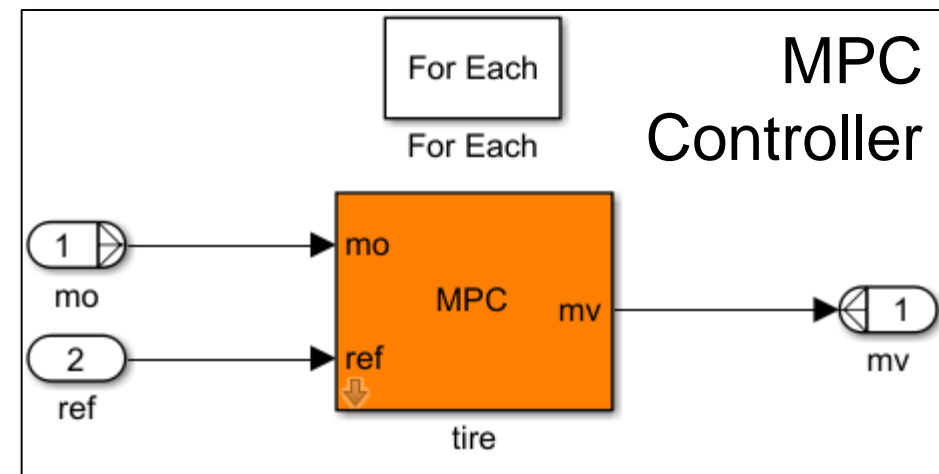
Chassis Controls Study: Braking Test



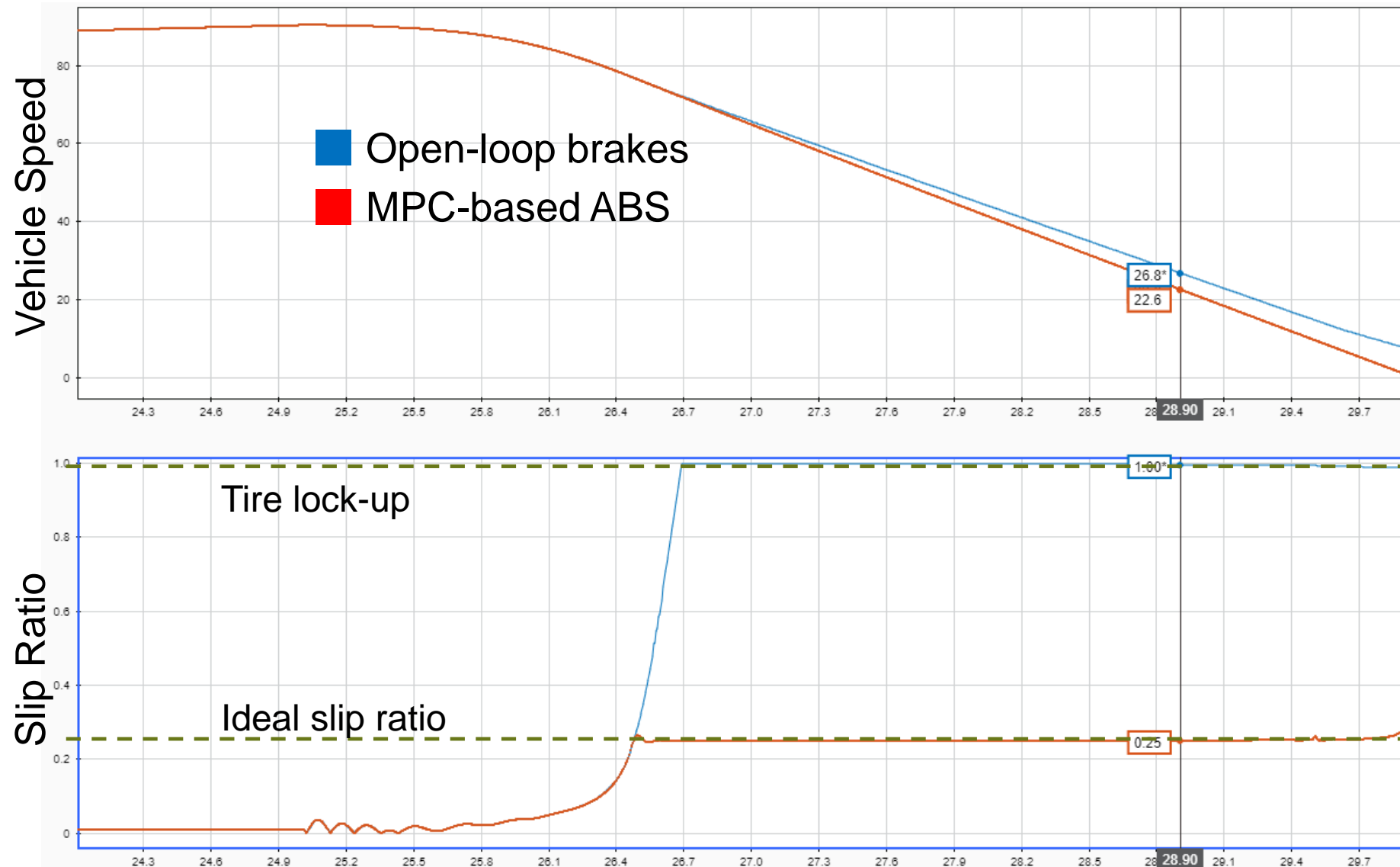
Chassis Controls Study: ABS Controller



- Added custom MPC variant to brake controller subsystem
- At each time step, finds optimal brake pressure for target slip ratio



