

How to Win Using Modeling and Simulation

– 2019 IEF Solar Car Conference

Swaroop Seshadri

(All models and code in this presentation can be downloaded [here](#))



Swaroop Seshadri

Supporting automotive student
competitions @ MathWorks

Based in Natick, Massachusetts

M.S. in mechanical engineering:
Dynamic systems, controls and
optimization

Agenda

15 mins

1

Why model?

10 mins

2

MathWorks
Overview

5 mins

3

Get the Software

45 mins

4

Get Going

5 mins

5

Learn

5 mins

6

Win!

Agenda

1

Why model?

2

MathWorks
Overview

3

Get the Software

4

Get Going

5

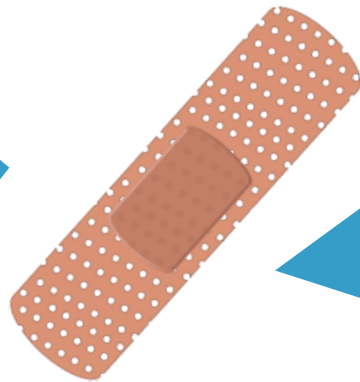
Learn

6

Win!

1

Why model?



fun

inefficient

too
big



USER STORY

ABB Optimizes Ship
Energy Flows

too
difficult



USER STORY

DCNS Simulates
Handling System

one
chance



USER STORY

Lockheed Martin
Develops MRO

World Record?

0 - 100 km/h

in

1.9 seconds



Academic Motorsports Club Zurich (AMZ) Formula Student Team



World Record?
Averaged ~107 km/h
over
500 km

University of New South Wales World Solar Challenge Racing Team



Applications Demo

Example Modeling Tasks on a Solar Car

Full-Vehicle modeling
Aerodynamic package optimization
Lap time simulation

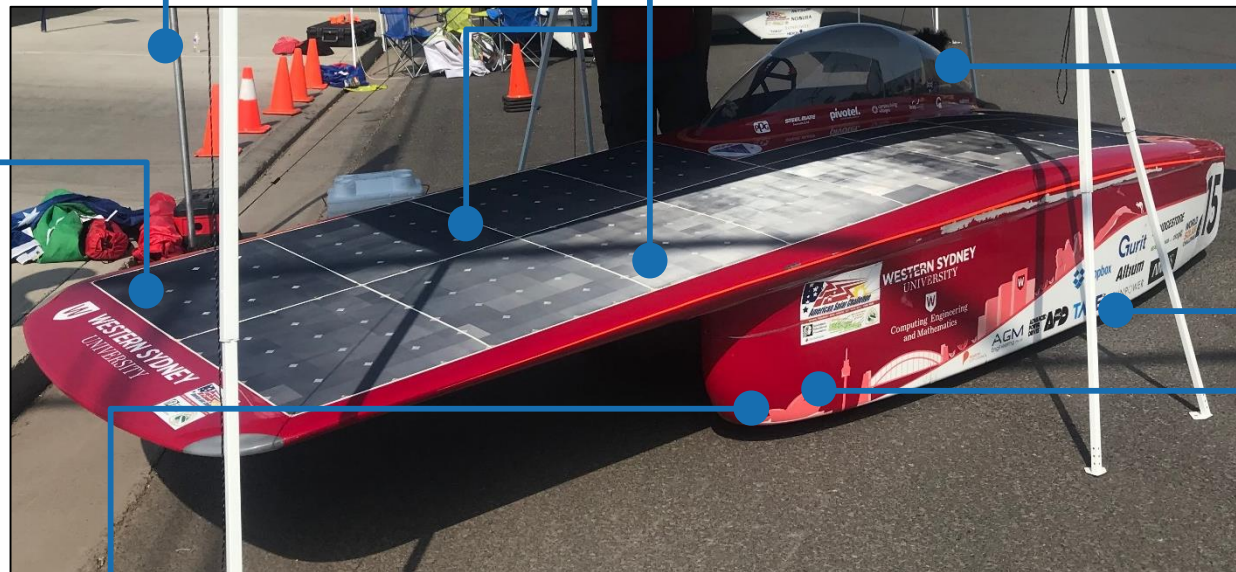
PV array characterization
Battery modeling
BMS design

Data logging/processing
CAN communication

Control system design
ECU programming
Automated driving

Torque vectoring

3D suspension tuning

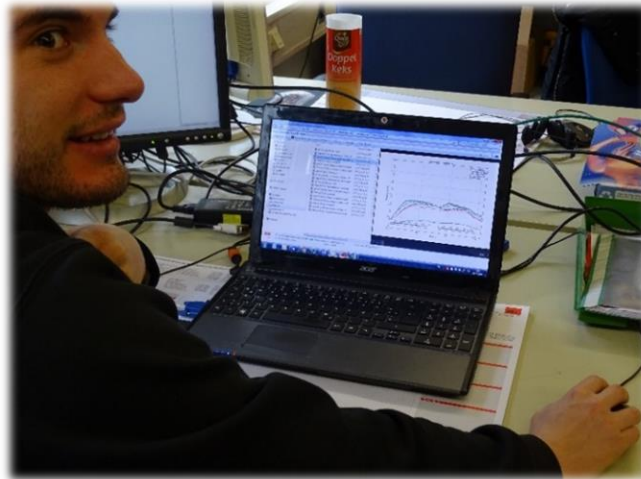


PC: American Solar Challenge, Western Sydney University Team

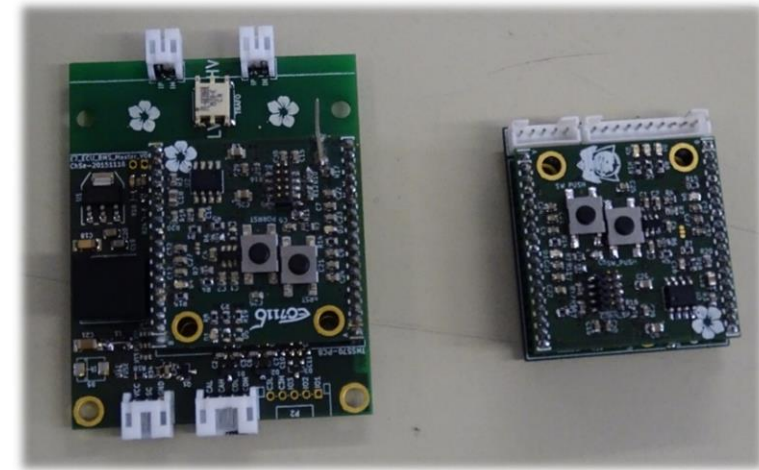
Tire modeling

Drivetrain modeling
Electrical motors

Model-Based Design



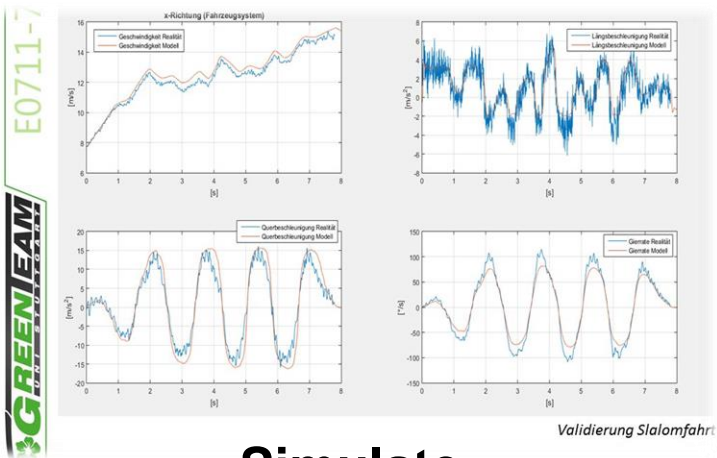
Model



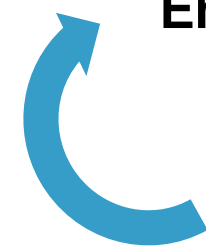
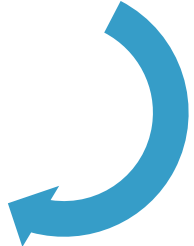
Embedded Code Generation



Rapid Prototyping



Simulate



2

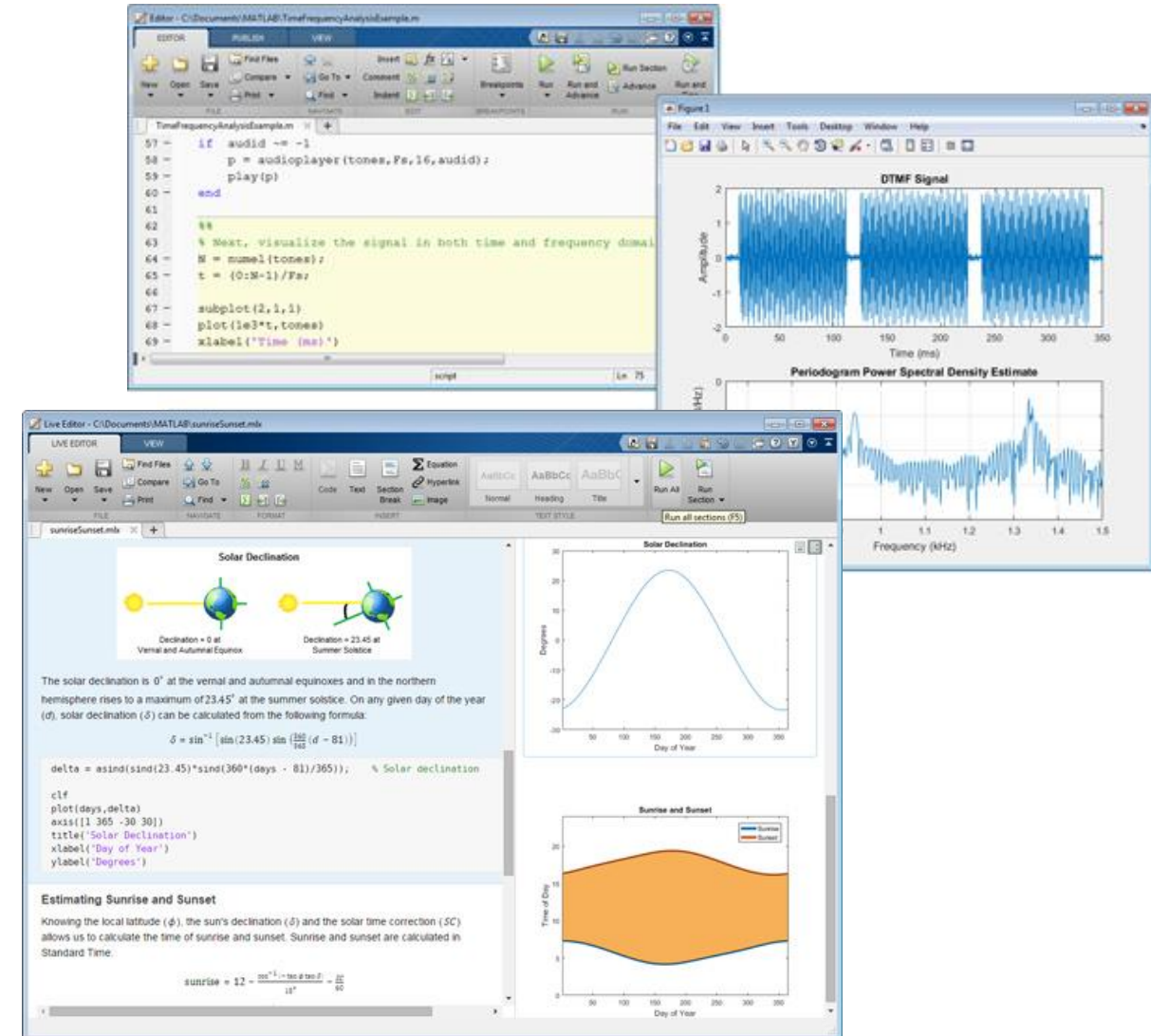
MathWorks Overview

MATLAB®

Math, graphics, and programming

- **Numeric computation**
- **Data analytics and visualization**
- **Algorithm development and collaboration**
- **Toolboxes for:**
 - Signal and image processing
 - Statistics and machine learning
 - Optimization
 - Symbolic math

