

2022 MathWorks 中国汽车年会

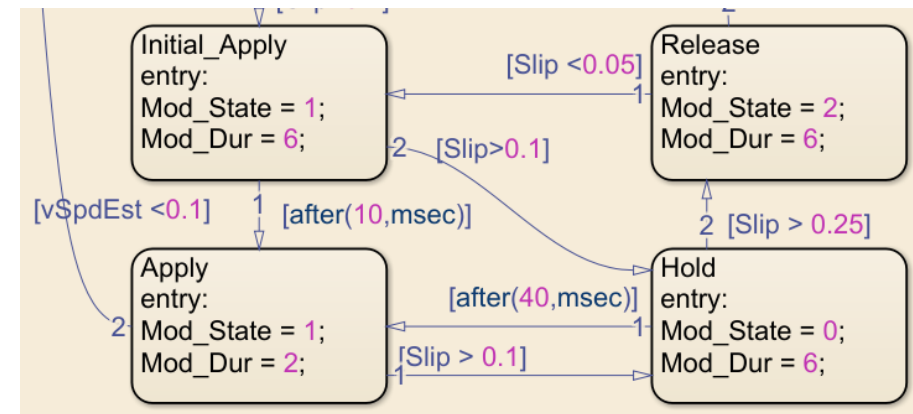
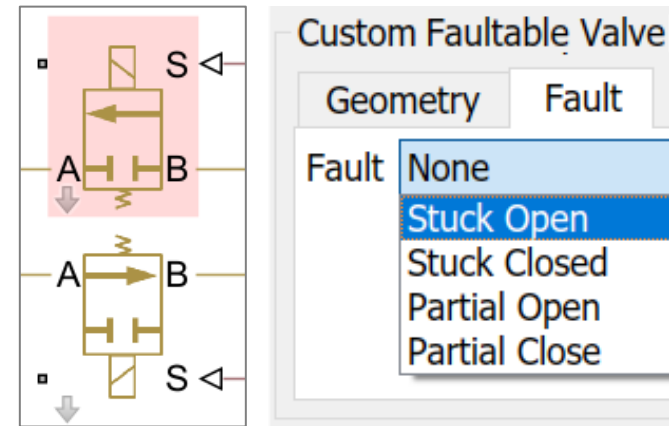
车辆动力学建模仿真助力底盘控制开发

杨兴, MathWorks

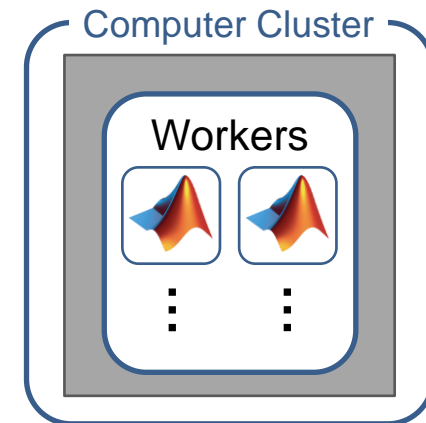


要点

- MathWorks 为不同的仿真目的提供了多种建模方法
- 可以结合 Simscape 建立子系统物理模型，定义和分析零件功能失效对系统整体性能的影响
- 集成控制策略模型并利用并行加速仿真，能帮助我们快速测试和评估算法的有效性



```
set_fault mdl, 'Valve FL'
out = parsim mdl;
```



零件失效对 ABS 控制的影响

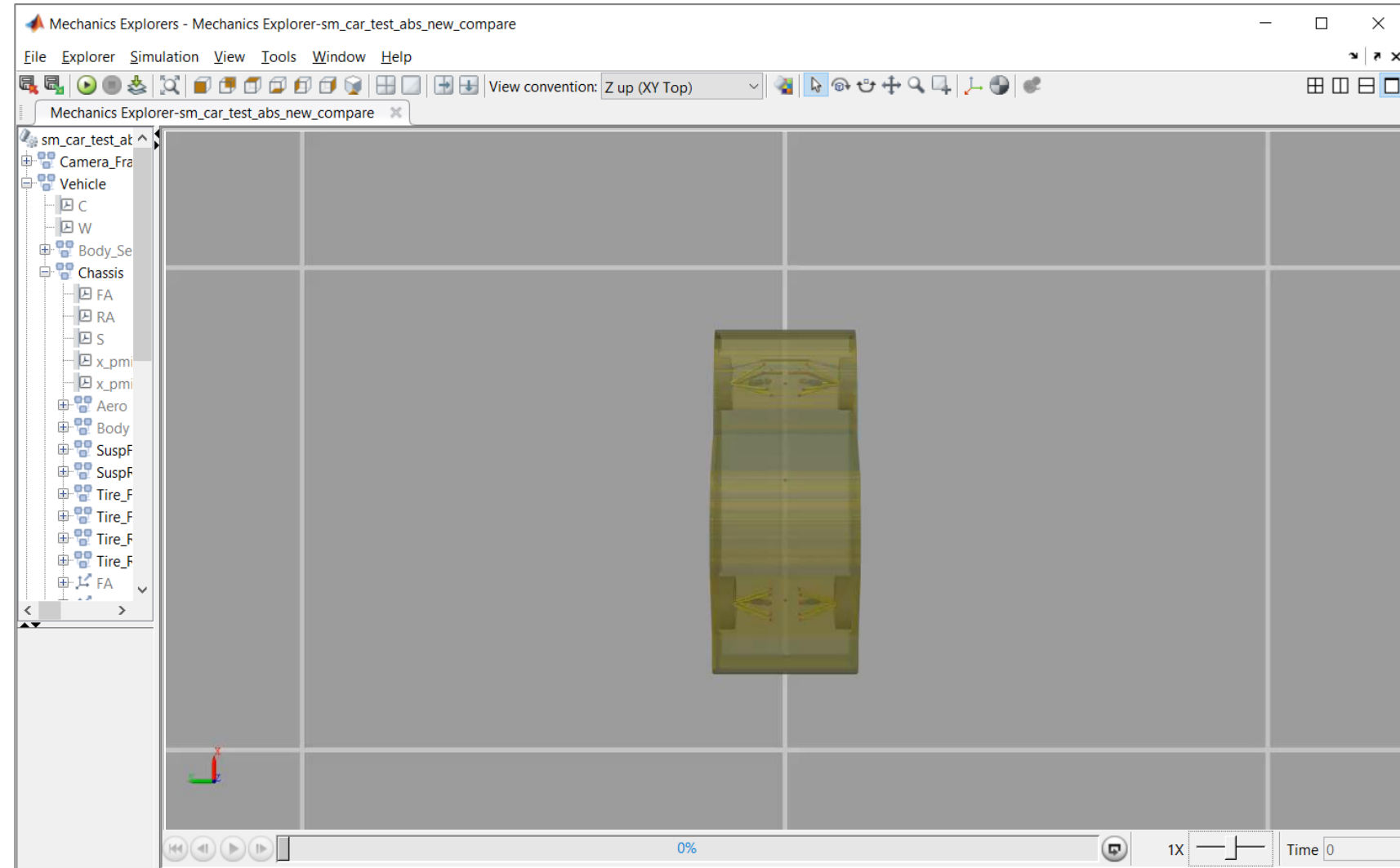
变道, 顶视图



Driver can steer
Shorter braking distance



Driver cannot steer
Longer braking distance



零件失效对 ABS 控制的影响

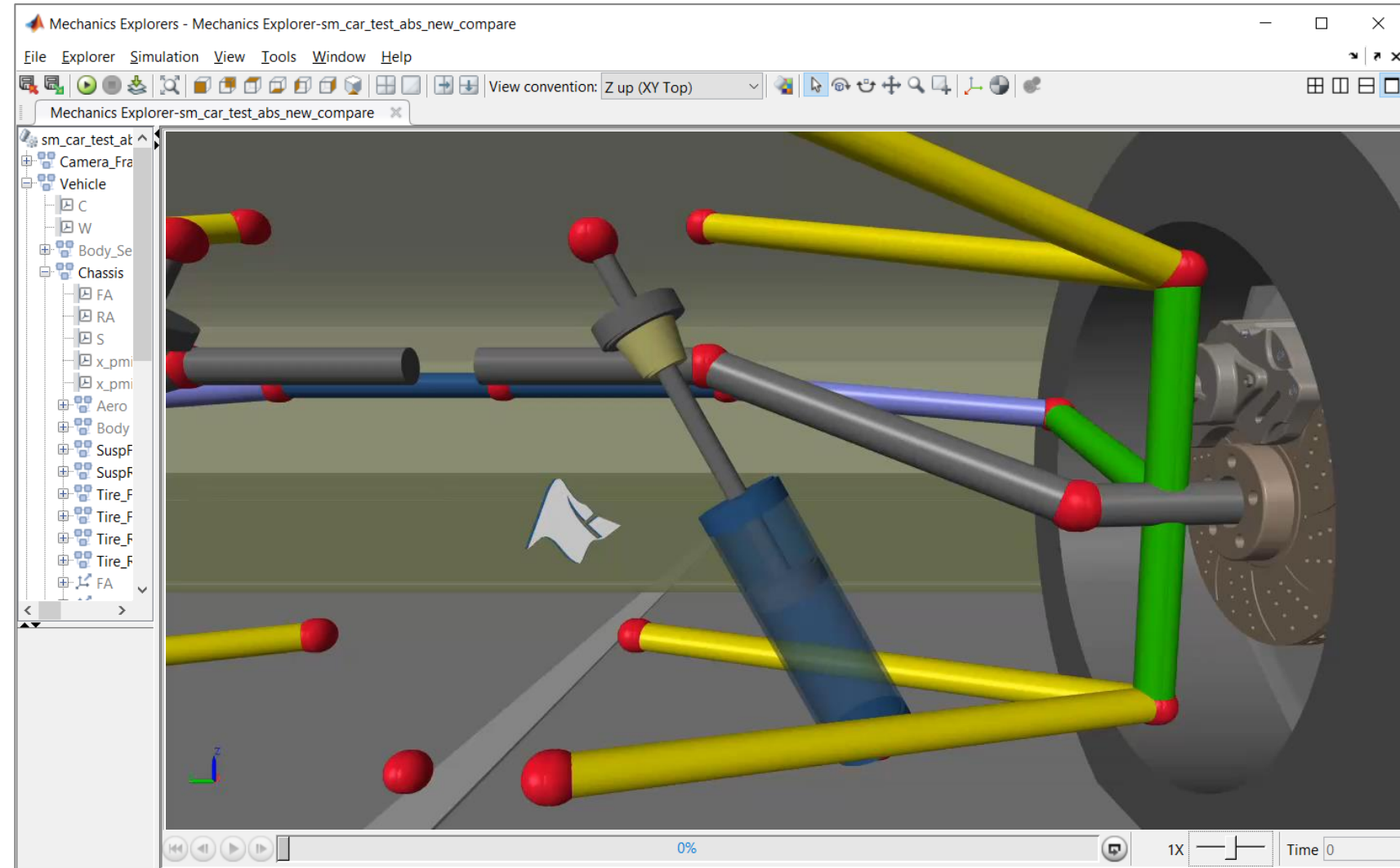
变道, 右前轮视图



Driver can steer
Shorter braking distance



Driver cannot steer
Longer braking distance



针对不同的问题需要细化不同的子部件模型

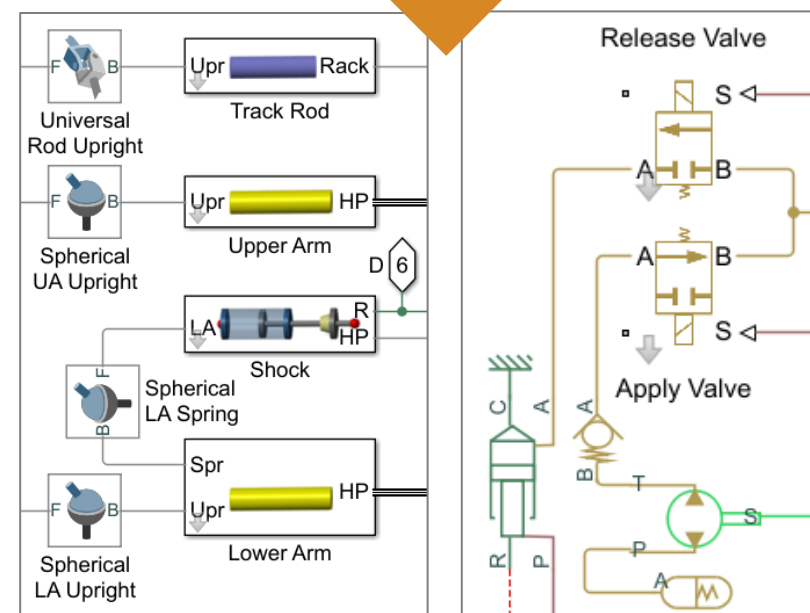
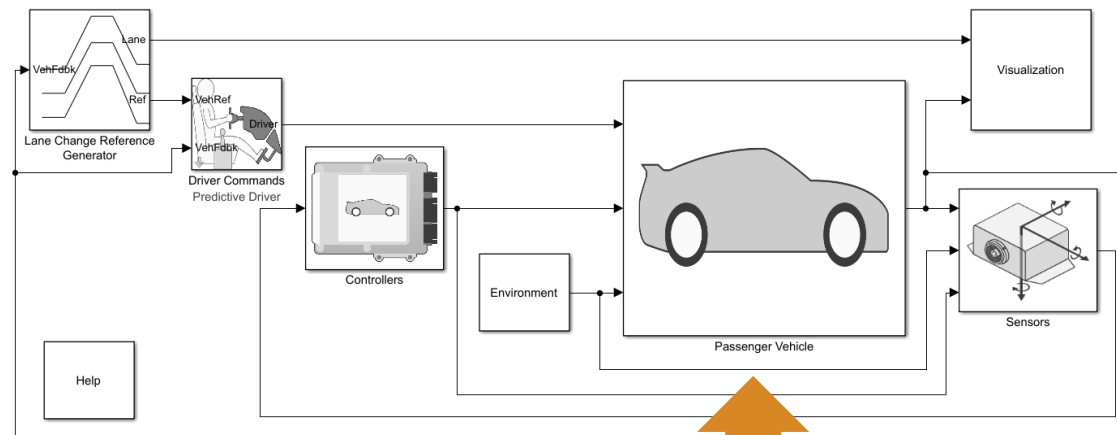
■ 底盘系统