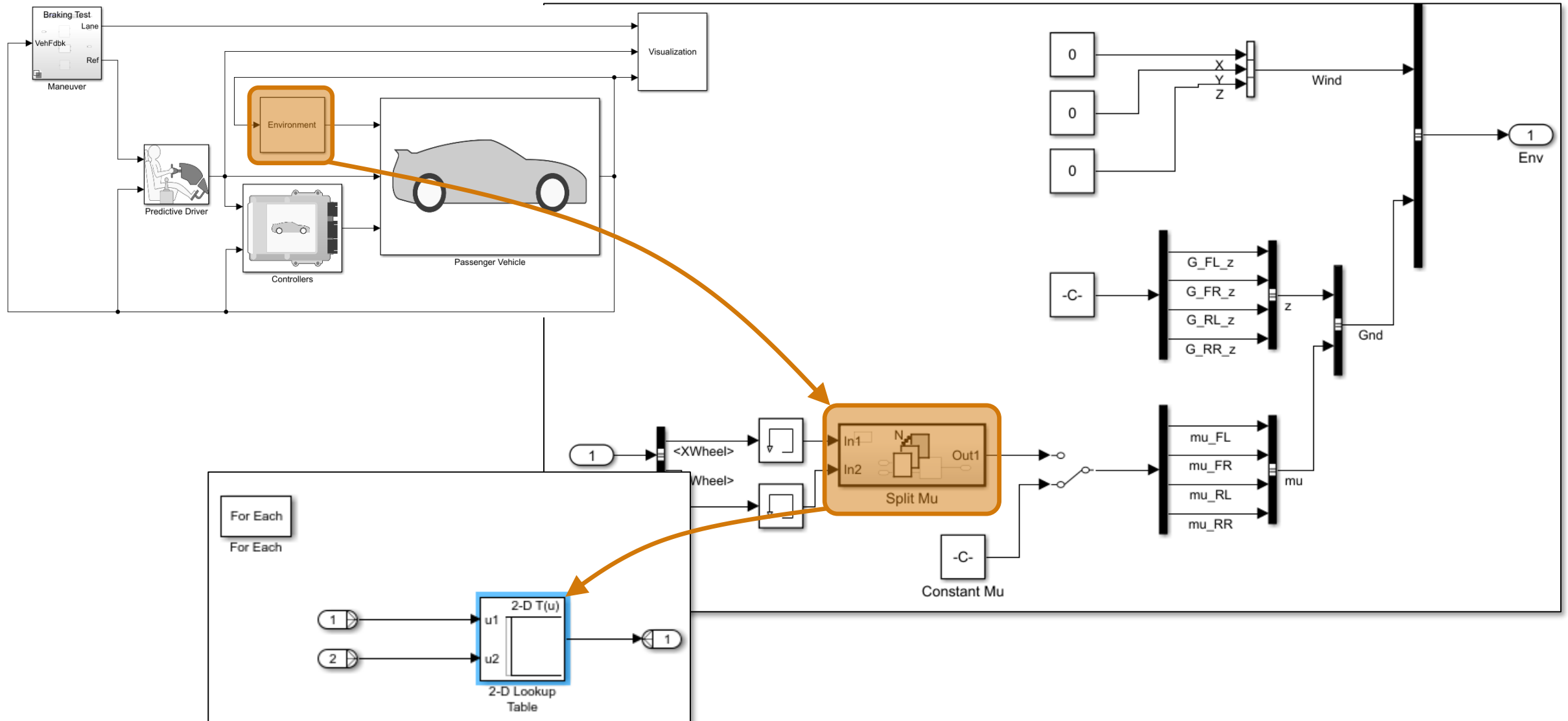
Chassis Controls Study: ABS Controller



Chassis Controls Study: Braking Test with ABS



Split Mu Test



Chassis Controls Study: Split Mu Test




Chassis Controls Development

- Study the impact of controller on vehicle behavior
- Incorporate custom control features
- Test the closed-loop system over a wide range of scenarios



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 - Chassis controls development
 - **ADAS / AD testing**  – Test in a virtual 3D environment