... and more



SIMULINK®

Modeling, simulation, and embedded systems

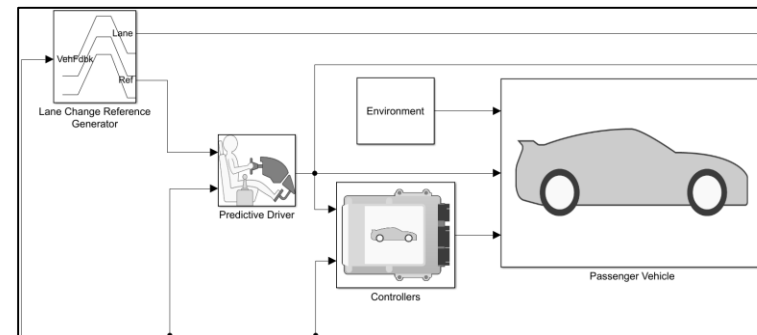
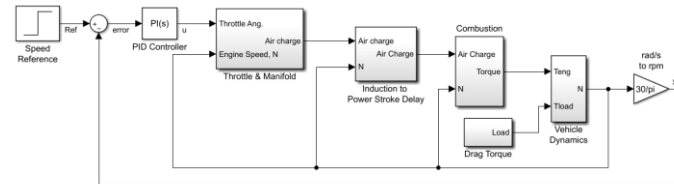
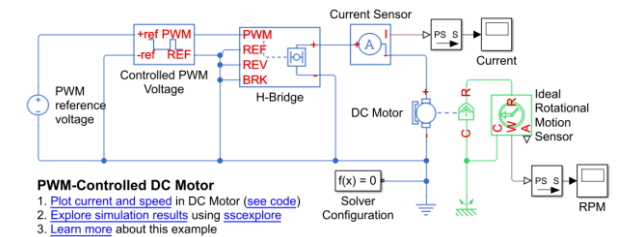
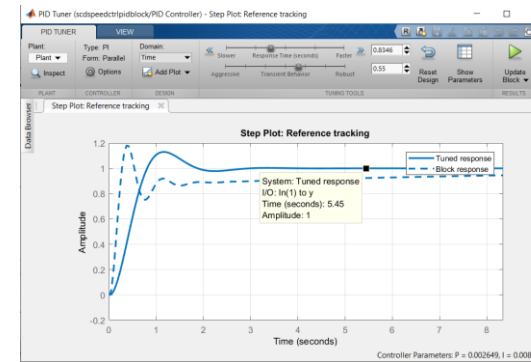
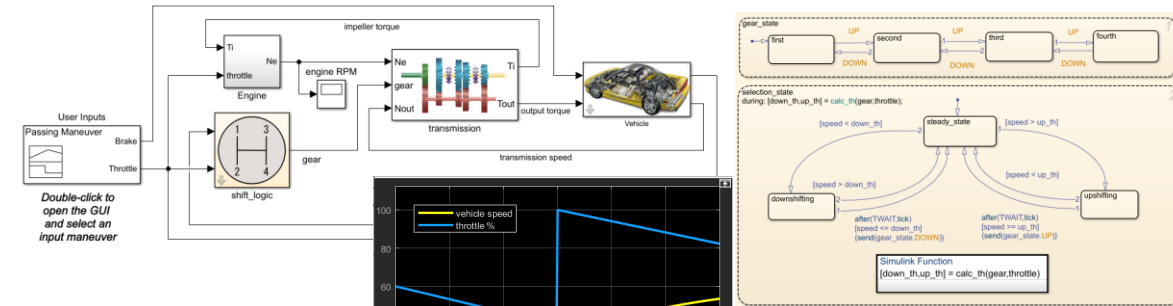
- Platform for **Model-Based Design**

- Block diagram modeling
- Simulation of physical systems
- Automatic code generation

- Applications in:

- Control systems
- Dynamics modeling
- Signal processing
- Communications systems

... and more



Deeply Involved in Education



“Everyone who comes in as a new hire already knows MATLAB, because **they all had it in college**. The learning curve is significantly lessened as a result.”

Jeff Corn, Chief of Engineering Projects Section
U.S. Air Force

MATLAB and Simulink are the tools of inspiration and innovation used by students, educators, and researchers around the world.



5000+ colleges and universities



1900+ MATLAB and Simulink-based books



Tens of thousands of skilled graduates each year

Student Competitions

Sponsored **47 competitions** and provided software to **>3000 teams** in 2018

Fields include automotive, aerospace, biotech, programming, and robotics



3

Get the Software

Complimentary Software

- Work with MATLAB, Simulink and ~90 toolboxes
Bigger than some campus licenses
- Install it on your personal / team machines
Great freedom and ease of use
- Access the technical support
Solve your problems faster