- 悬架
- 刹车
- 转向

■ 子系统类型

- 机械 (drivetrain, suspension, tires)
- 液压 (cylinder, valves, calipers, pump)
- 传感器 (wheel speed, accelerometer)
- 控制

■ 使用 Simscape 实现子部件物理模型



MathWorks 虚拟车辆解决方案概览

本节关注

软件集成

车辆建模

场景搭建

仿真分析

HIL以及云

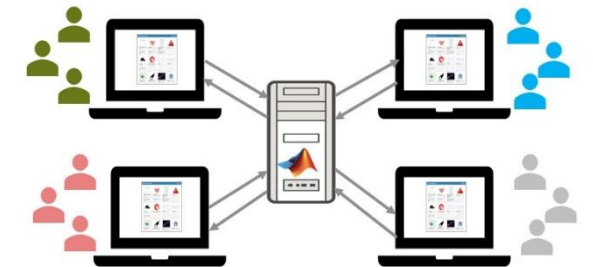
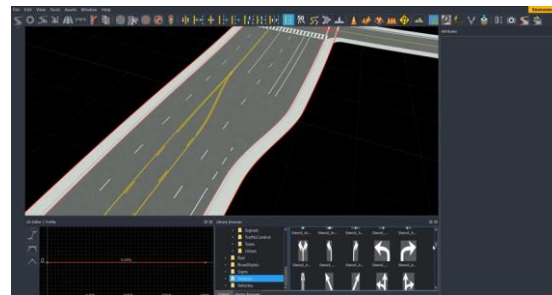
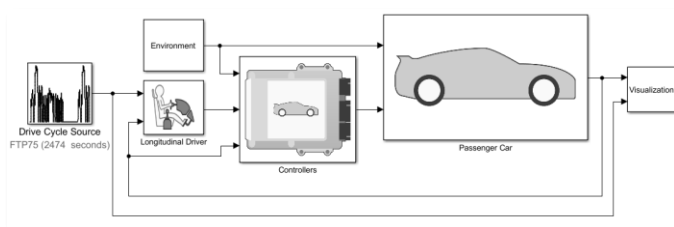
Vehicle Templates
Subsystem Libraries
Modeling Guidelines

C/C++ Interface
Reduced Order Models
FMU Integration

Scene & Scenarios
Open Standards
Drive Cycles

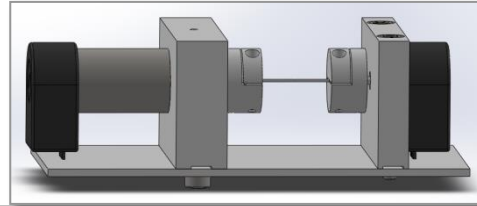
Visualization
Data Analysis
Report Generation

Cloud Integration
DataLake Integration
HIL Deployment



Learn more:
[Virtual Vehicle](#)

MathWorks 建模工具链



Modeling Approaches

First Principles Modeling

Data-Driven Modeling



Programming
(MATLAB, C)

Physical Networks
(Simscape Products)

Statistical Methods
(Model Based
Calibration Toolbox)

**System
Identification**
(System Identification
Toolbox)

Block Diagram
(Simulink)

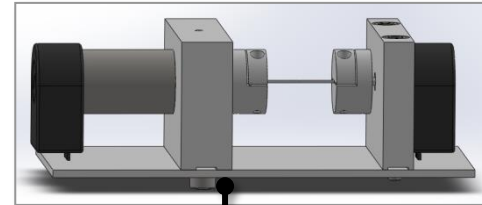
Modeling Language
(Simscape language)

Neural Networks
(Deep Learning
Toolbox)

Symbolic Methods
(Symbolic Math
Toolbox)

Parameter Tuning
(Simulink Design Optimization)

信号流建模方法



Modeling Approaches

First Principles Modeling



Programming
(MATLAB, C)

Block Diagram
(Simulink)

Modeling Language
(Simscape language)

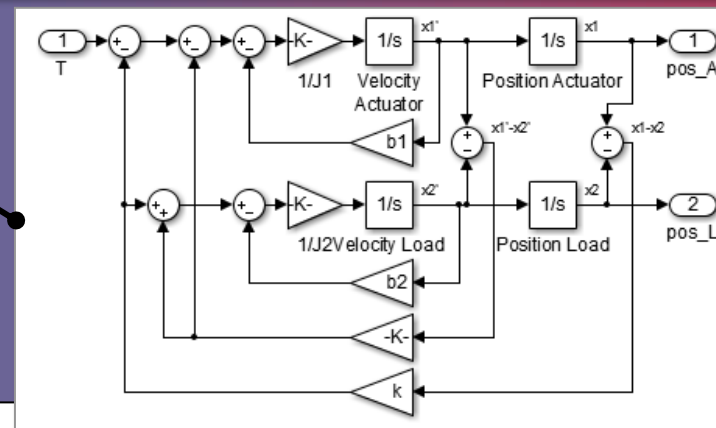
Symbolic Methods
(Symbolic Math
Toolbox)

Physical Networks

$$J_1 x_1'' = -b_1 x_1' - k(x_1 - x_2) - b_{12}(x_1' - x_2') + T$$

$$J_2 x_2'' = -b_2 x_2' + k(x_1 - x_2) - b_{12}(x_1' - x_2')$$

Statistical Methods



Powertrain Blockset

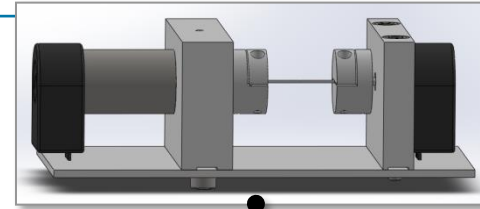
- Energy Storage and Auxilia
- Drivetrain
- Propulsion
- Transmission
- Vehicle Dynamics
- Vehicle Scenario Builder

Vehicle Dynamics Blockset

- Powertrain
- Vehicle Body
- Sensors
- Vehicle Scenarios
- Utilities

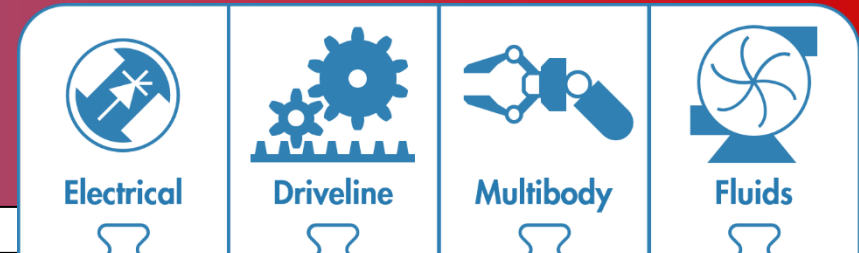
MATLAB & Simulink

物理建模方法



Modeling Approaches

First Principles Modeling



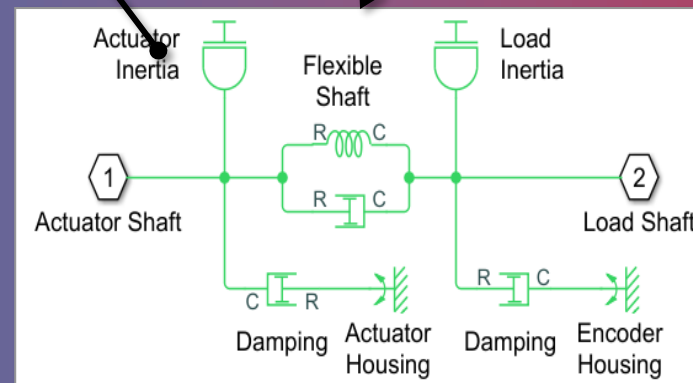
Simscape
MATLAB & Simulink

Programming
(MATLAB, C)

Physical Networks
(Simscape Products)

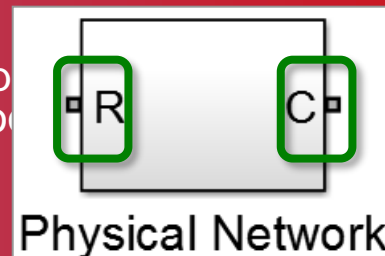
Statistical
(Model Calibration)

Block Diagram
(Simulink)



Modeling Language
(Simscape language)

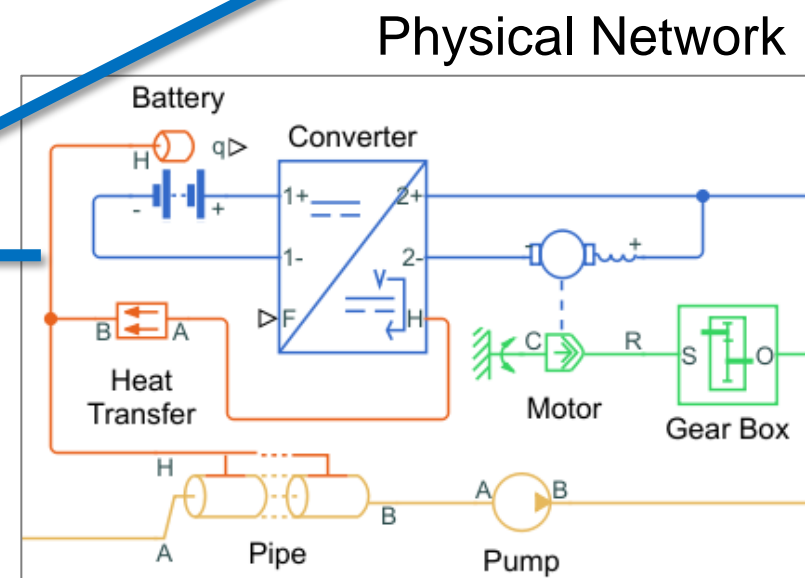
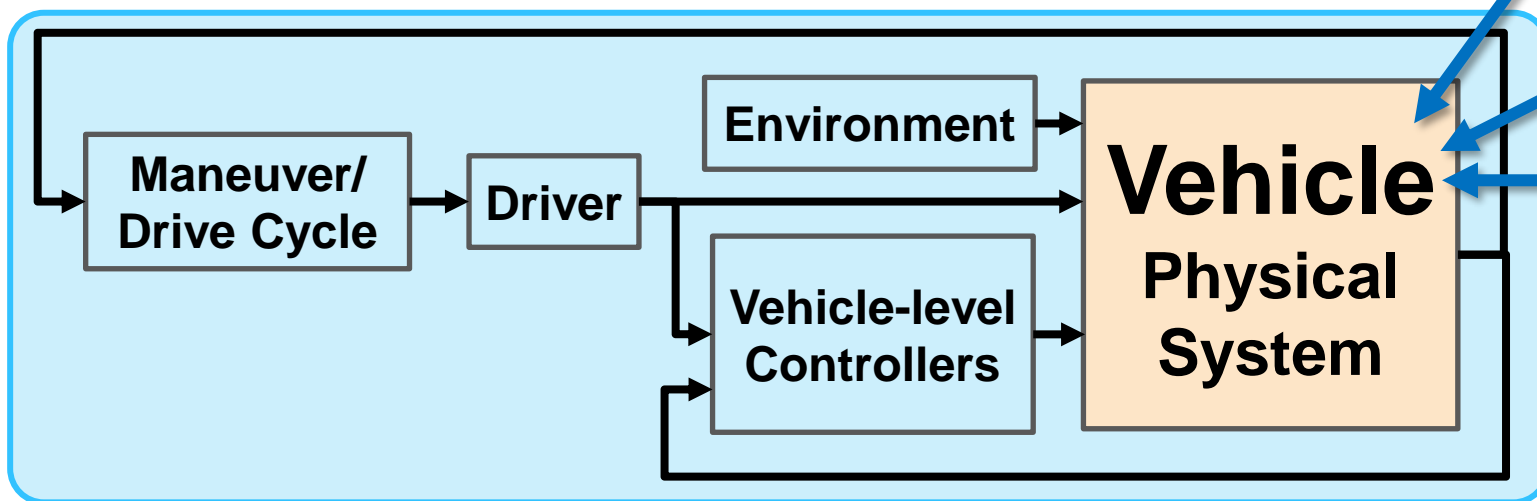
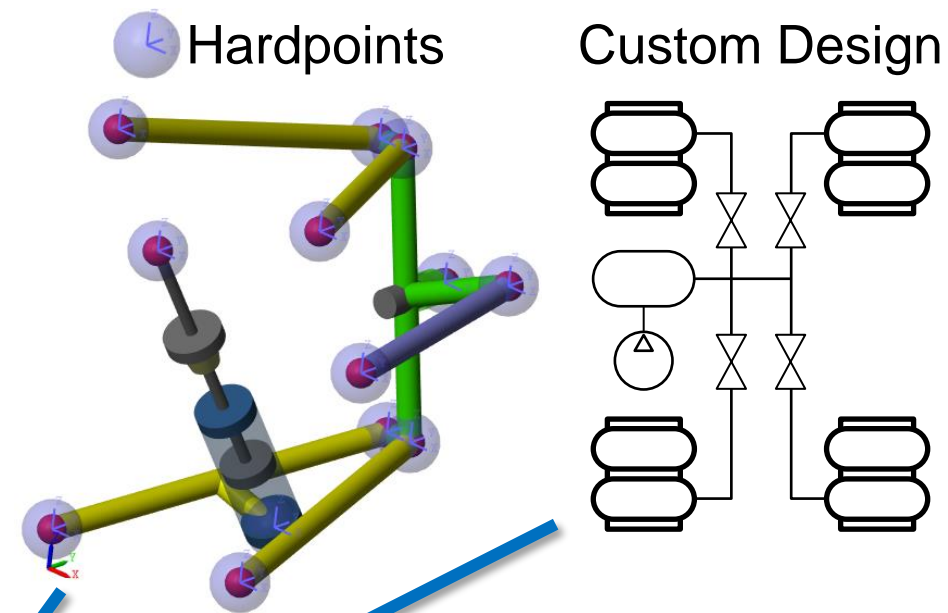
Neural
(Deep Learning)