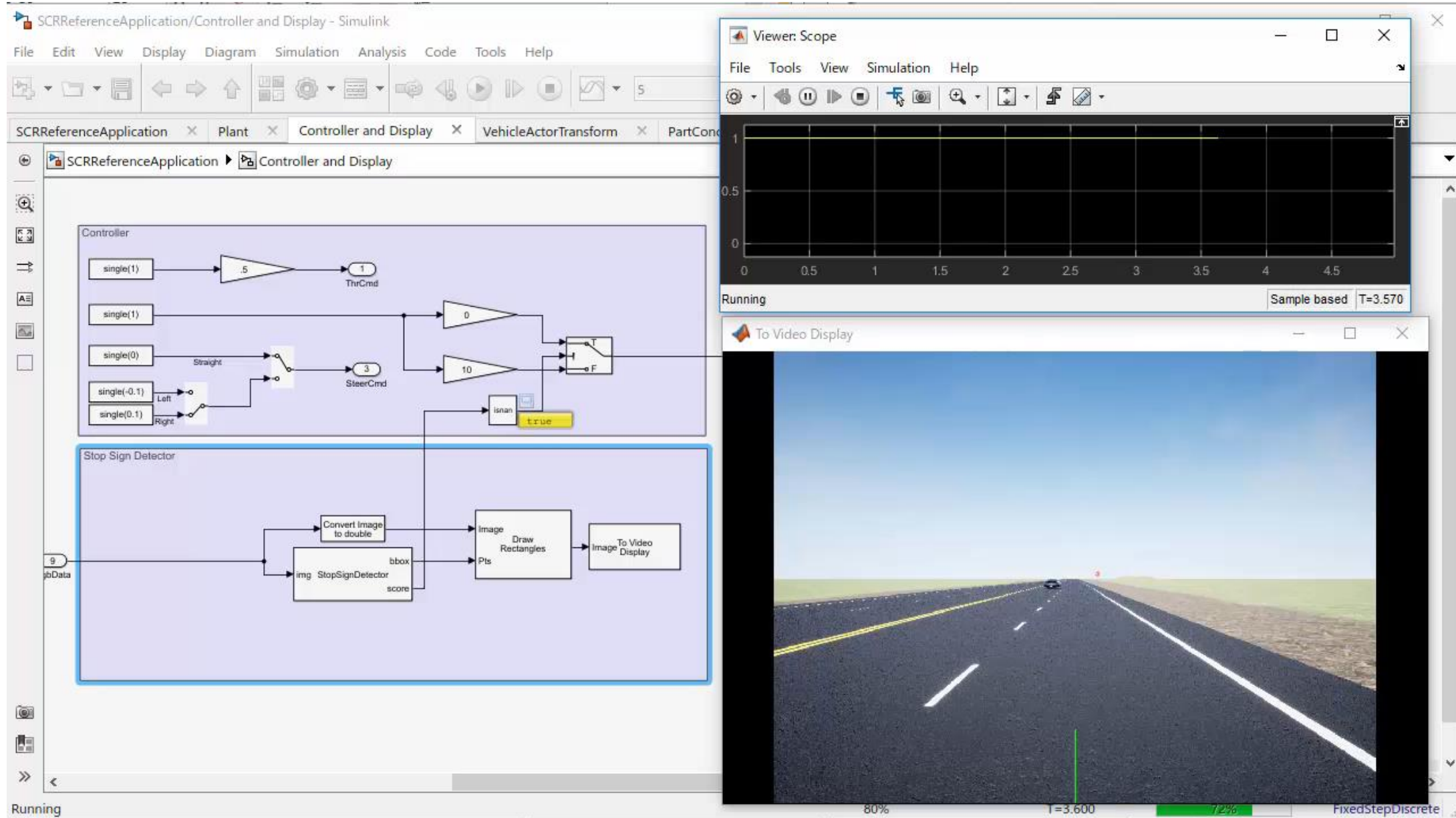
ADAS / AD Testing: Virtual 3D Scene



Camera sensor sends video to Simulink

Synthetic video used for testing vision-based algorithms (e.g., lane detection)