Request software

<https://www.mathworks.com/academia/student-competitions/american-solar.html>

Competition License

R2018b

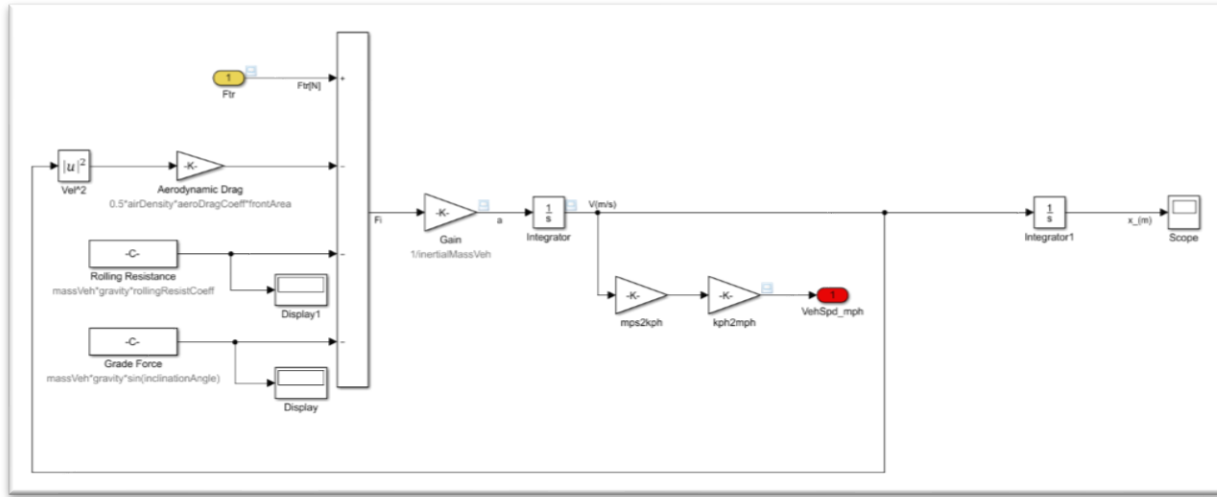
MATLAB, Simulink,



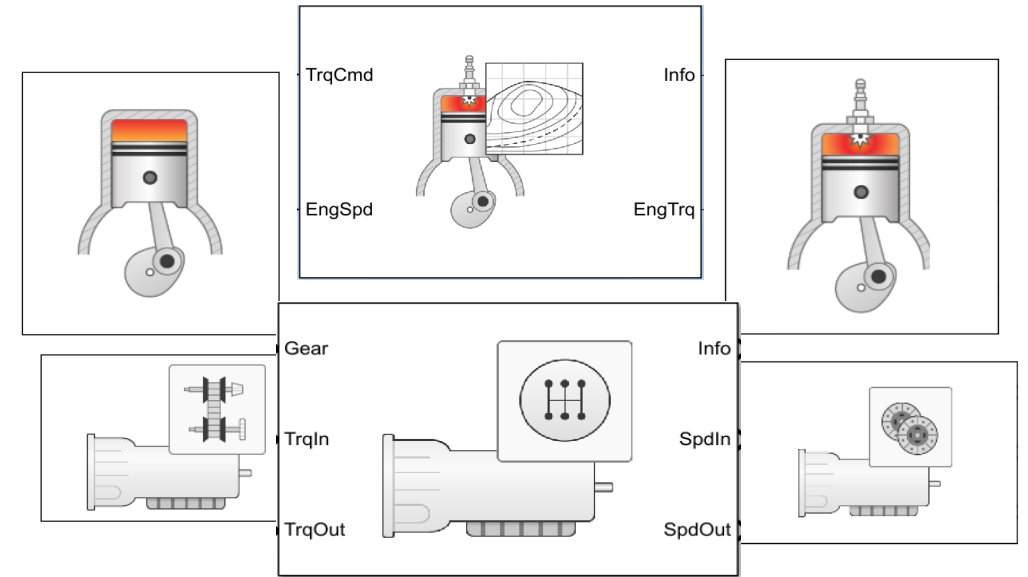
4

Get Going

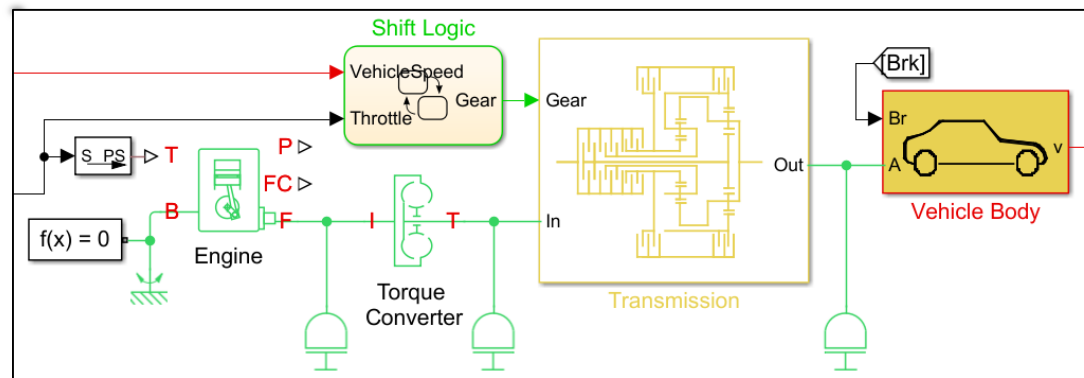
Modeling Techniques



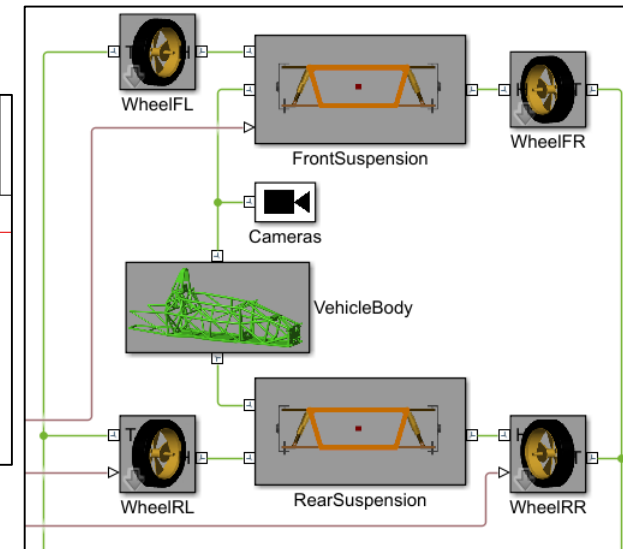
Equation Based Modeling



Data Driven Modeling



Physical Modeling



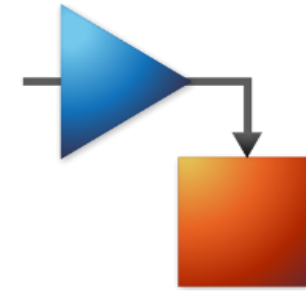
Equation Based Modeling

Simulink

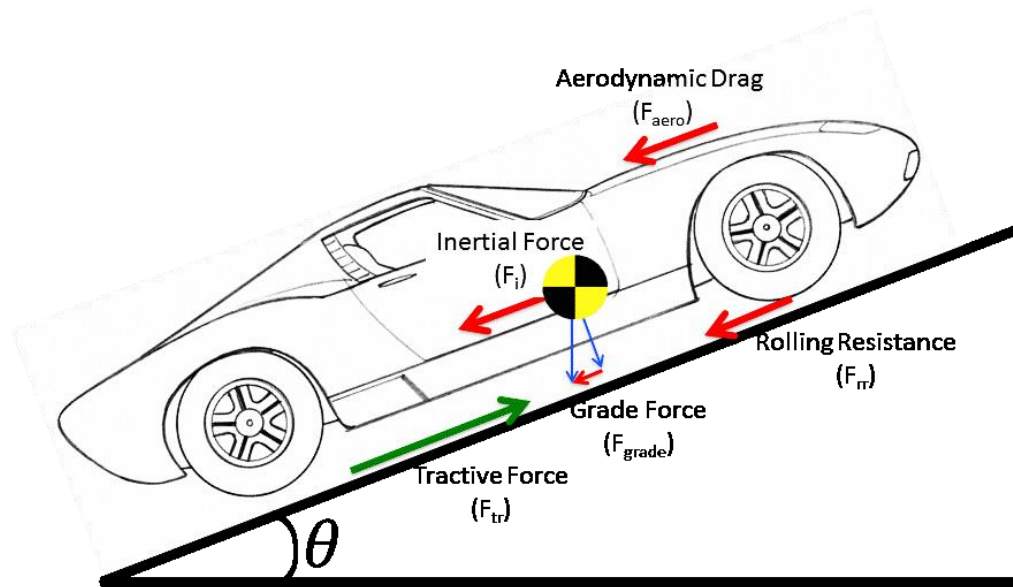
- Quasi-standard for control design in academia and industry
- Baseline tool that supports many add-ons (e.g. Simscape, Powertrain Blockset)
- Equation-based modeling approach
- Code generation support for hardware testing and deployment

Great choice if:

- You want to get started with vehicle modeling
- You seek simplicity and speed for models
- You like the equation-based approach
 - [Getting Started with Simulink](#)



Vehicle Dynamics Represented with Glider Model



$$F_{tr} = F_{aero} + F_i + F_{grade} + F_{rr}$$

$$F_{aero} = \frac{1}{2} \rho C_d A_f V^2$$

$$m_i = 1.04m$$

$$F_i = a m_i$$

$$a = \frac{F_{tr} - (F_{aero} + F_{grade} + F_{rr})}{m_i}$$

$$F_{grade} = m g \sin(\theta)$$

$$F_{rr} = m g C_{rr}$$

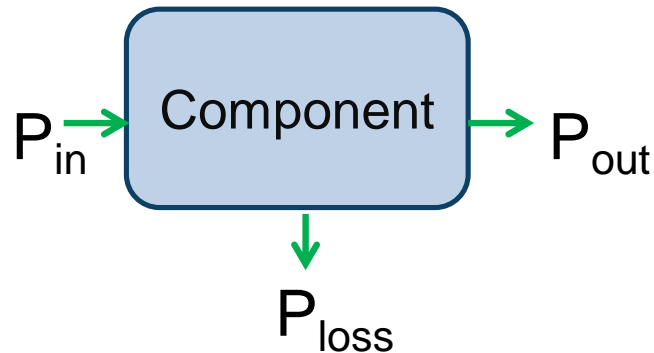
Parameter	Units	Description
ρ	kg/m^3	Air density
C_d	-	Drag coefficient
A_f	m^2	Vehicle frontal area
V	m/s	Vehicle speed
a	m/s^2	Vehicle acceleration
m_i	kg	Vehicle inertial mass
m	kg	Vehicle mass
g	m/s^2	Gravity
θ^*	<i>Degrees</i>	Road angle
C_{rr}	-	Rolling resistance coefficient

Racing Lounge [video](#)

Source: Sun, Zhu 2015 [1]
 Model input: US06 Drive Cycle [2]

Vehicle Dynamics of a BEV Describing Power Loss

Power Loss Modeling



- Power loss models look at the power flow through the vehicle
- Account for the losses associated with each component
- Easy to understand

$$P_{out} = P_{in} - P_{loss}(P_{in})$$

$$P_{loss} = C_0 + C_1 * P_{in} + C_2 * P_{in}^2$$

Source: Zhang & Mi 2011 [3]

Racing Lounge [video](#)

References

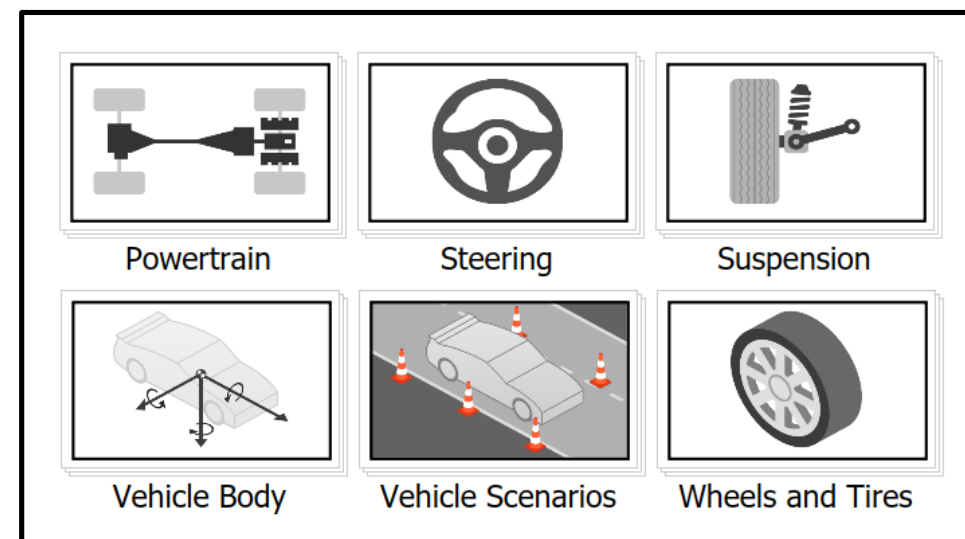
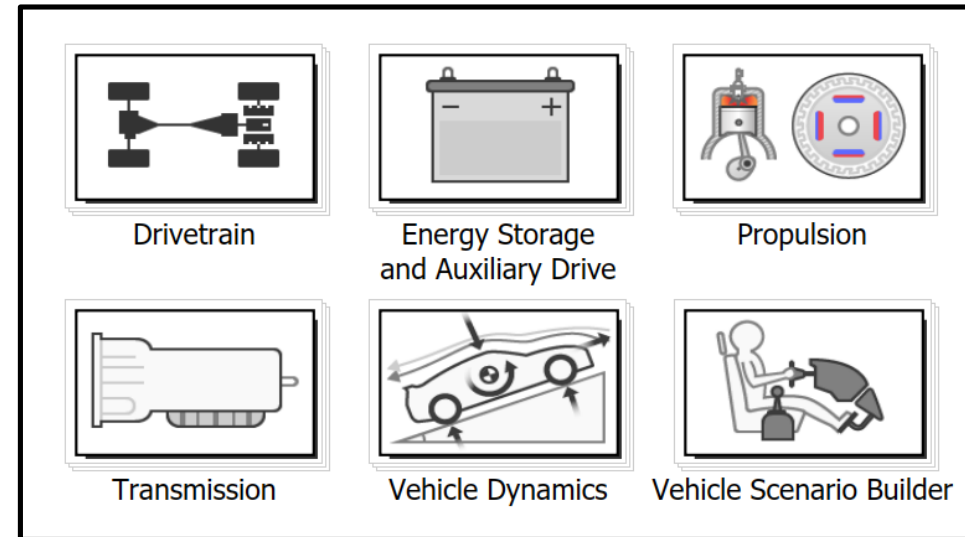
- [1] Sun, Zongxuan, and Guoming Zhu. *Design and control of automotive propulsion systems*. Boca Raton, Fla: CRC Press, 2015. Print.
- [2] "Dynamometer Drive Schedules." *EPA*. Environmental Protection Agency, 31 Jan. 2017. Web. Apr. 2017.
- [3] Zhang, B, and Mi, C. (2011), "Charge-Depleting Control Strategies and Fuel Optimization of Blended-Mode Plug-In Hybrid Electric Vehicles", *IEEE Transactions on Vehicular Technology*, Vol. 60, No. 4, May 2011.