Symbolic Methods
(Symbolic Math Toolbox)

与 Simscape 物理建模方法的有机结合

- 结构设计分析
- 详细物理特性分析
- 单个子系统特性分析
- 多物理域模型

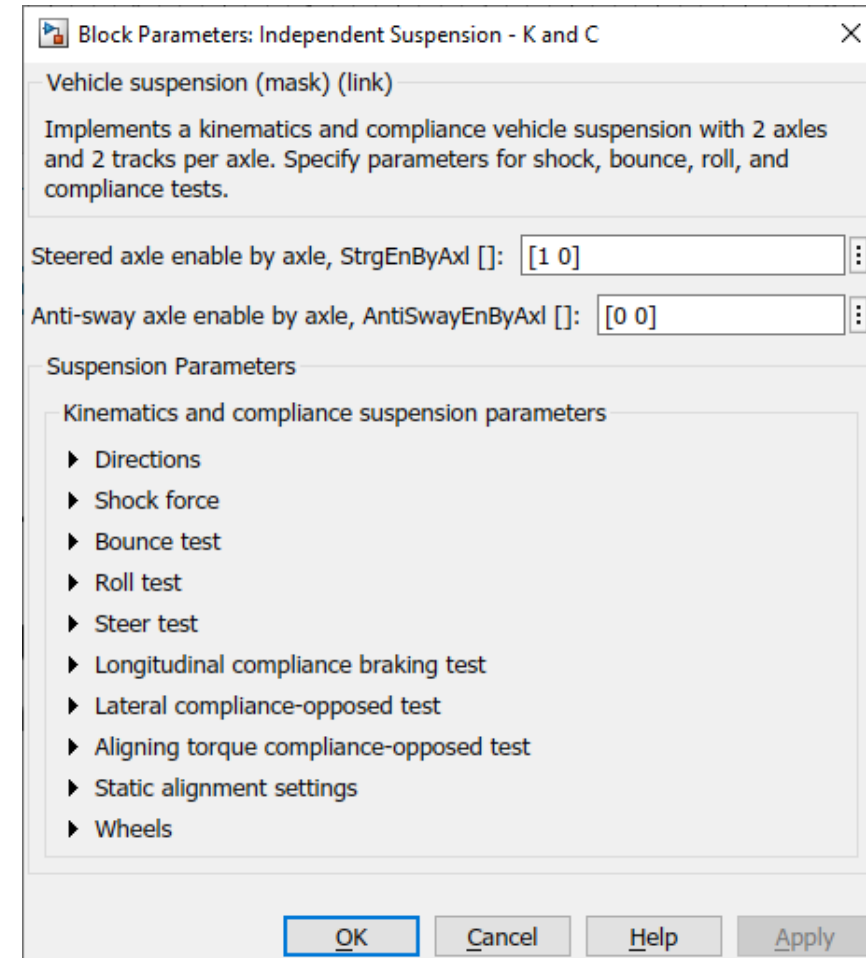
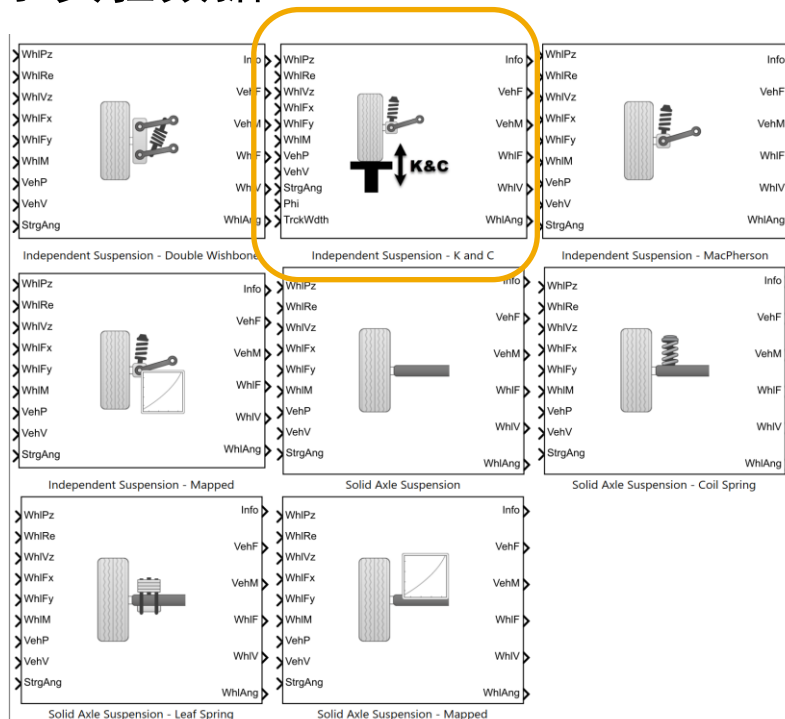


悬架

整车模型中的悬架特性模型

■ 悬架外特性模型

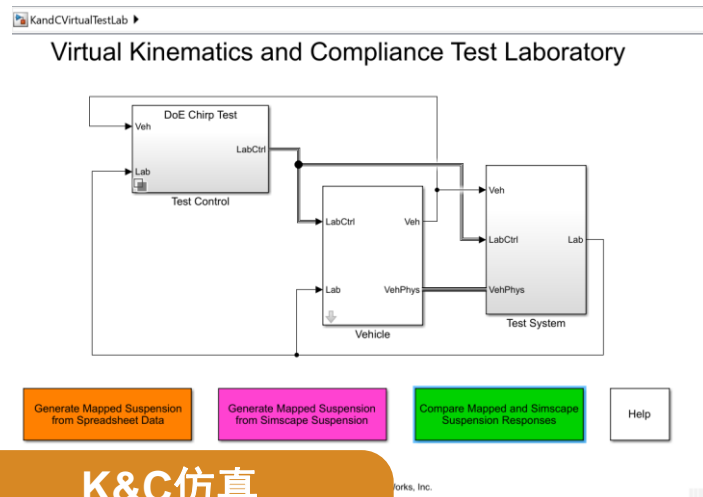
- 基于结构参数
- 基于实验数据



Learn more:

[K&C Suspension Block](#)

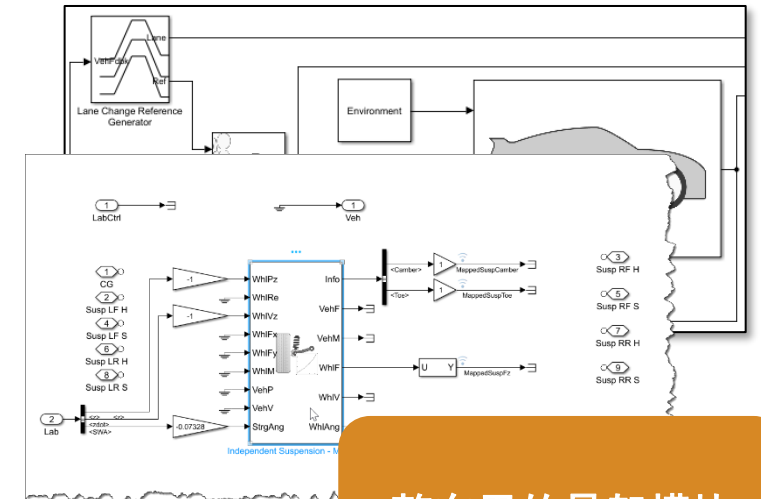
基于数据的 KC 悬架模型



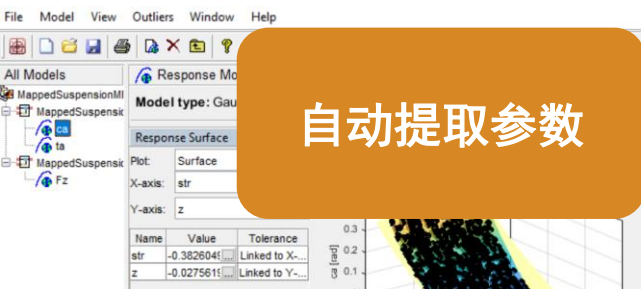
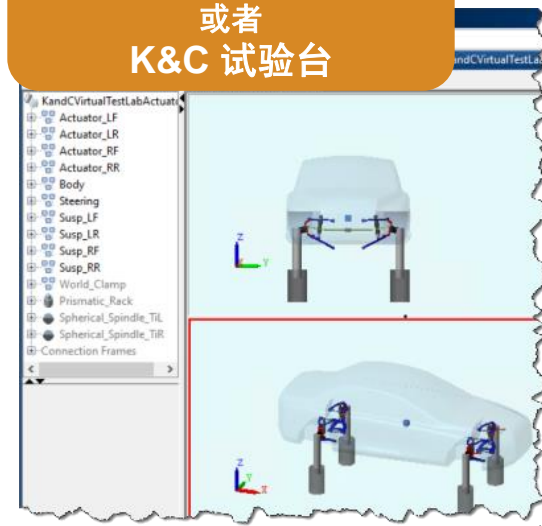
K&C仿真
(如: Simscape Multibody)
或者
K&C 试验台

Name:	z	zdot	str
Unit:	m	m/s	rad
Data:	0.025272	-0.03986	-0.3211
	-0.00292	-0.0027	-0.3413
	-0.00169	-0.03507	-0.3401
	0.023073	-0.1549	-0.3227
	0.043822	-0.21954	-0.3080
	0.045796	0.347944	-0.3066
	0.000125	0.231725	-0.3399
	0.04673	0.37698	-0.3059
	-0.00132	-0.18836	-0.34014
	0.020074	-0.60862	-0.32479
	0.047525	-0.41	-0.3053
	0.044979	-0.48288	-0.30721
	0.051302	0.069675	0.523951
	0.049667	0.058341	0.52092
	0.065471	0.325574	0.555821
	0.093998	-0.28294	0.674893
	0.08098	-0.38535	0.607151
	0.065016	-0.50861	0.554617
	0.069245	0.582267	0.566382
			7342.927
			0.193063
			0.053309