Stop Sign Detection and Braking



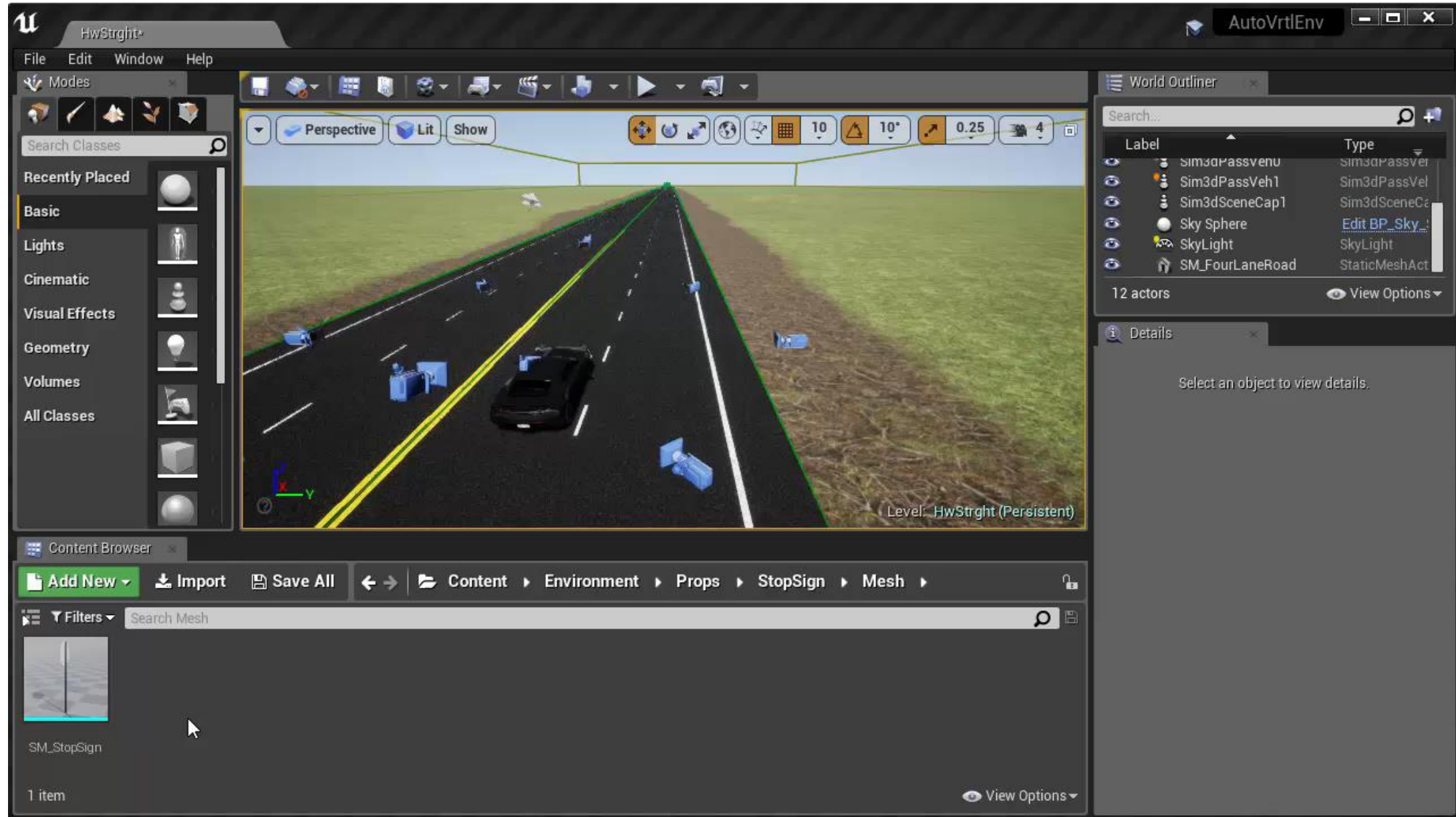
Customizing Scene with Support Package

- Create your own scenes with Unreal Editor and our Simulink plug-in
- Unreal Editor project files available in our Support Package:
“[Vehicle Dynamics Blockset interface for Unreal Engine 4](#)”



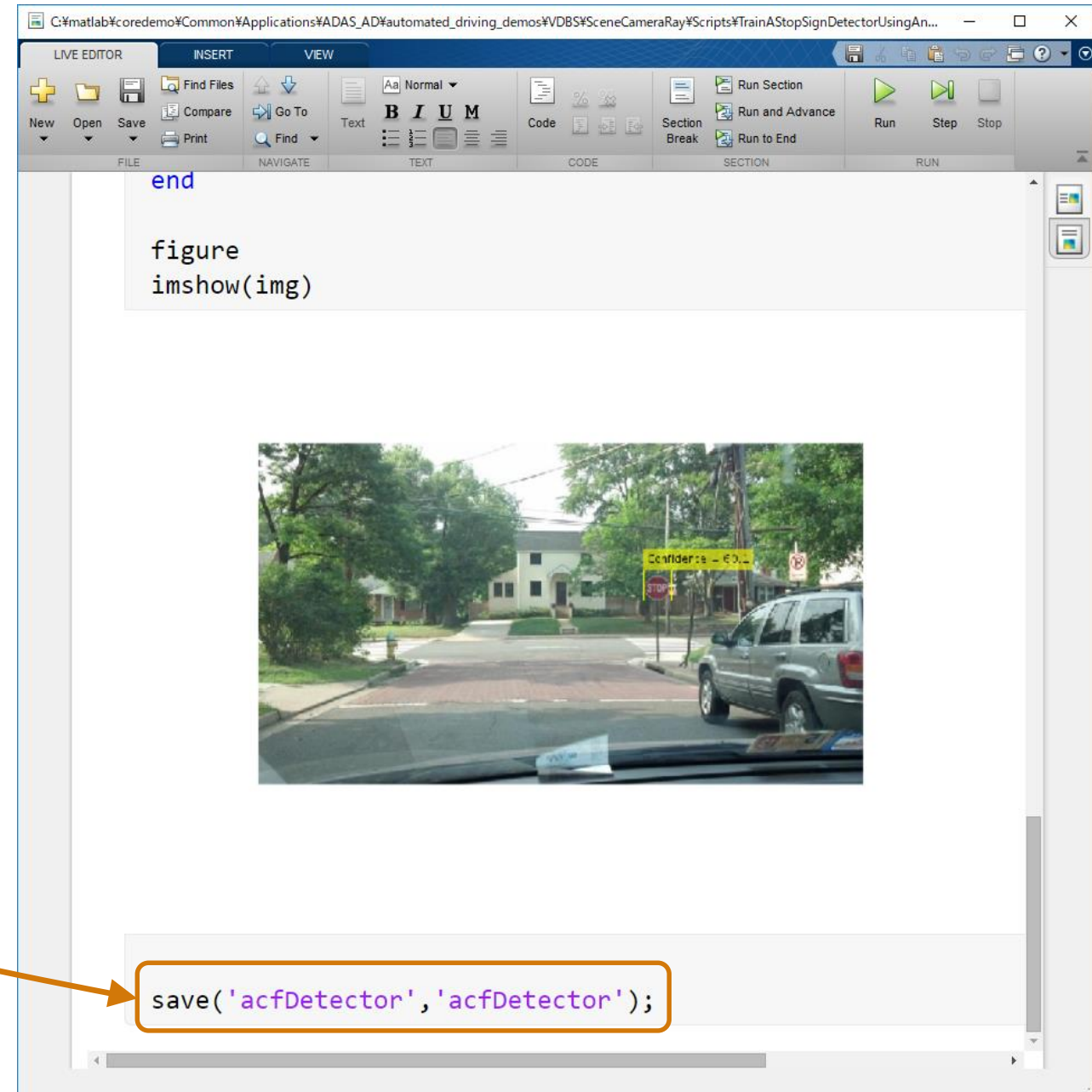
The screenshot displays the MathWorks File Exchange interface. At the top, the MathWorks logo is on the left, and navigation links for Products, Solutions, Academia, Support, Community (highlighted), and Events are on the right. Below this is a blue header bar with the text 'File Exchange' and a search box labeled 'Search File Exchange'. Under the header, there is a row of links: MATLAB Central (with a dropdown arrow), Files, Authors, Tags, Comments, My File Exchange, and Submit. Below these links is an 'About' link. The main content area features a large orange title 'Vehicle Dynamics Blockset interface for Unreal Engine 4'. To the left of the title is a small image of a red car on a road. Below the title, it says 'version 1.0 (15.1 KB) by MathWorks Automotive Community Profile'. At the bottom, it says 'Simulink integration for Unreal Engine 4'.