Data Driven Modeling

Powertrain Blockset™ and Vehicle Dynamics Blockset™

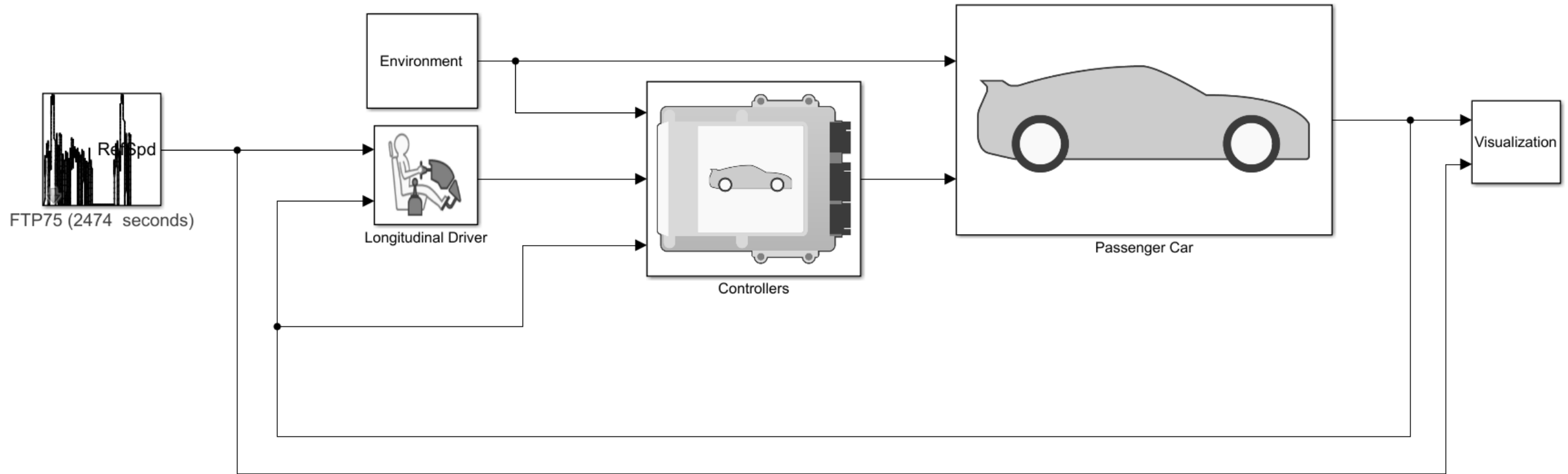
- Specialized Simulink blocks for vehicle component modeling
- Well-documented, open, and reconfigurable models
- Parameterize models using equations or data
- Reference application examples
- Code generation support

Racing Lounge [video](#)



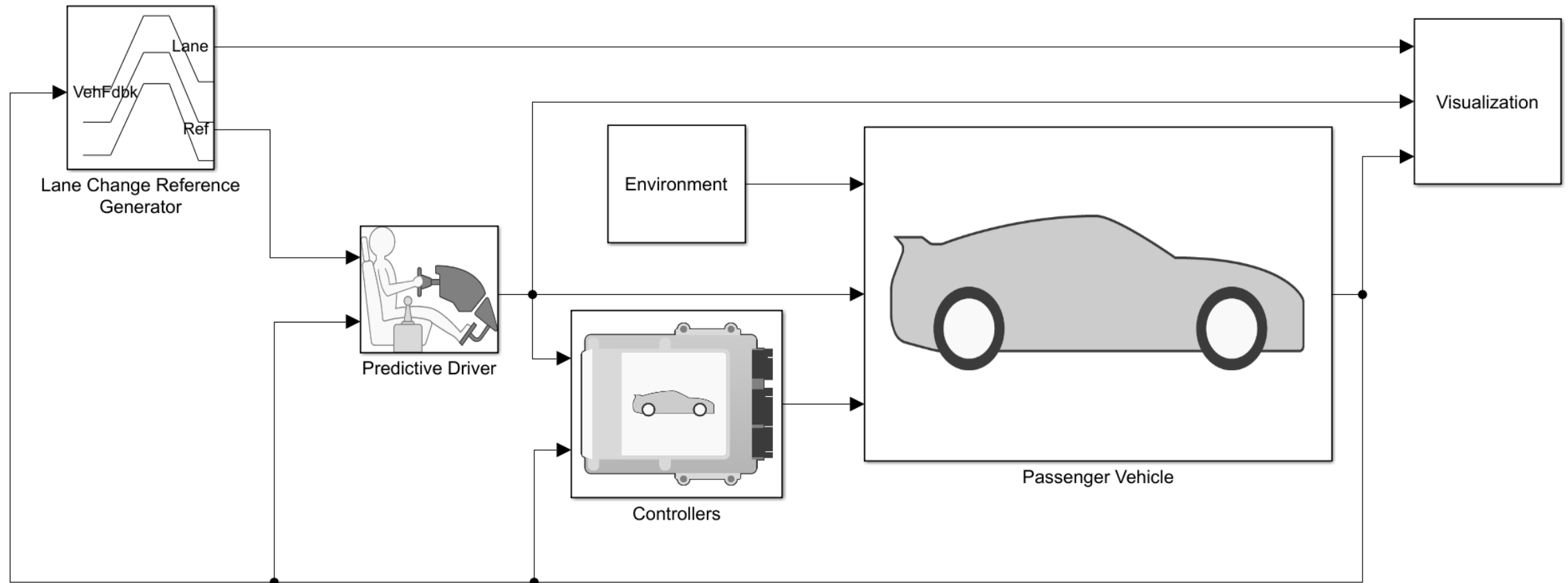
Powertrain Blockset™ Example: Electric Vehicle

>> autoblkEvStart



Vehicle Dynamics Blockset™ Example: Double Lane Change

```
>> vdynblksDb1LaneChangeStart
```



Vehicle Dynamics Blockset™ Features:

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



Ride & handling



Chassis controls



ADAS / AD

Physical Modeling

Simscape™

- Model multidomain systems
 - Mechanical, electrical, fluid, thermal, and more!
 - Create custom domains and blocks

- Automatically derives equations from physical block connections
- Units and unit conversion

Simscape

Electrical

Mechanical

Magnetic

Thermal

Custom equations

```
if v > v:
    i == ('
else
```

Hydraulic

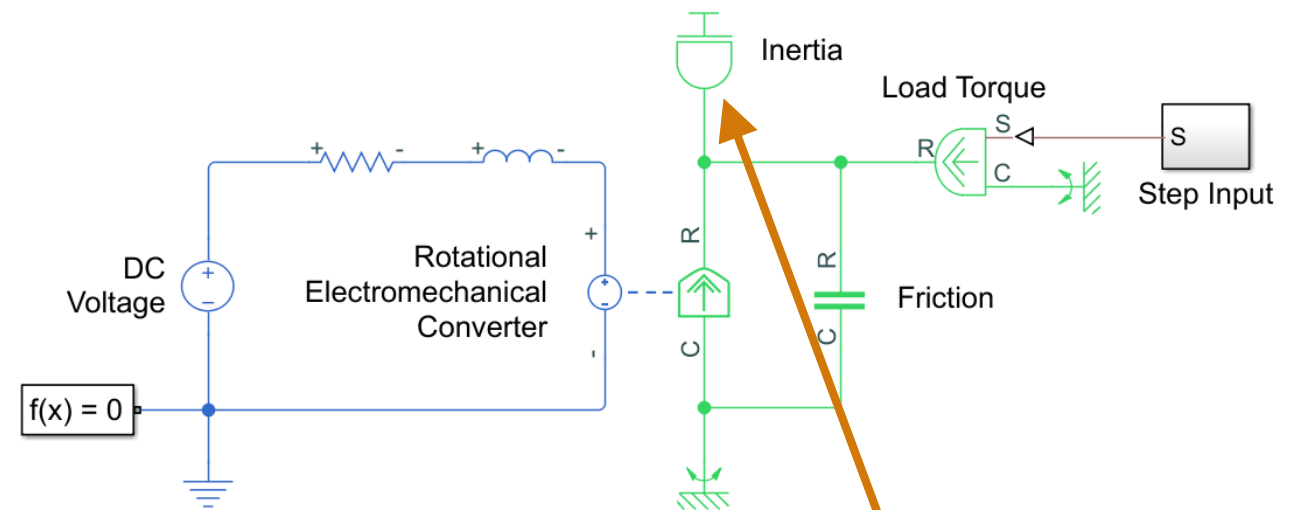
Thermal Liquid

Two-Phase Fluid

Gas

Moist Air

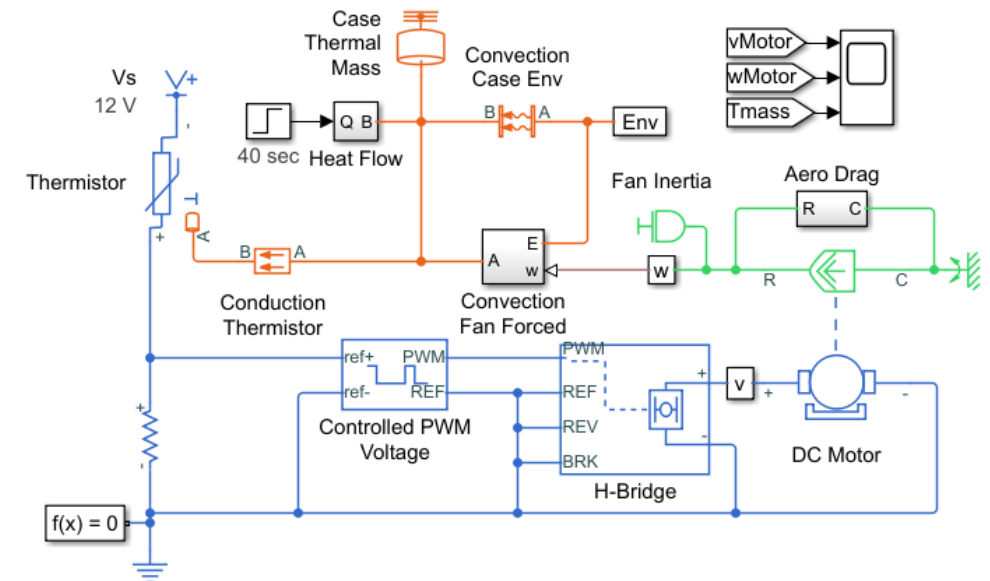
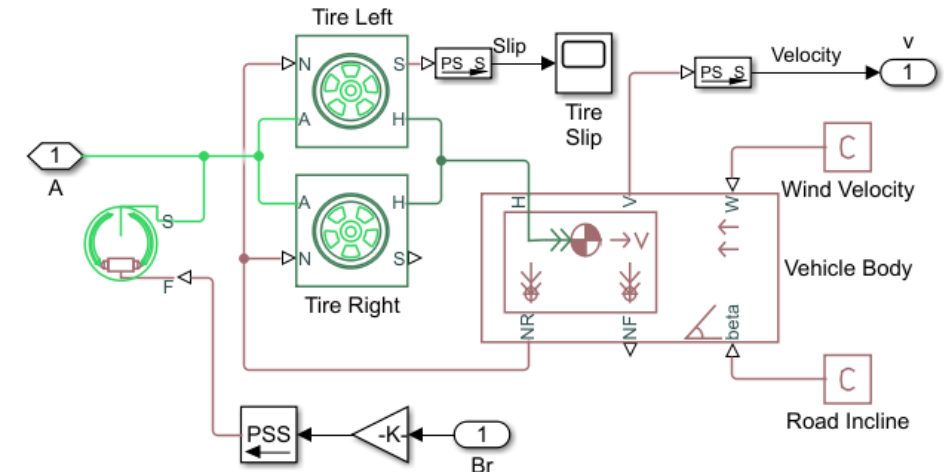
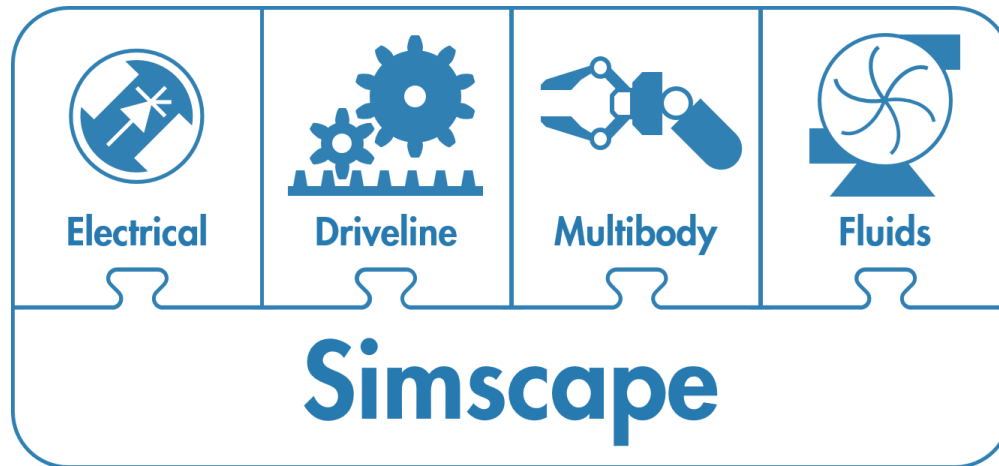
Racing Lounge [video](#)