动态响应数据



整车里的悬架模块



自动提取参数

Model Hierarchy

- Simulink Root
 - Base Workspace
 - KandCVirtualTestLab
 - Model Workspace*
 - Configurations
 - Subsystem4
 - Test Control
 - Test System
 - Vehicle

Contents of: Model Workspace* (only)

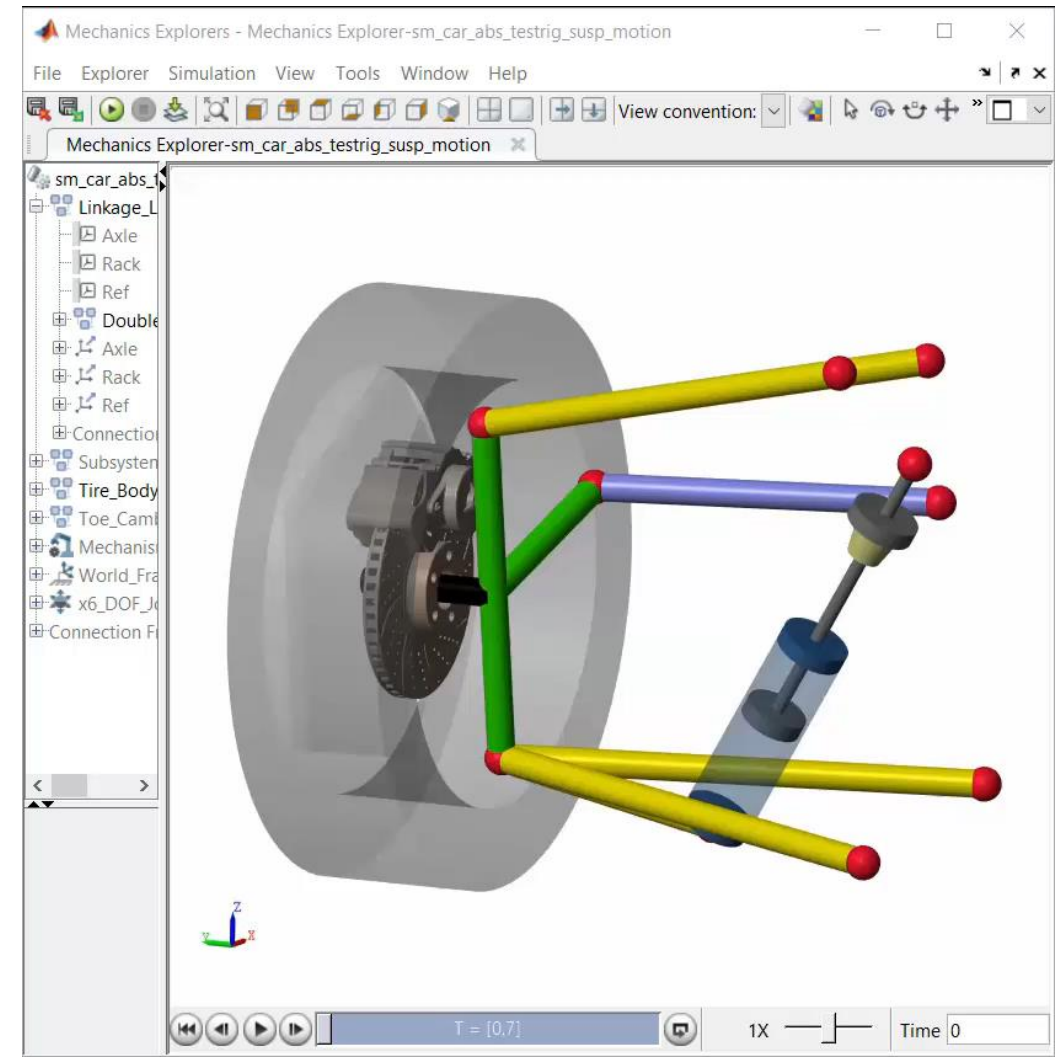
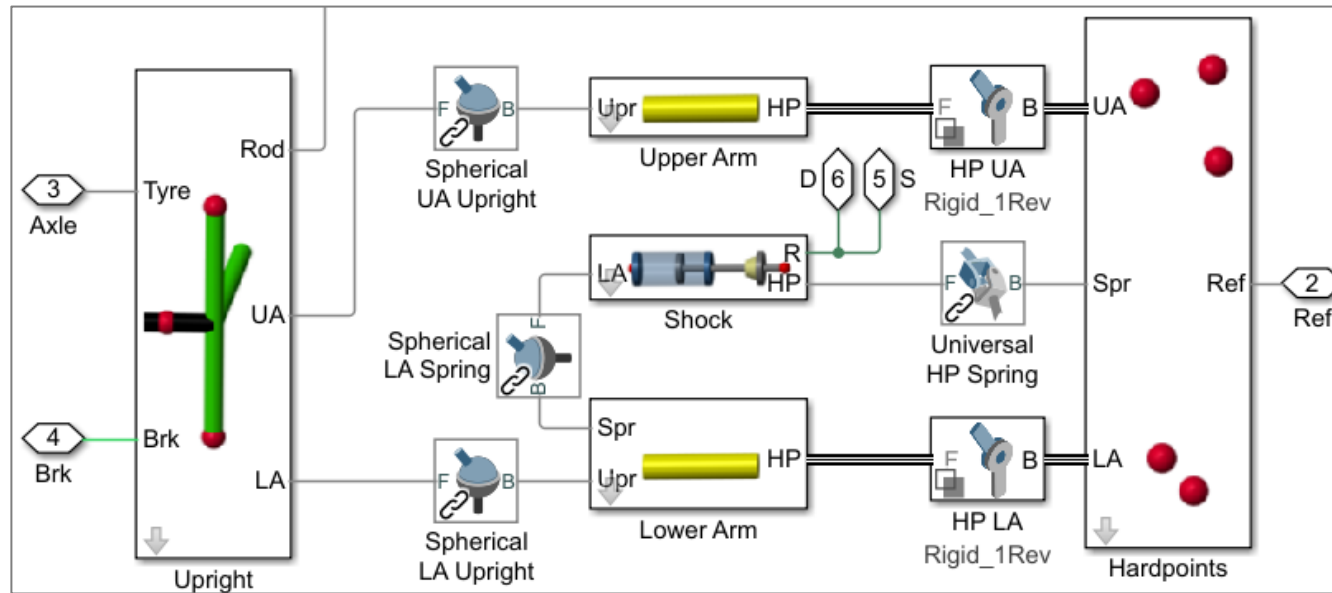
Column View: Data Objects Show Details

Name	Value
DOEMAT	[0.05 0 0.05 0.1 2 100]
Veh_PARAM	<1x1 struct>
f_susp_axl_bp	[1 2]
f_susp_dz_bp	[-0.0275619067514496 -0.02067
f_susp_dzdot_bp	[-0.720046014836431 -0.540034
f_susp_fmz	<5-D double>
f_susp_geom	<4-D double>
f_susp_strgdelta_bp	[-0.382604972274104 -0.369851

Model-Based Calibration Toolbox
Simulink Design Optimization

细化的悬架多体动力学模型

- 基于 Simscape Multibody
- CAD 模型获取硬点参数
- 导入 CAD 模型

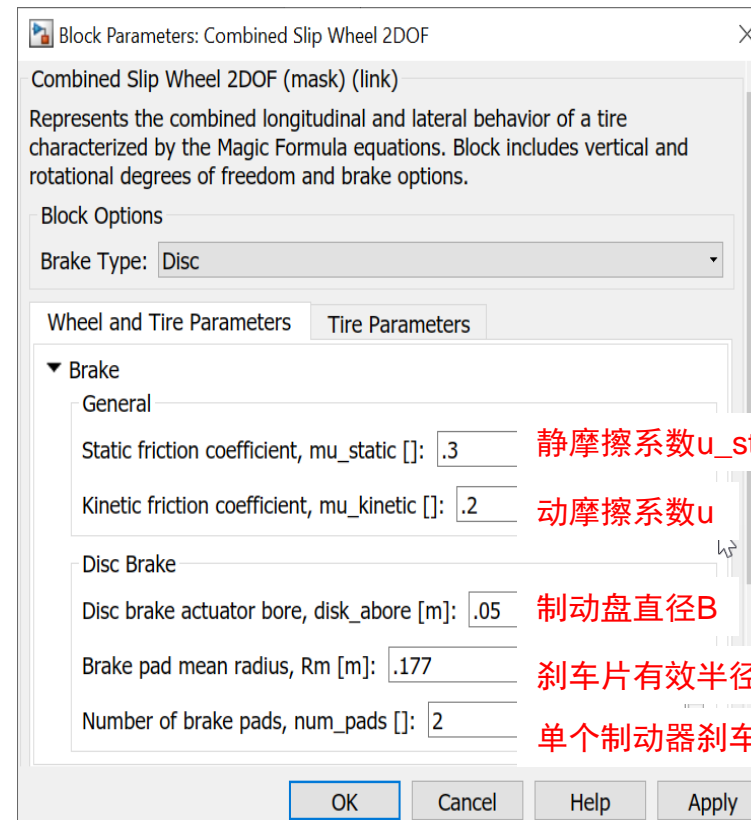


刹车

整车模型中的制动单元

描述制动扭矩和制动压力的映射关系

- VDBS 工具箱提供多种制动单元类型



$$T = \begin{cases} \frac{\mu P \pi B_a^2 R_m N_{pads}}{4} & \text{when } N \neq 0 \\ \frac{\mu_{static} P \pi B_a^2 R_m N_{pads}}{4} & \text{when } N = 0 \end{cases}$$

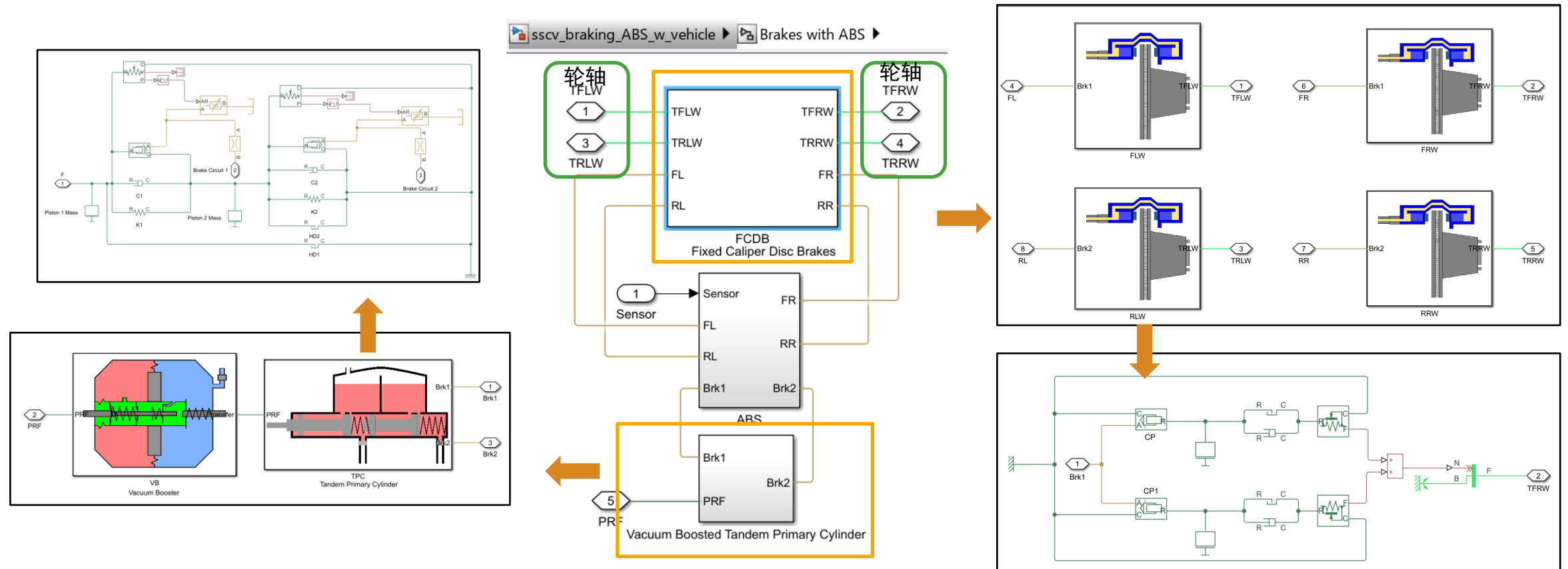
$$R_m = \frac{R_o + R_i}{2}$$

P: 制动液压力
N: 转速
R0: 刹车片外半径
Ri: 刹车片内半径

细化的制动系统物理模型

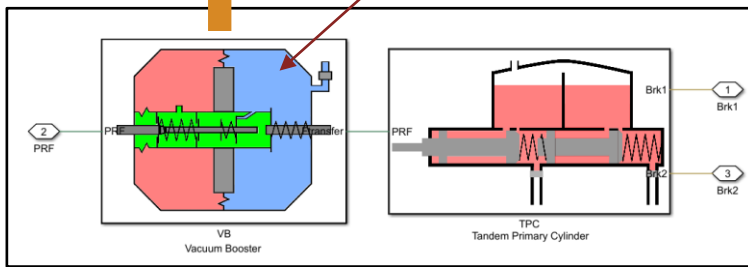
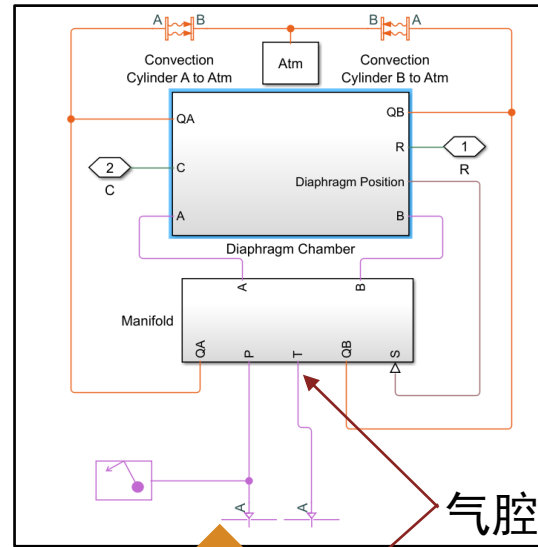
制动扭矩的动态响应