Editing Support Package Scene to Add Stop Sign



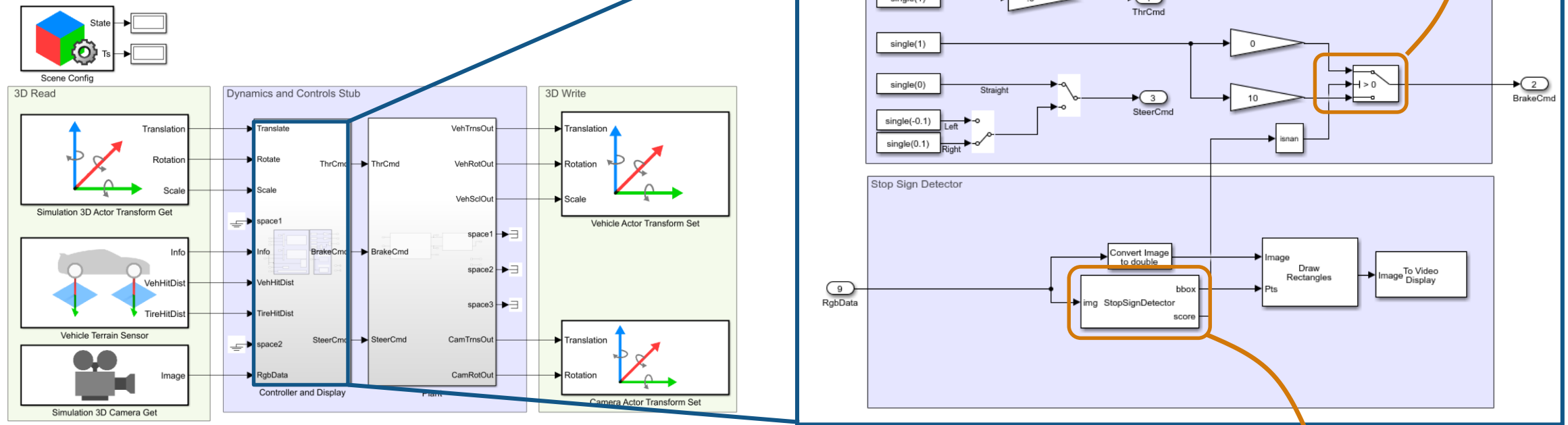
Training Stop Sign Detector

- Train a stop sign detector as an Aggregate Channel Feature (ACF) object detector
- The detector is trained based on the Computer Vision System Toolbox (CVST) [example](#) and saved as a MAT-file