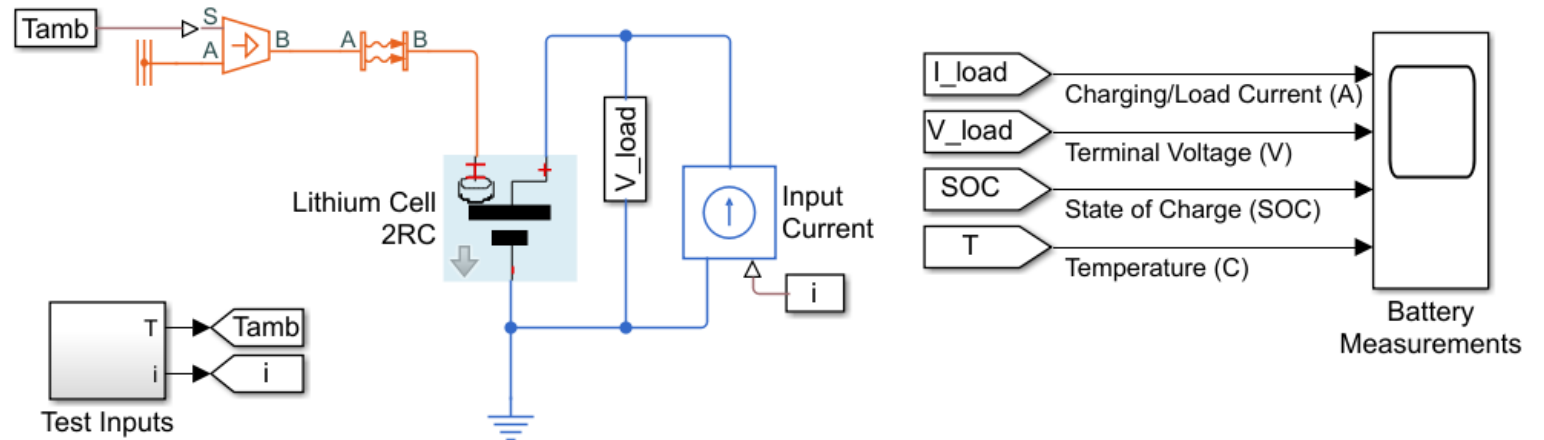
Parameters	Variables
Inertia:	<input type="text" value="0.01"/> <input type="text" value="g*cm^2"/>

Simscape™ Product Family

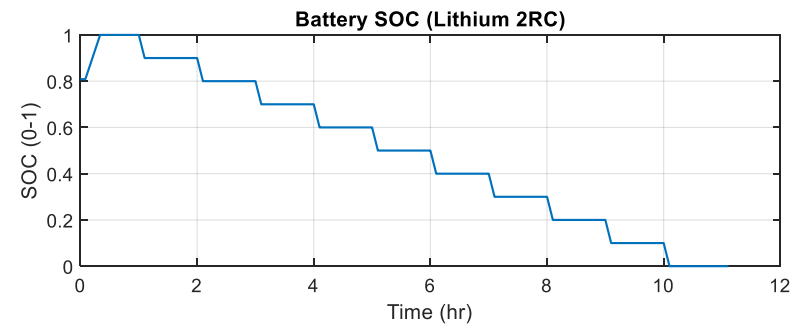
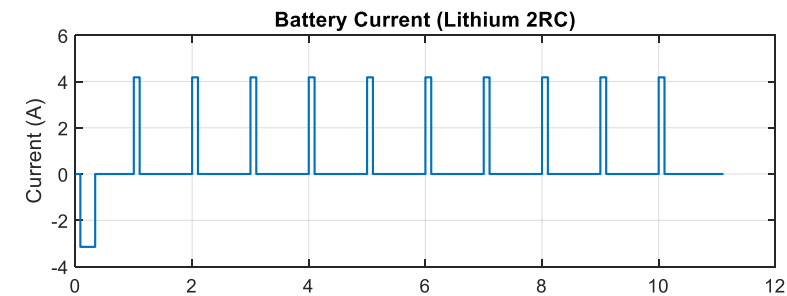
- Specialized Simscape add-on products
- Mechanical, fluid, and electrical systems



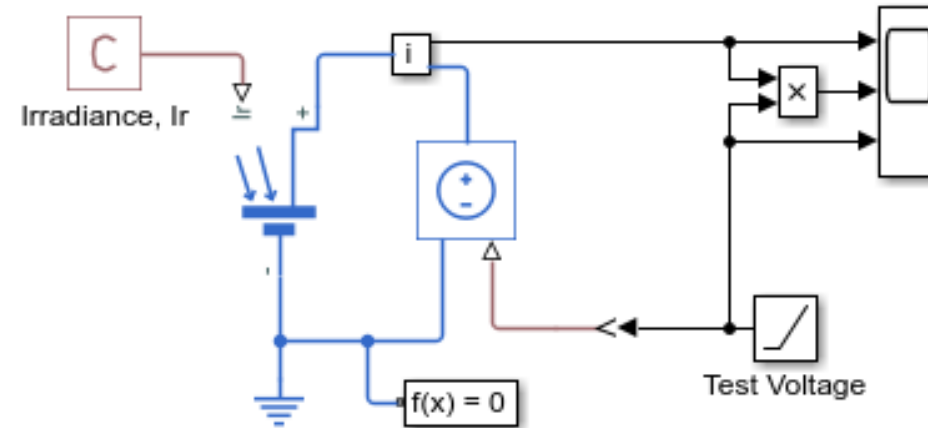
Simscape™ Example: Lithium Cell Equivalent Circuit Model



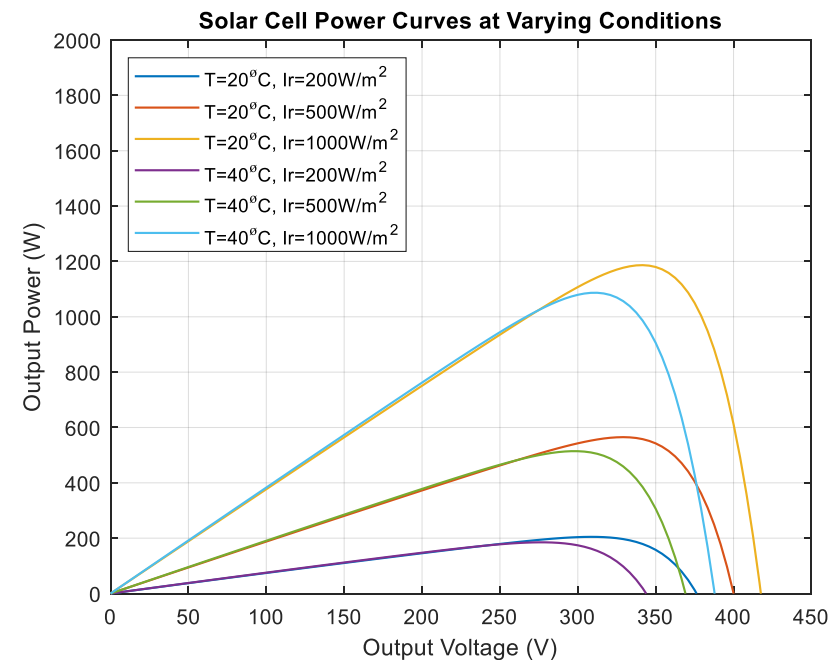
```
>> ssc_lithium_cell_2RC
```



Simscape™ Example: Solar Cell Power Curve

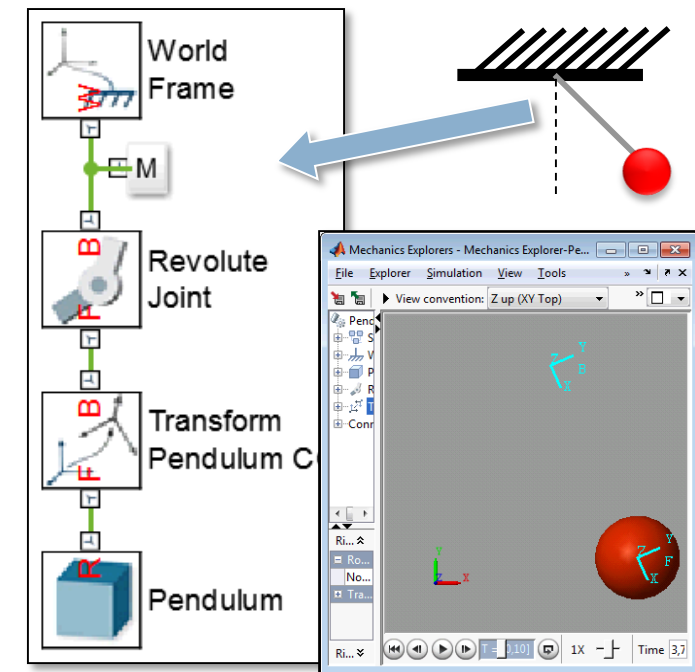
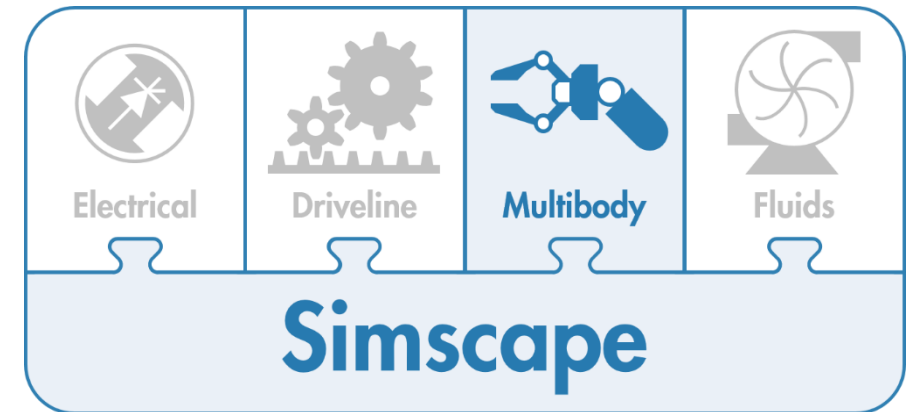


```
>> elec_solar_cell
```