- 使用 Simscape 元件复现制动系统多物理域模型

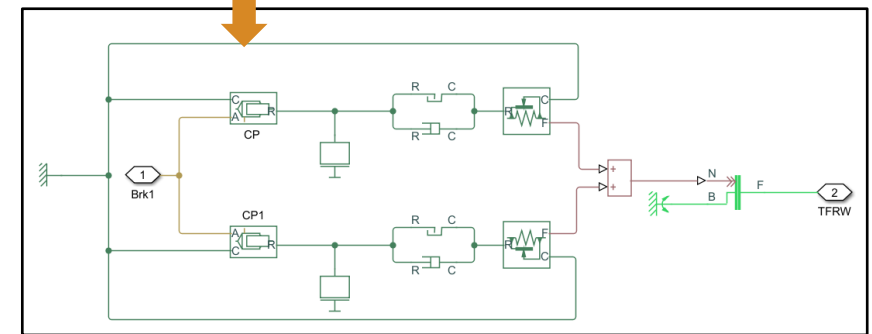
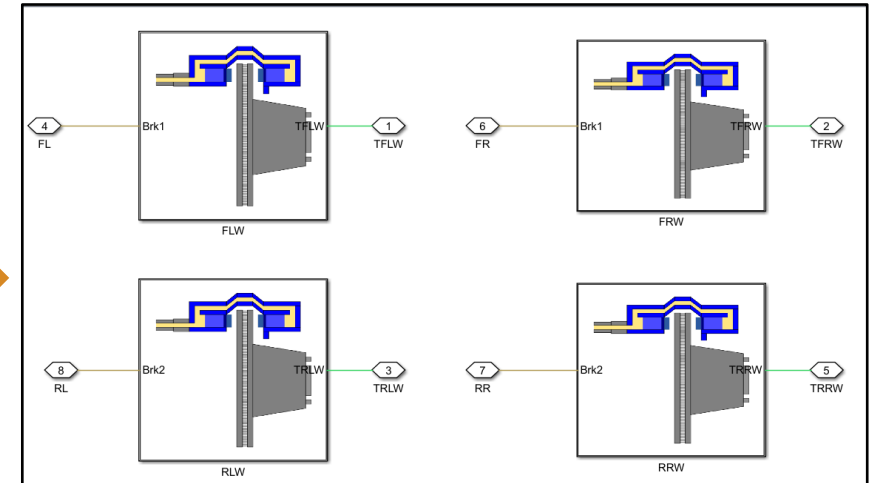
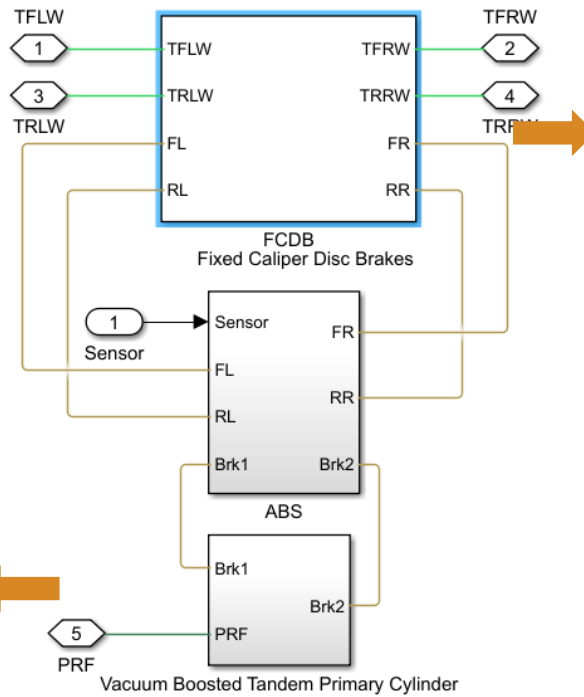


细化的制动系统物理模型

制动扭矩的动态响应



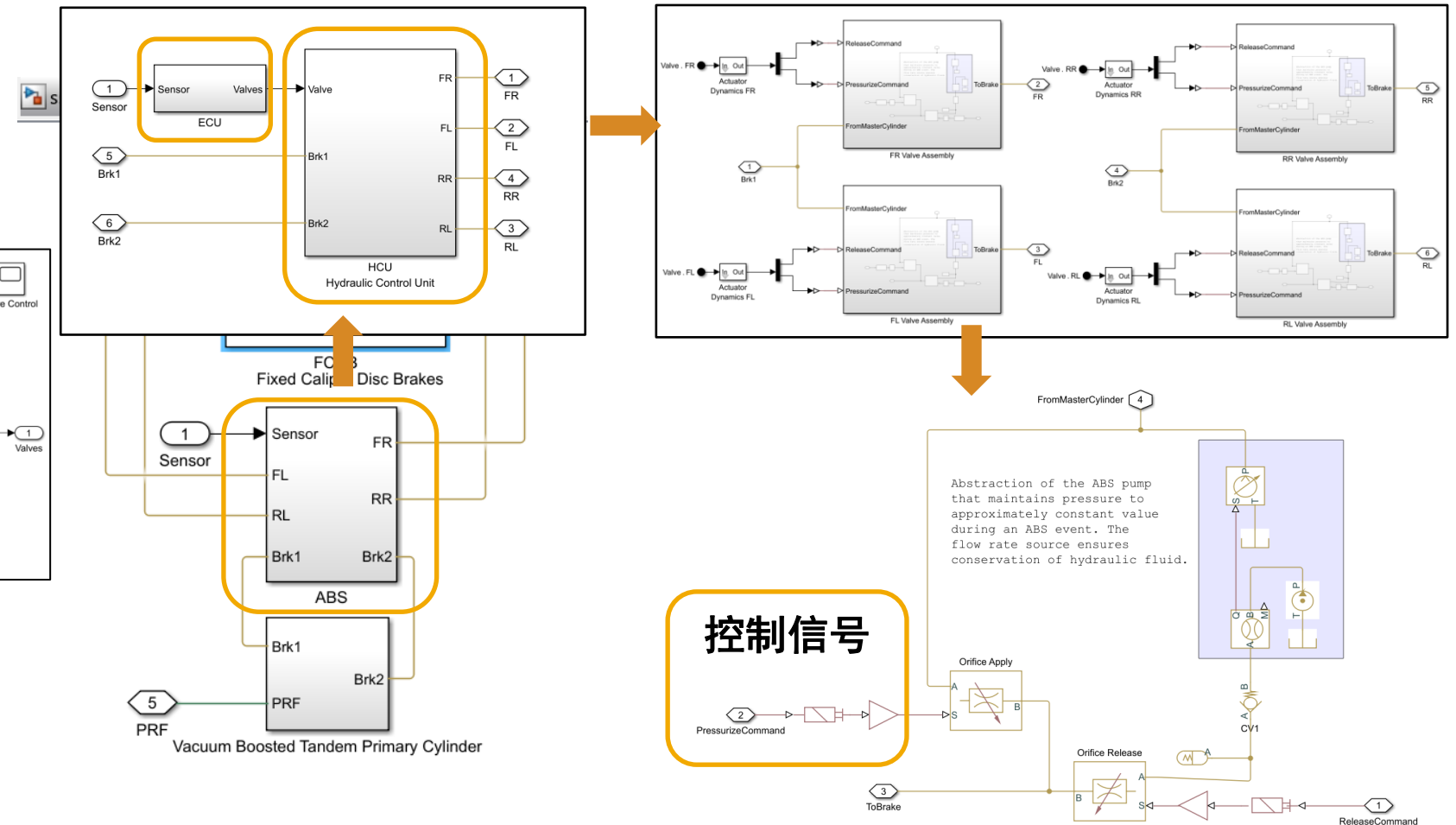
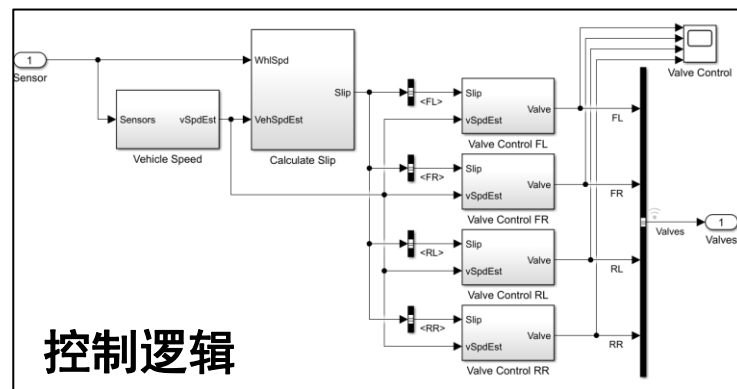
sscv_braking_ABS_w_vehicle ▶ Brakes with ABS ▶