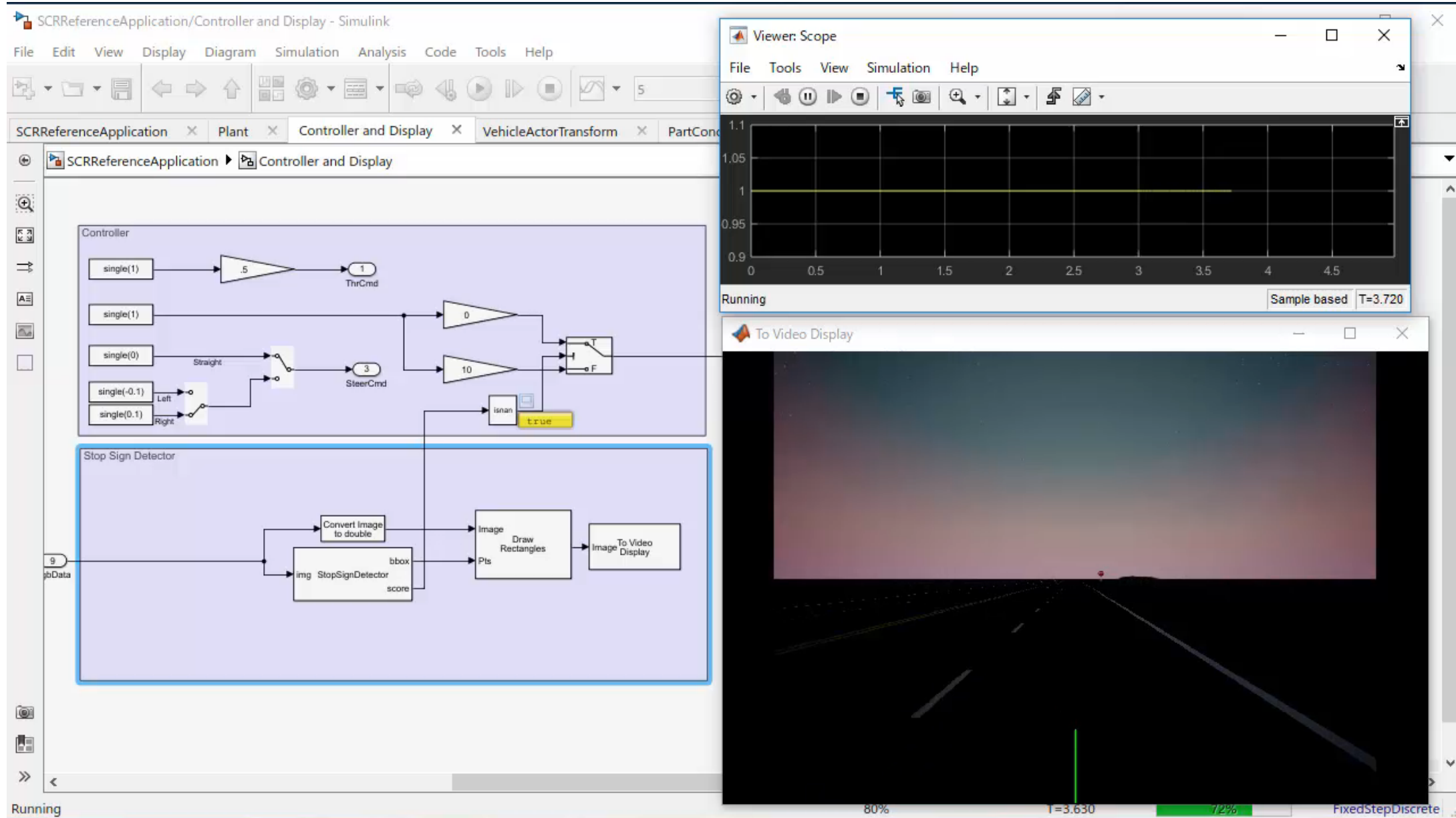
Implementing Braking Logic

- Start with Scene Interrogation reference application
- Add braking logic to stop when the stop sign appears