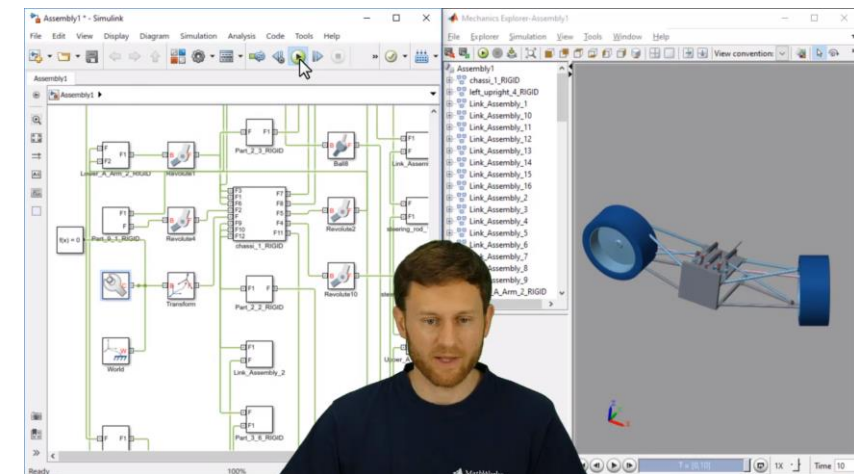
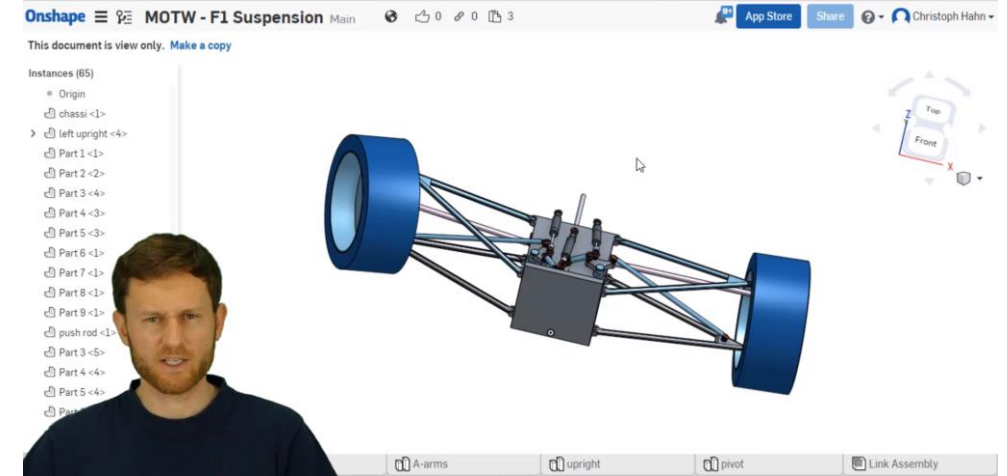
Introduction to Simscape Multibody™

- Model 3D rigid body mechanical systems
- **Bodies, joints, and transforms**
 - Model matches structure of system
 - No need to derive and program equations
- Add dynamic effects
 - Stiffness/damping, external forces, constraints
- **Mechanics Explorer** visualization tool

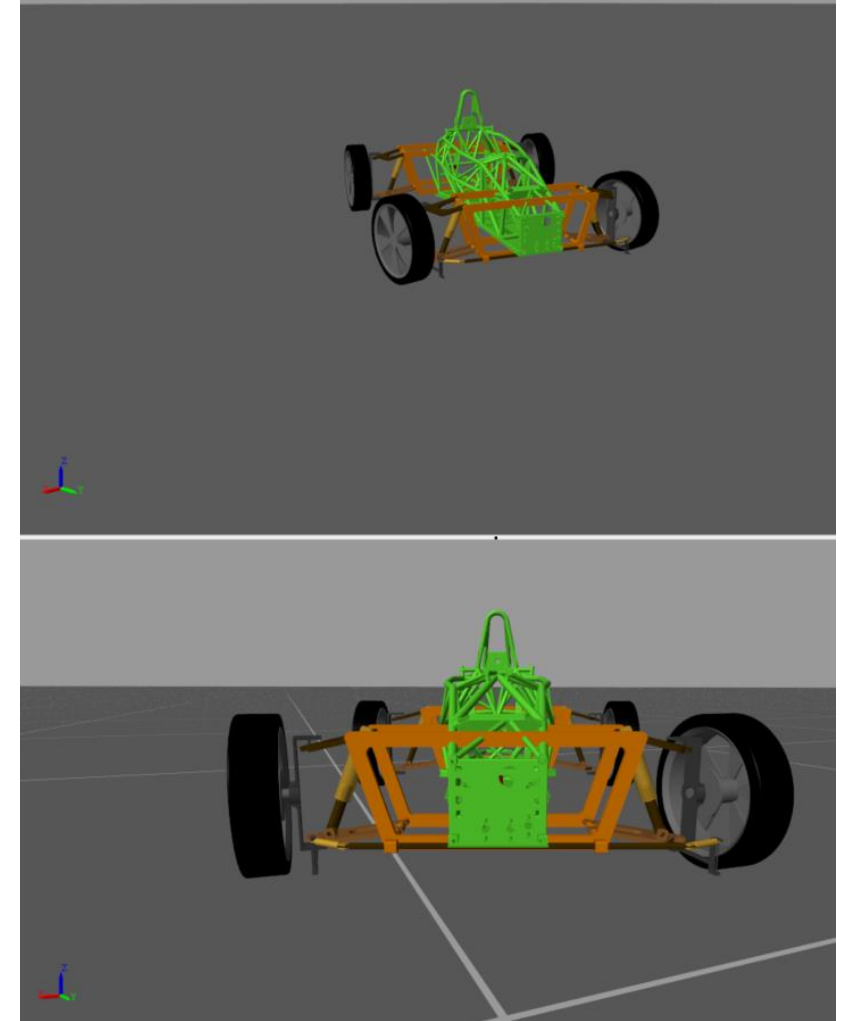
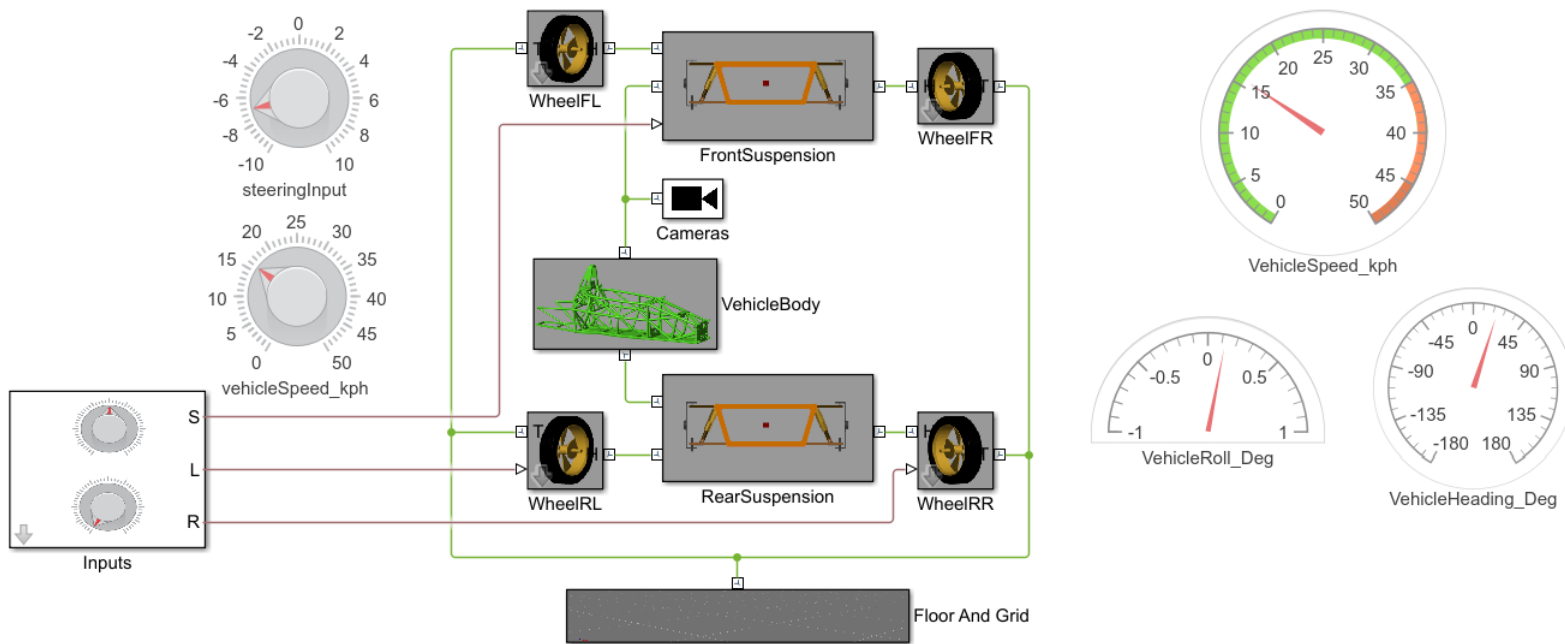


Simscape Multibody™ Import from CAD

- Plugins: **SolidWorks, Creo, Inventor**
- Supports **Onshape**
 - Cloud-based CAD tool
 - Supports native CAD (CATIA, NX, DWG, etc.) and neutral CAD (IGES, SAT, STEP, ACIS, JT, Parasolid, DXF, etc.) formats
- Racing Lounge [blog post](#) and [video](#)