细化的制动系统物理模型

制动扭矩的动态响应

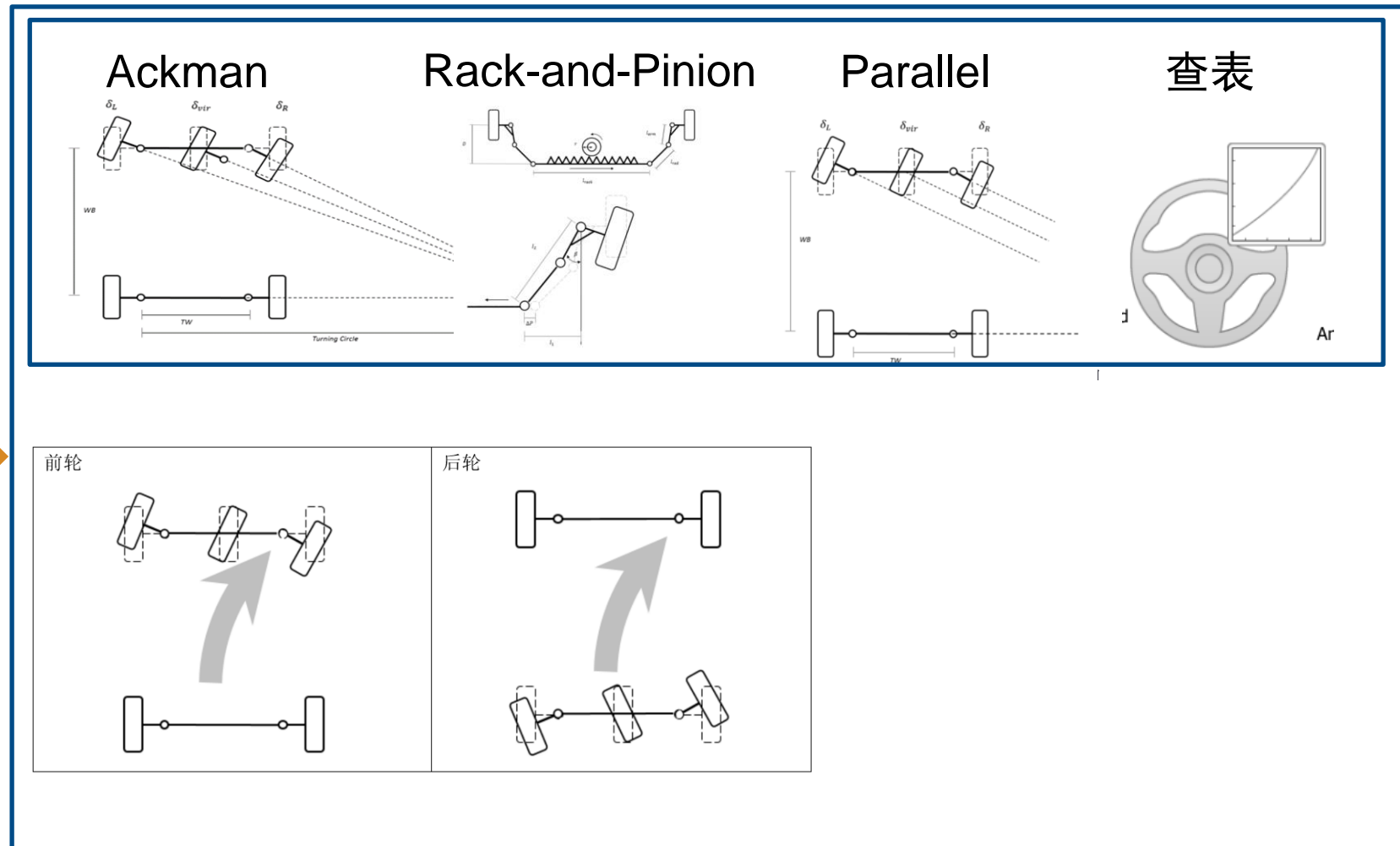
- 与 Simulink 自然集成



转向

整车模型中的转向结构

- 三种结构
- 两种布局



方向盘
转向扭矩/转角



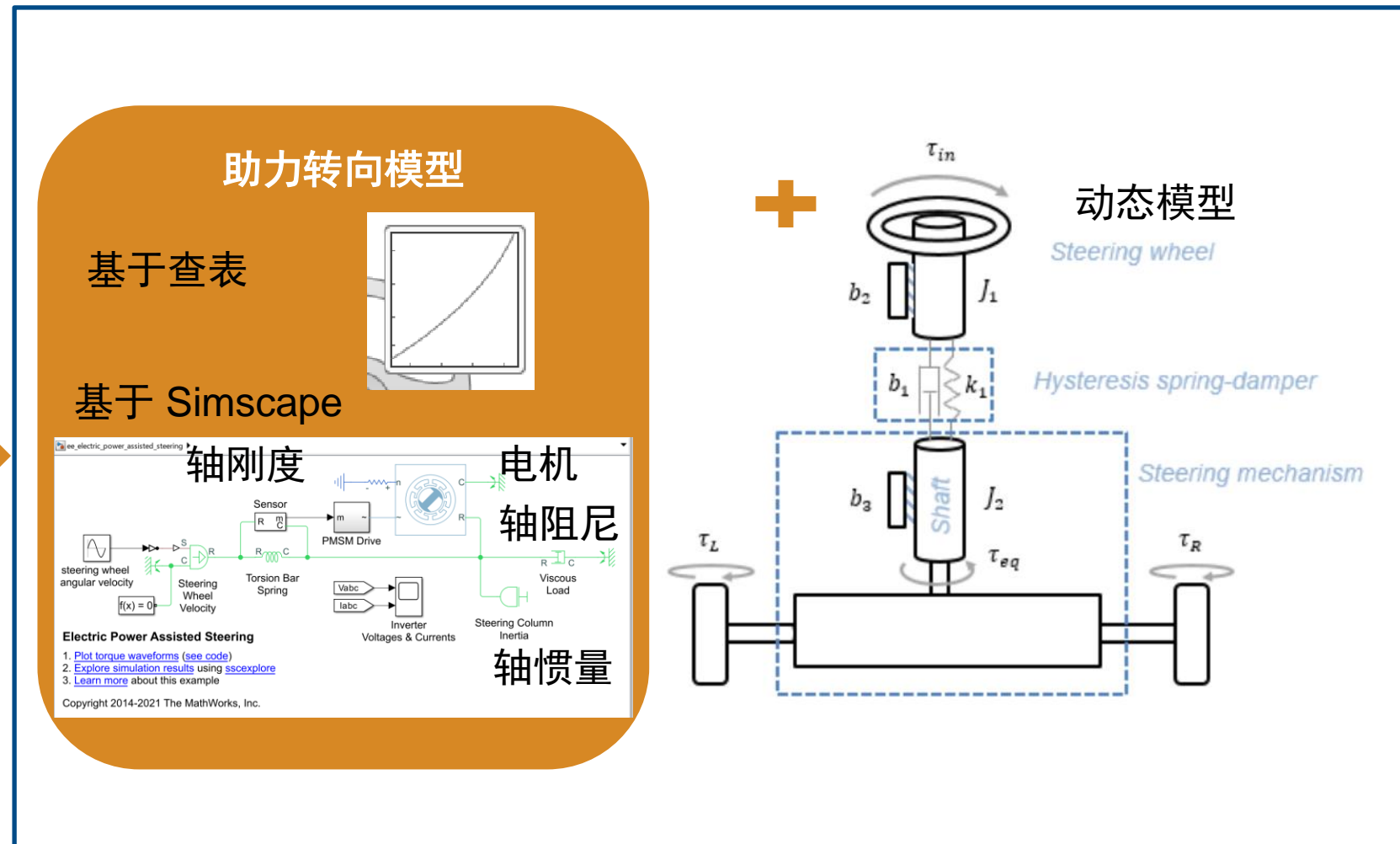
左右轮
转向角



整车模型中的动态转向机构模型

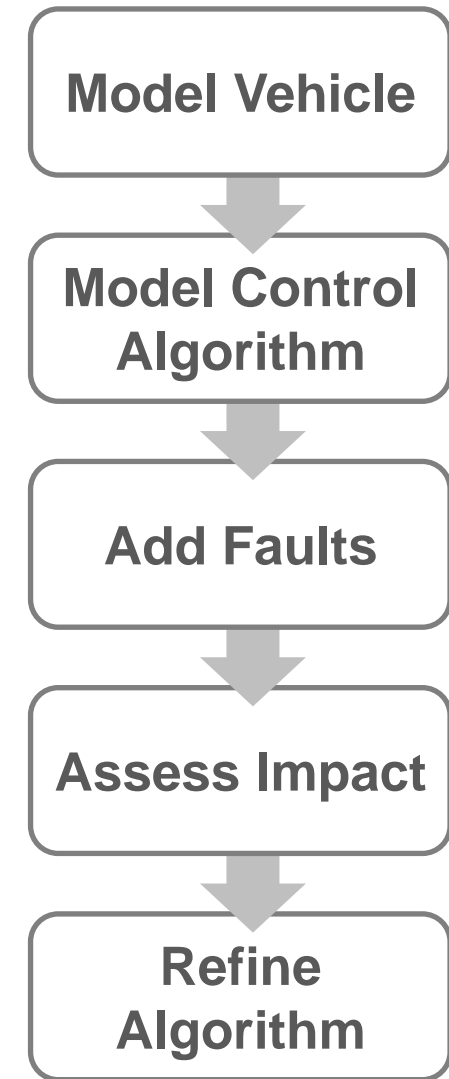
- 三种结构
- 两种布局
- 动态模型
- 助力转向

方向盘
转向扭矩/转角



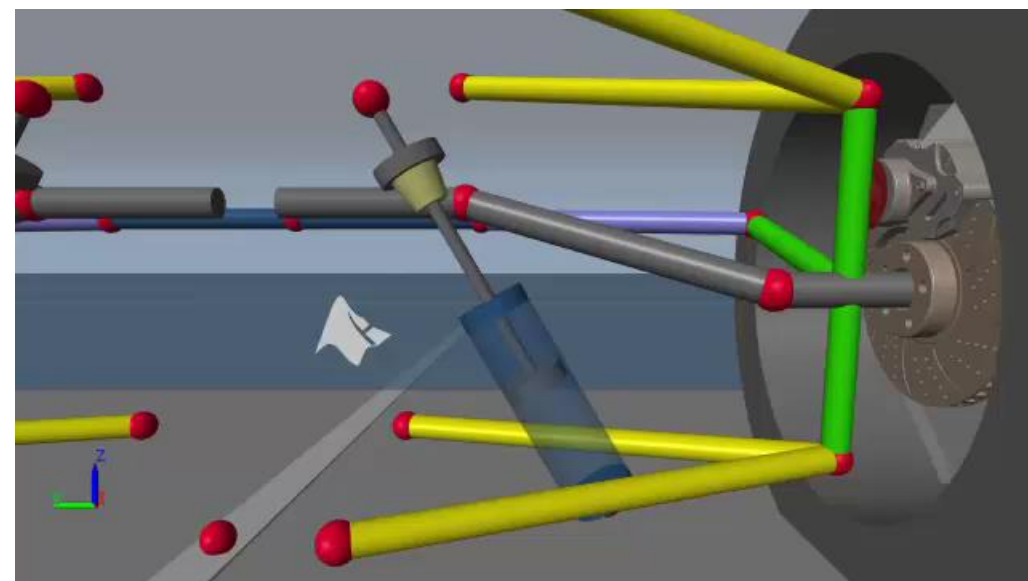
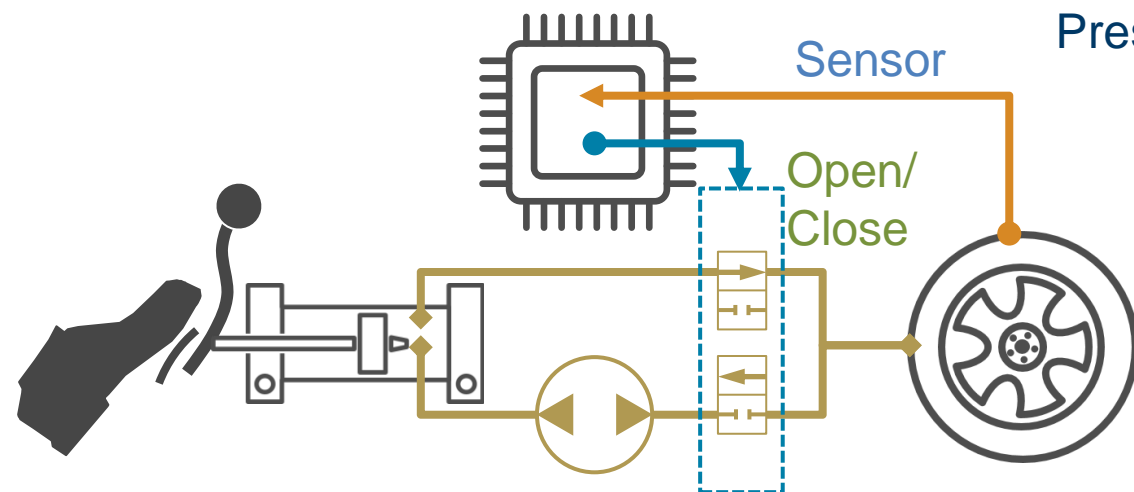
例：零件失效对 ABS 控制的影响分析