Add stop sign detector as
MATLAB System Object

Changing the Lighting to Night Conditions



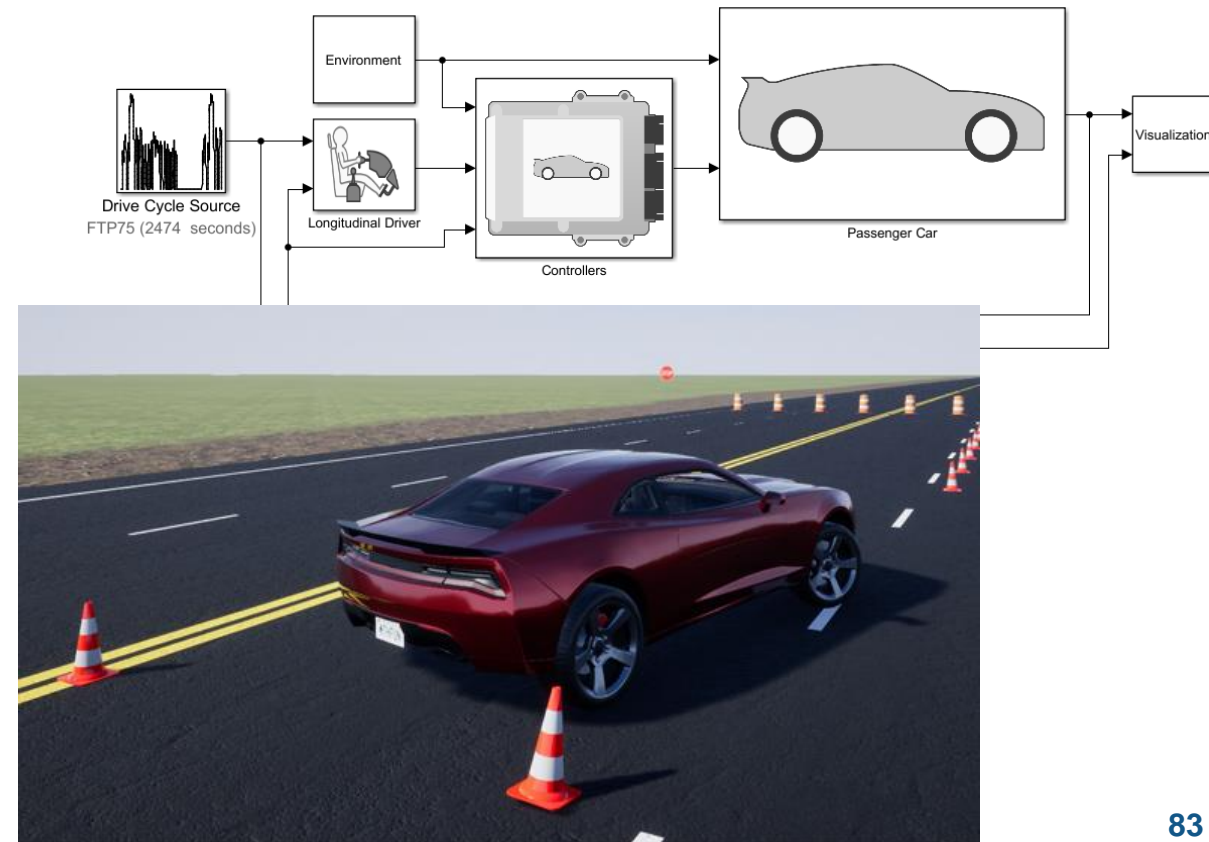
ADAS / AD Testing

- Use Unreal Engine as a virtual test environment for ADAS / AD control features
- Incorporate and test custom sensor models
- Create custom scenes for exercising the system



Value Proposition

- MathWorks provides vertical products to serve automotive industry, including
 - Powertrain Blockset: powertrain controls, fuel economy and performance simulation
 - Vehicle Dynamics Blockset: ride and handling, chassis controls, AD / ADAS testing
- These products offer
 - **Open** and documented library of component and subsystem models
 - Prebuilt vehicle models that you can parameterize and **customize**
 - **Fast**-running models that are ready for HIL deployment
 - **Framework** that supports integration with 3rd party software



Thank You

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Product Manager

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