Simscape Multibody™ Example: Full Vehicle + Suspension

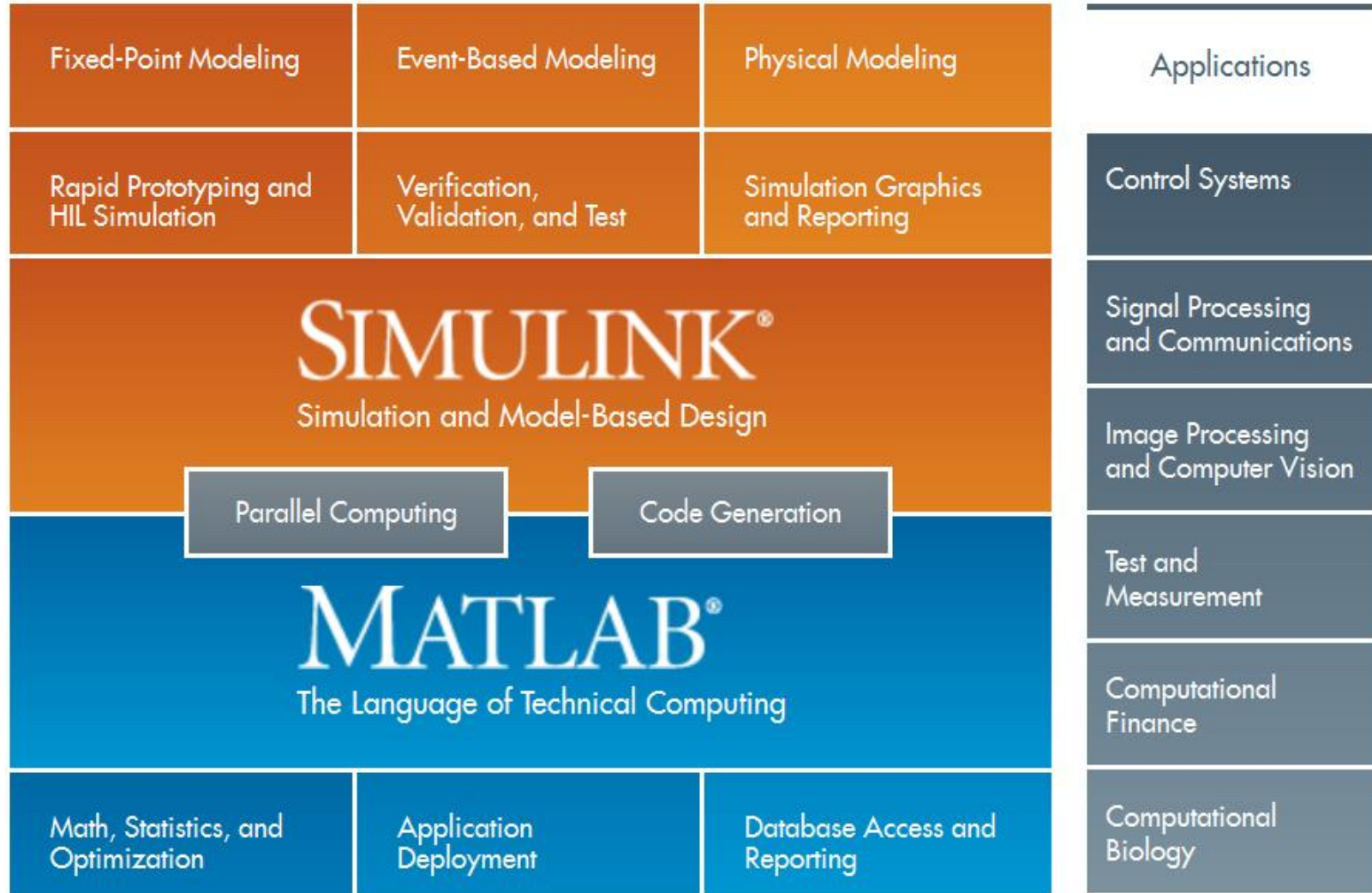


Racing Lounge [video](#)

Recap: Which Tools To Use?

Modeling Technique	When To Choose	Software Tool
Equation based	<ul style="list-style-type: none"> System equations are already known or can be derived <i>“Need a calculator to solve my equations and process results”</i> 	MATLAB + Simulink
Data driven	<ul style="list-style-type: none"> Combine pre-made, detailed, and customizable models for powertrain and vehicle dynamics components Connect to Unreal Engine for virtual environments and sensing 	Powertrain Blockset + Vehicle Dynamics Blockset
Physical Modeling	<ul style="list-style-type: none"> Model 1D mechanisms (motors, shifter actuators, etc.) Model multidomain systems (mechatronic, fluid, thermal) Reduce visual complexity: model without deriving equations 	Simscape
	<ul style="list-style-type: none"> Model 3D rigid body systems (suspension, steering, etc.) Import kinematic models from CAD and add dynamics 	Simscape Multibody

... and you can combine them all!



<https://www.mathworks.com/products>

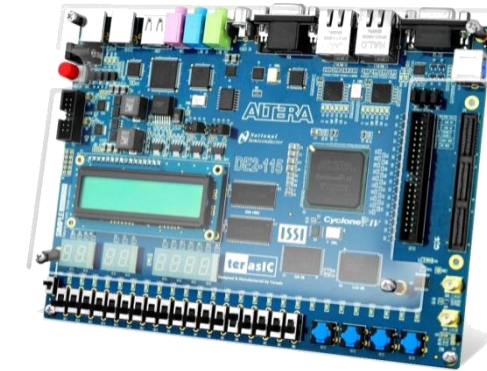
Automatic Code Generation

ANSI **C/C++** for embedded systems

MATLAB Coder

Simulink Coder

Embedded Coder



HDL for FPGAs

HDL Coder

HDL Verifier



Structured text for **PLCs**

Simulink PLC Coder



Programming **GPUs**

GPU Coder



Hardware Support

Hardware Support ▾

Overview | Search Hardware Support | Request Hardware Support

Trial software Contact sales

Results 1 - 25 of 173 >

Refine by Product

MATLAB	13	^
Simulink	12	
Audio System Toolbox	1	
Communications System Toolbox	6	
Computer Vision System Toolbox	1	
Data Acquisition Toolbox	15	
DSP System Toolbox	2	v

Refine by Product Family and Category

MATLAB Product Family	103
Simulink Product Family	121

Refine by Vendor

3D Robotics	1	^
3S-Smart Software Solutions	1	
ADLINK	3	
ARM	17	
AUTOSAR Development Partnership	1	
Adimec	3	



ADALM-PLUTO Radio Support from Communications System Toolbox

Prototype and test software-defined radio (SDR) systems using Analog Devices ADALM-PLUTO with MATLAB and Simulink

Vendors: Analog Devices

Tags: Support Package Installer Enabled, MathWorks Supported



Adimec Camera Support from Image Acquisition Toolbox

Use Adimec cameras with MATLAB and Simulink to acquire video and images.

Vendors: Adimec

Tags: MathWorks Supported



ADLINK Support from Data Acquisition Toolbox

Create your own waveforms, measurement and analysis routines, and applications for ADLINK DAQ hardware using MATLAB and Data Acquisition Toolbox

Vendors: ADLINK

Tags: Connections Program



Allied Vision Camera Support from Image Acquisition Toolbox

Use AV cameras with MATLAB and Simulink to acquire video and images

Vendors: Allied Vision

Tags: MathWorks Supported

<https://www.mathworks.com/hardware>

5

Learn

Student Competition Tutorials and Videos

Search MathWorks.com



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Hardware Support



Learn how to use MATLAB and Simulink to solve competition tasks.

<https://www.mathworks.com/academia/student-competitions/tutorials-videos.html>

Learn the basics with introductory courses.



MATLAB Onramp




Simulink Onramp



Deep Learning Onramp

Learn MATLAB and Simulink for Automotive Engineering

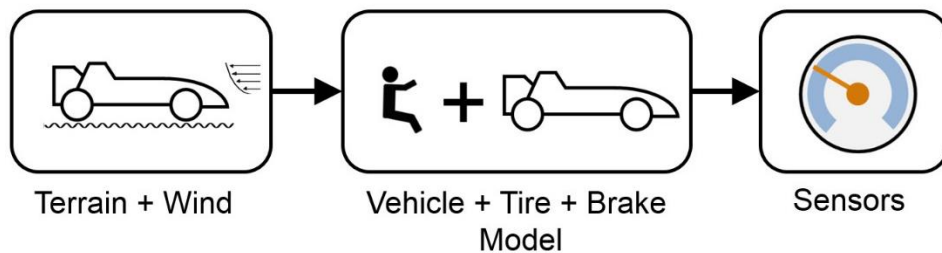


Student Competitions - Physical Modeling Training

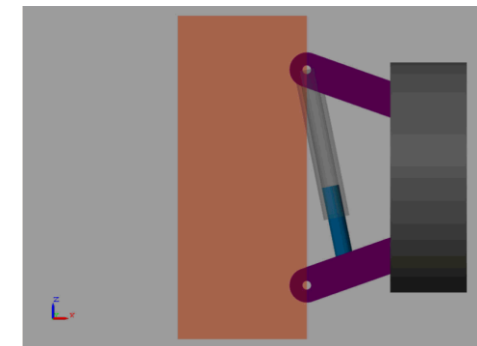
version 2.0.0.0 (17 MB) by [MathWorks Student Competitions Team](#)


All Files for the Student Competitions - Physical Modeling Training

Longitudinal Vehicle Dynamics




3D Suspension Modeling





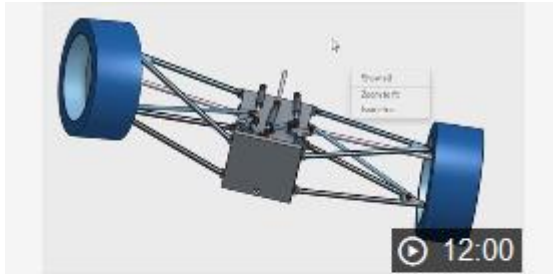
MATLAB and Simulink Racing Lounge



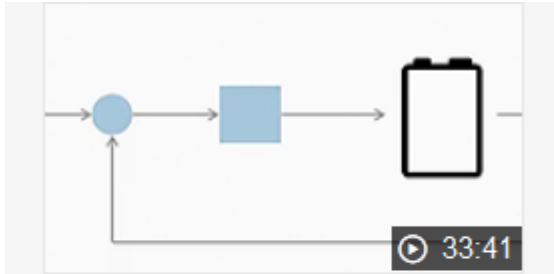
<https://www.mathworks.com/racinglounge>



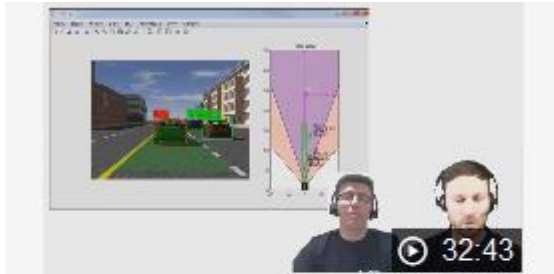
MATLAB and Simulink Racing Lounge: Lap Time Simulation; Essential Part of Concept Development



MATLAB and Simulink Racing Lounge: Importing CAD Assemblies into Simscape Multibody



MATLAB and Simulink Racing Lounge: Battery Modeling with Simulink

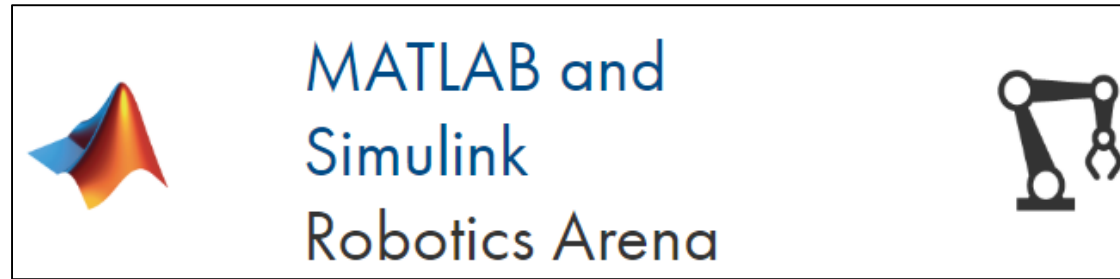


MATLAB and Simulink Racing Lounge: Developing Algorithms for ADAS Systems with MATLAB and Simulink



racinglounge@mathworks.com

Other Materials



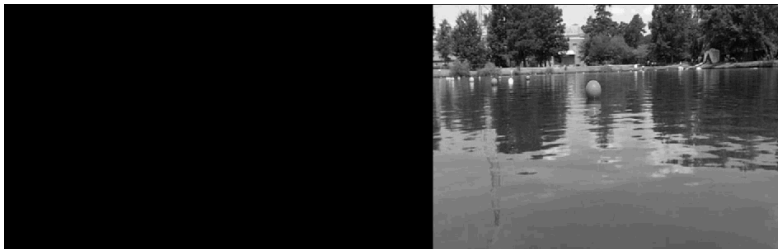
<https://www.mathworks.com/roboticsarena>

Computer Vision Training

Watch videos on:

- Object detection
- Feature matching
- Camera calibration
- Point clouds

Design algorithms to help with autonomous recognition of targets and obstacle avoidance!