- 虚拟车辆模型
 - 子系统细化
 - 控制逻辑
- 模块失效定义
 - 零件失效
 - 传感器失效
- 失效影响分析



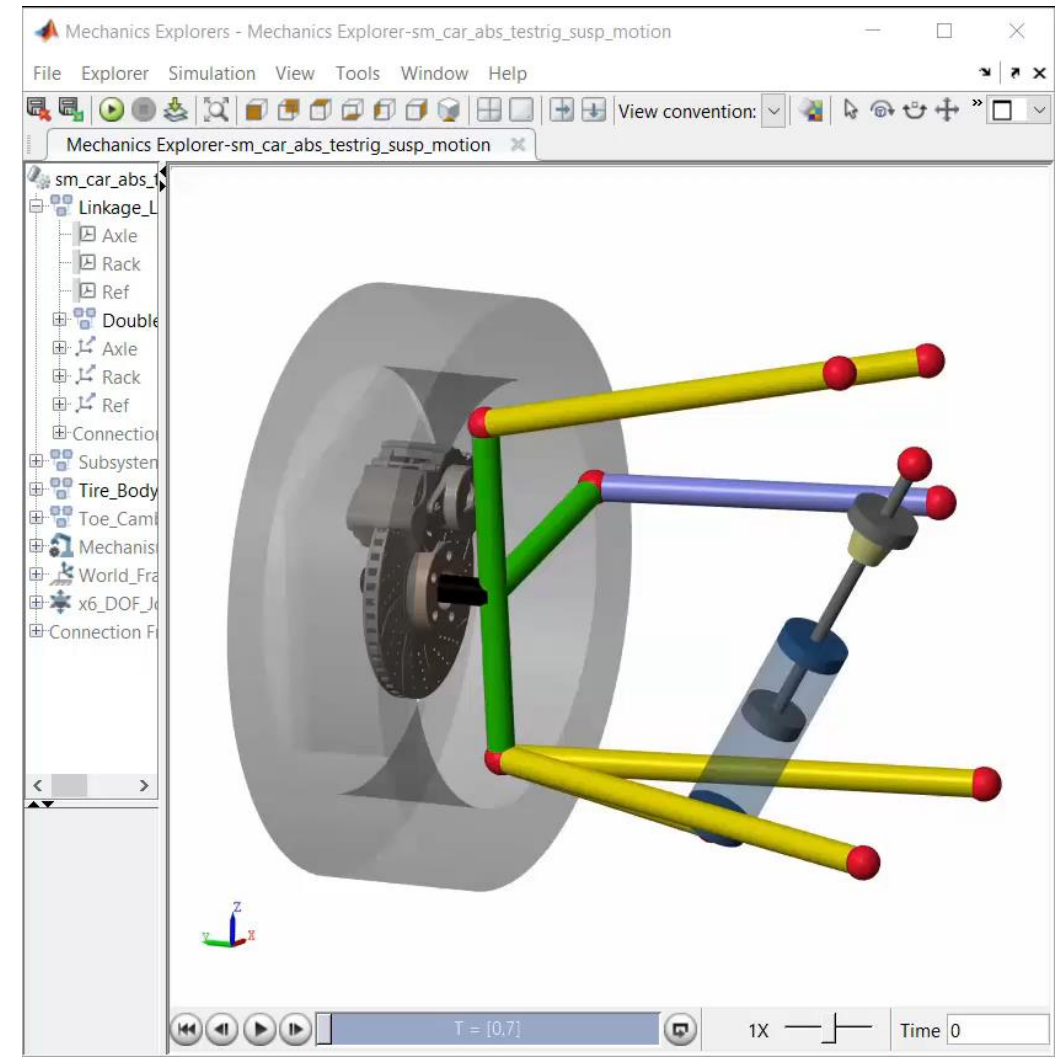
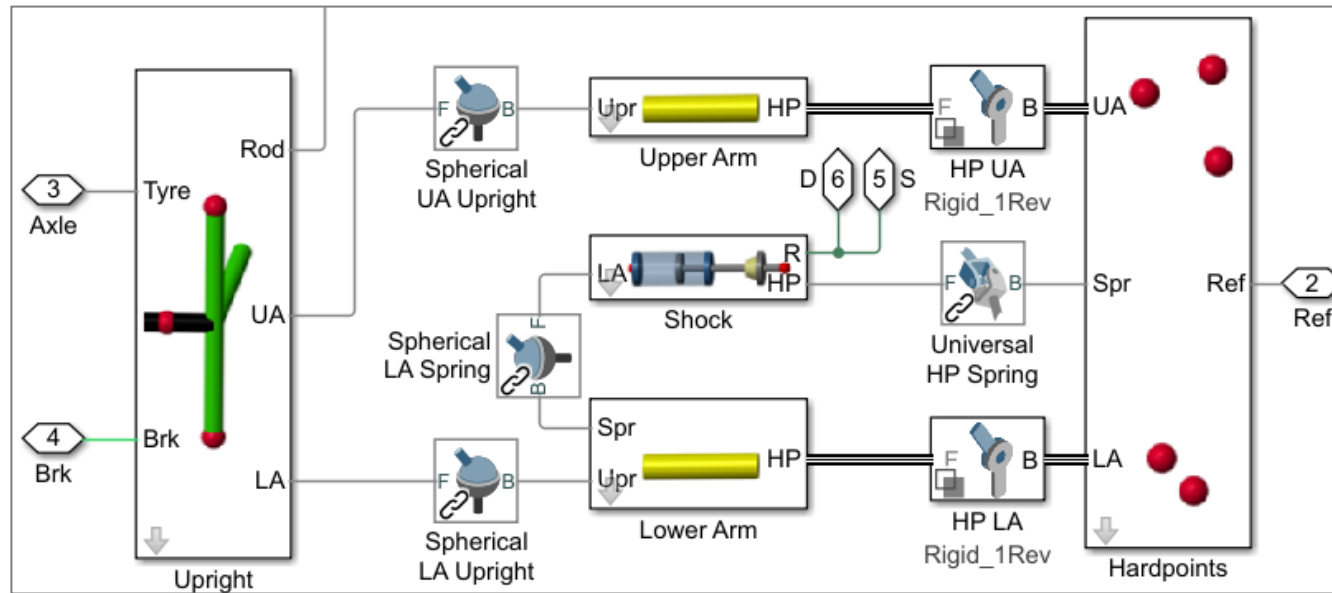
ABS 系统概览

- 防止车轮抱死，以防驾驶员在急刹车时转向失控
- 需要 **ABS 控制算法** 以及 **车辆模型**
 - 确认车轮是否打滑
 - 确定刹车压力
 - 考虑轮速传感器的影响



虚拟车辆：多体动力学系统模型

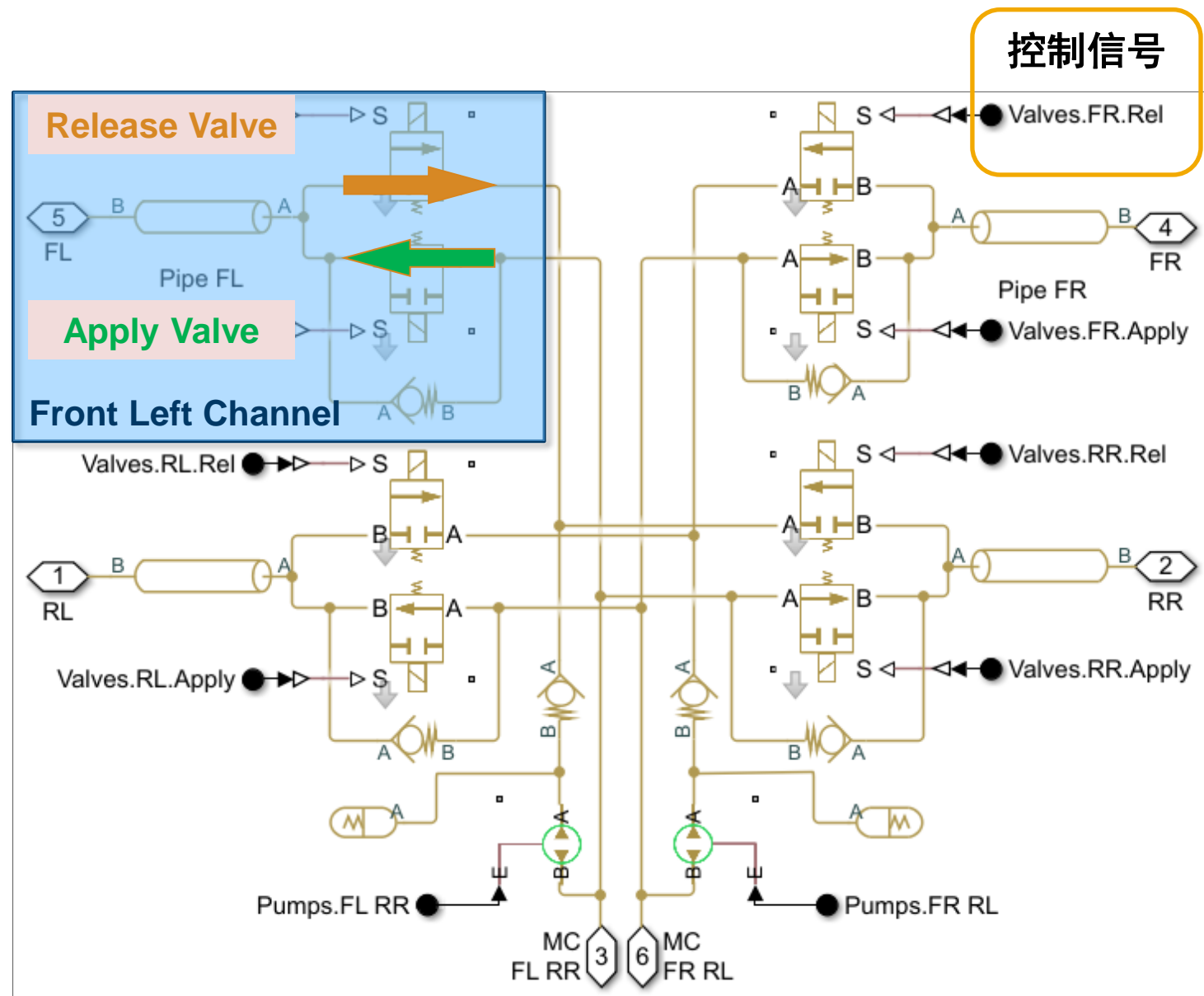
- 悬架
 - 多体动力学
 - 3D 仿真动画



虚拟车辆：液压系统模型

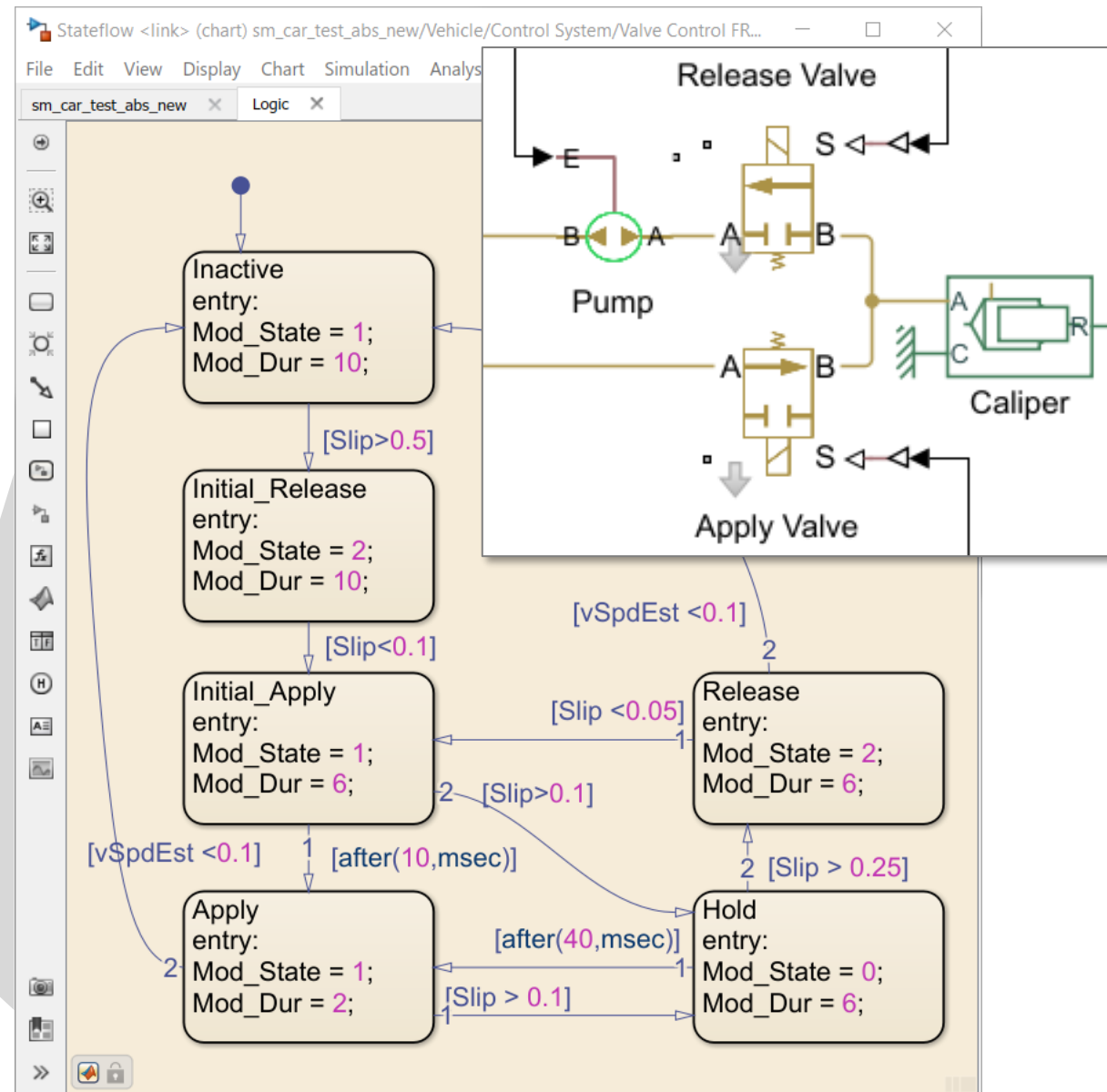
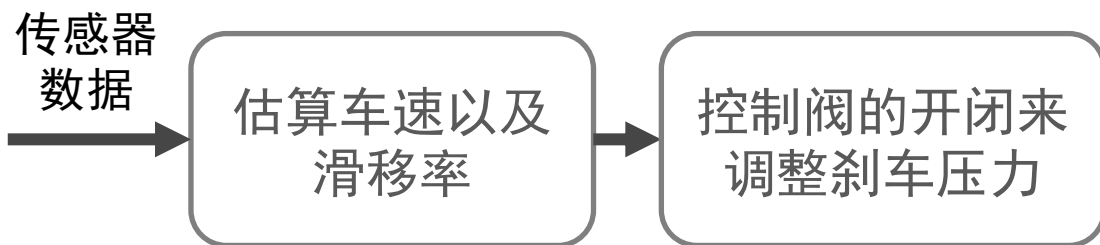
■ 刹车液压系统