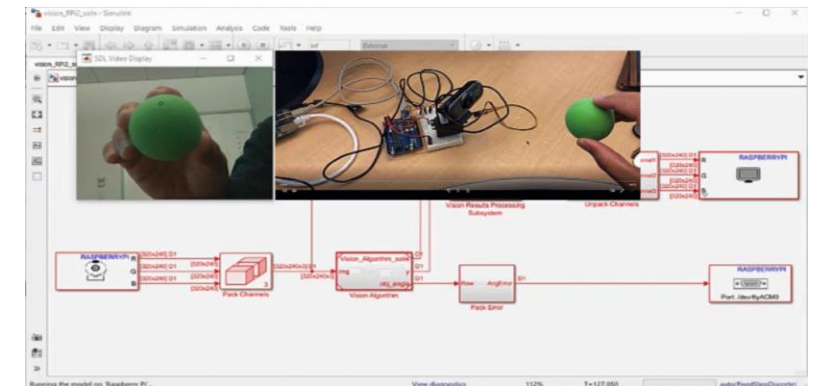


Code Generation Training

Learn to generate and use standalone C/C++ code from:

- MATLAB code
- Simulink models
- Stateflow charts

Deploy algorithms to
Arduino and Raspberry Pi!



6

Win!

Get Complimentary Software

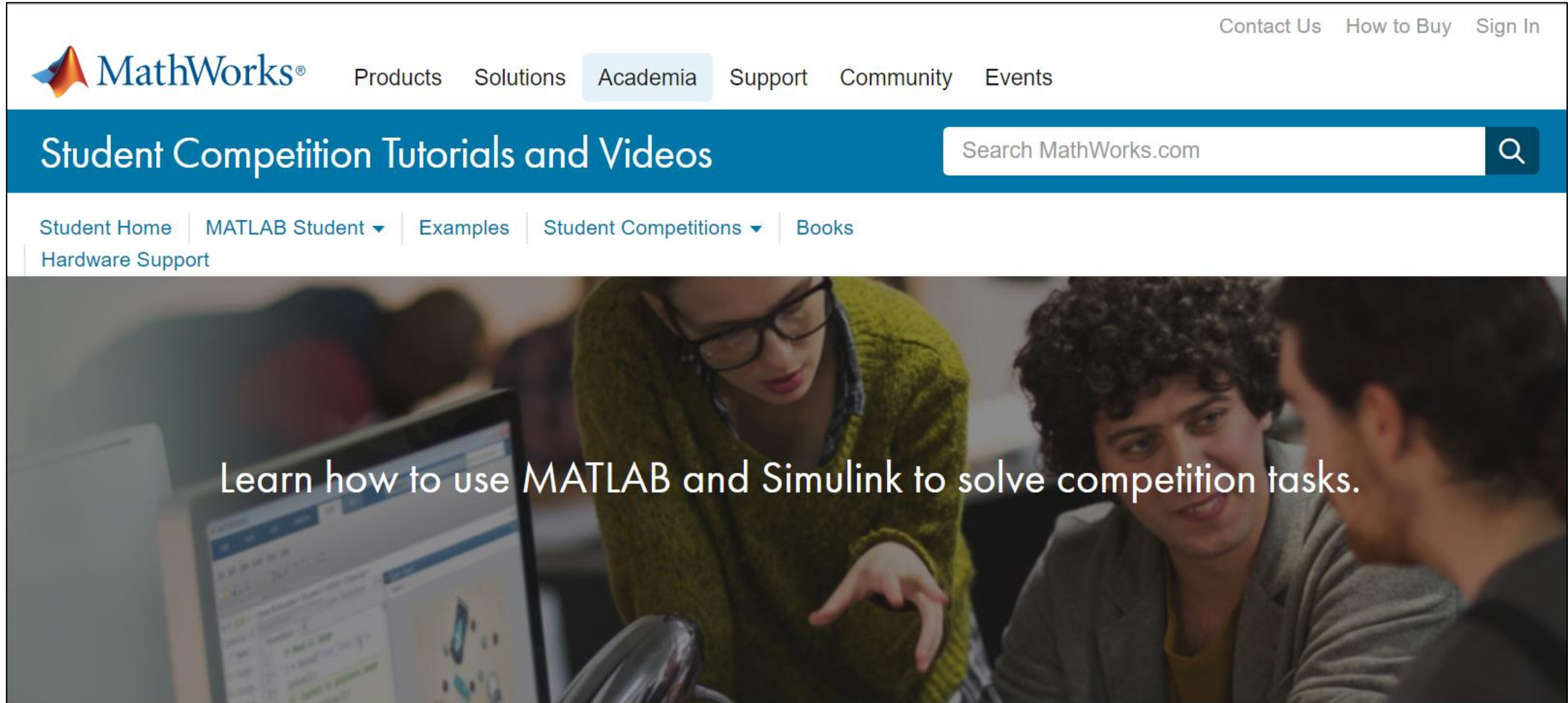
R2018b

~90 Toolboxes

<https://www.mathworks.com/academia/student-competitions/american-solar.html>

Request software

Learn Industry Grade Tools from Experts



MathWorks® Products Solutions **Academia** Support Community Events

Contact Us How to Buy Sign In

Student Competition Tutorials and Videos

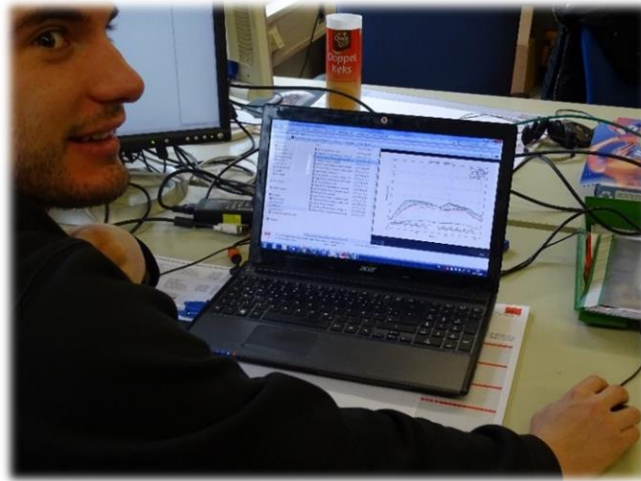
Search MathWorks.com

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Hardware Support

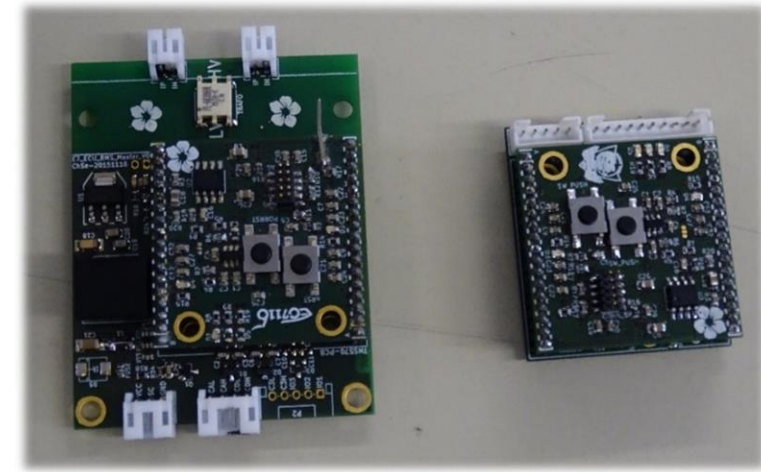
Learn how to use MATLAB and Simulink to solve competition tasks.

<https://www.mathworks.com/academia/student-competitions/tutorials-videos.html>

Use Model-Based Design



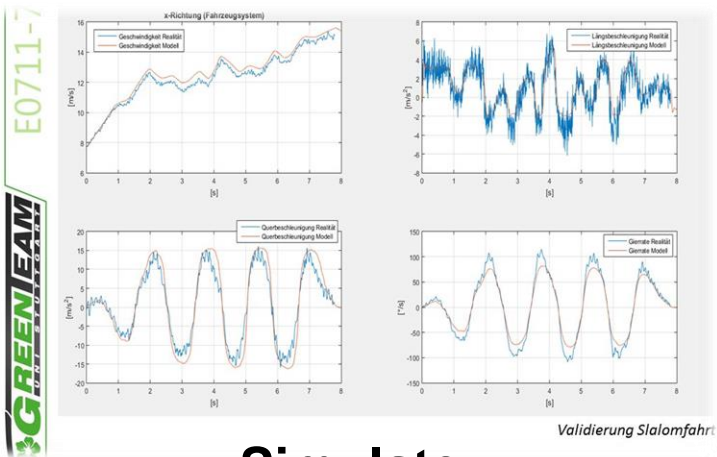
Model



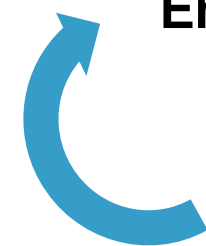
Embedded Code Generation



Rapid Prototyping



Simulate



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MATLAB and Simulink Racing Lounge



Community for competitions in automotive engineering



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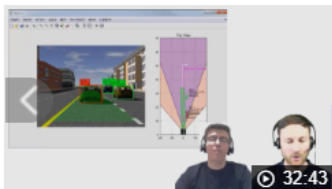


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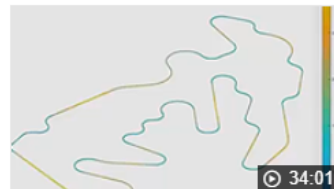
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Veer Alakshendra shared a link.
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Q&A

<https://bit.ly/2TigTGF>

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More Resources

- Battery Modeling:
 - <https://www.mathworks.com/discovery/battery-models.html>
- Motor Control:
 - <https://www.mathworks.com/discovery/motor-control.html>
- Solar Modeling related examples:
 - <https://www.mathworks.com/help/search.html?qdoc=solar+type%3Aex+product%3Asps>
- CFD Modeling in MATLAB:
 - <https://blogs.mathworks.com/racing-lounge/2018/06/20/cfd-modeling-using-matlab/>

Thank You!