- 4 控制通道, 4 传感器
- 串联主缸
- 各刹车油路
- 包括加压和释压力两位阀的 ABS 模块



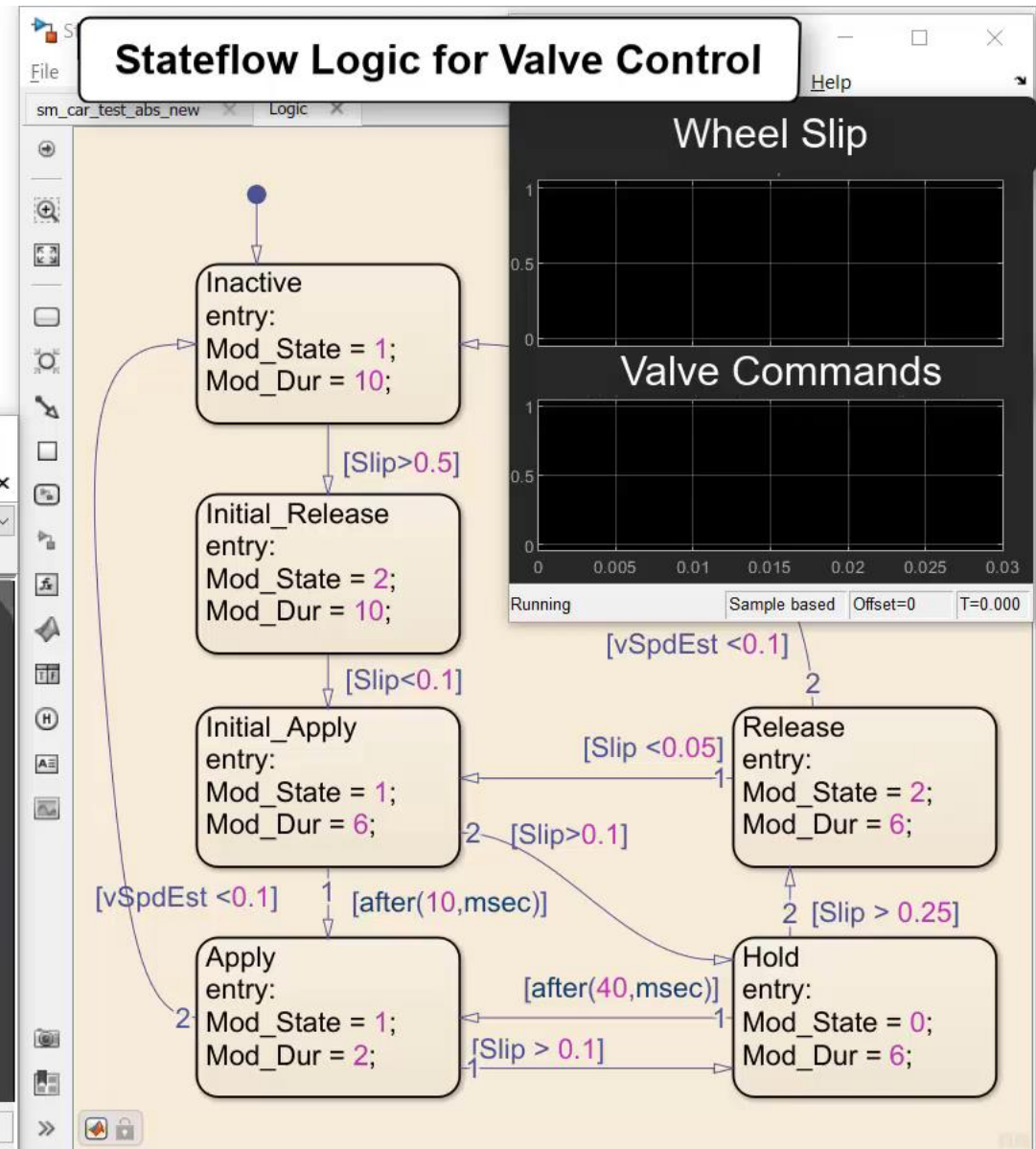
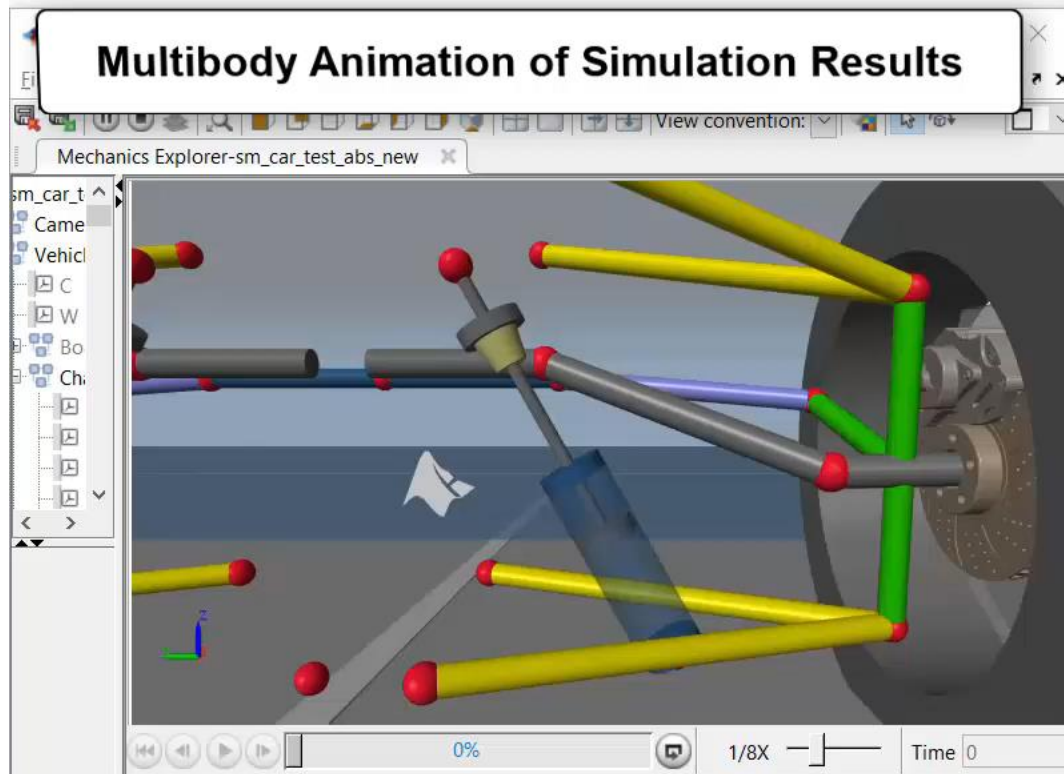
虚拟车辆：控制策略

- 控制: 通过控制两个单向阀的开闭, 来控制刹车压力
- 基于车轮滑移率来调整刹车压力
 - 基于传感器信号估算 (轮速以及加速度)



虚拟车辆：无缝集成

- 控制:
 - Apply, hold, release
 - 控制刹车压力



零件失效对 ABS 控制的影响分析

- 虚拟车辆模型
 - 子系统细化
 - 控制逻辑
- 模块失效定义
 - 零件失效
 - 传感器失效
- 失效影响分析

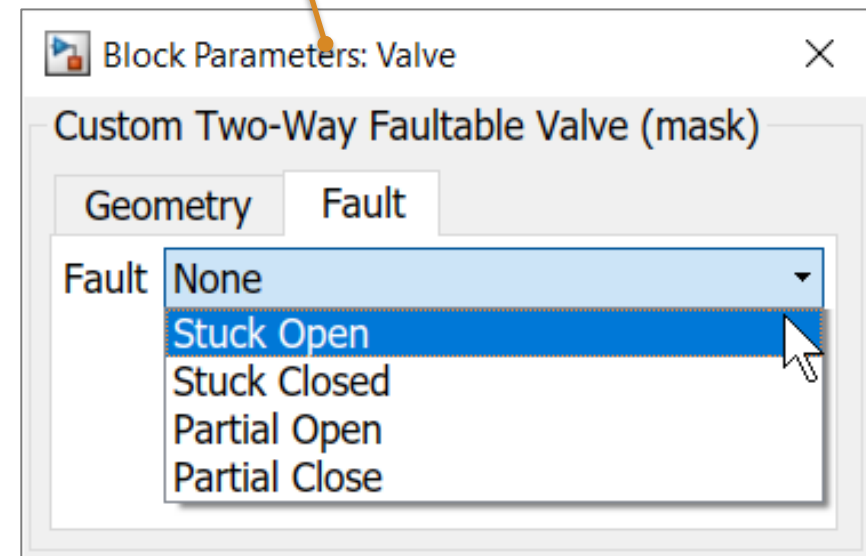
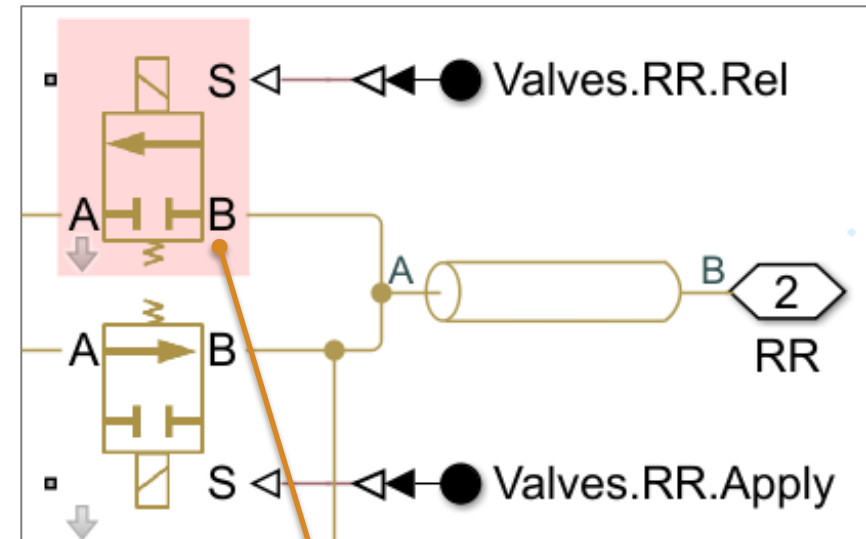
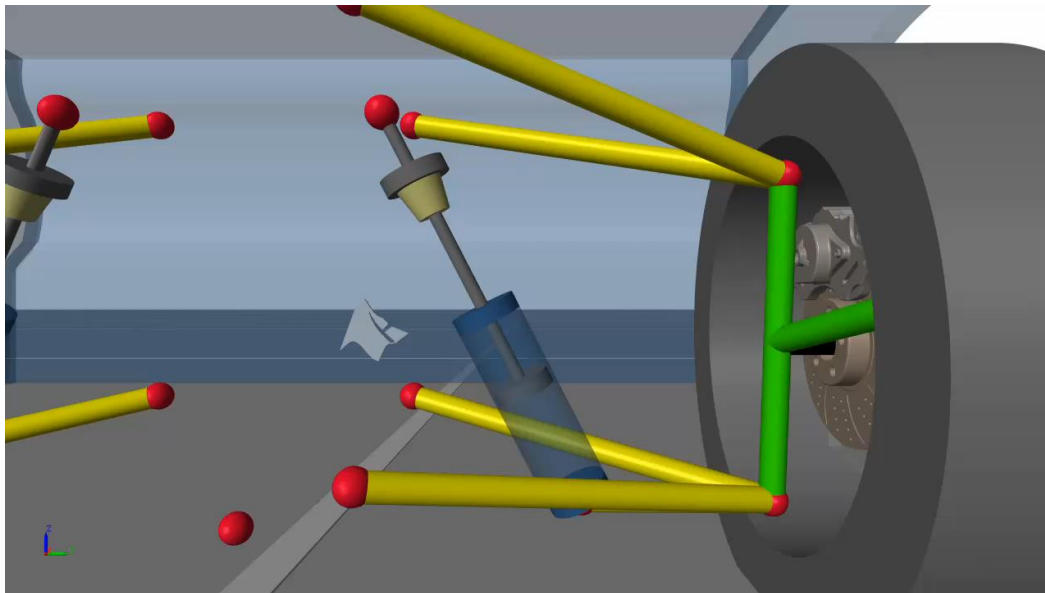


模块失效定义

零件失效

- 阀失效

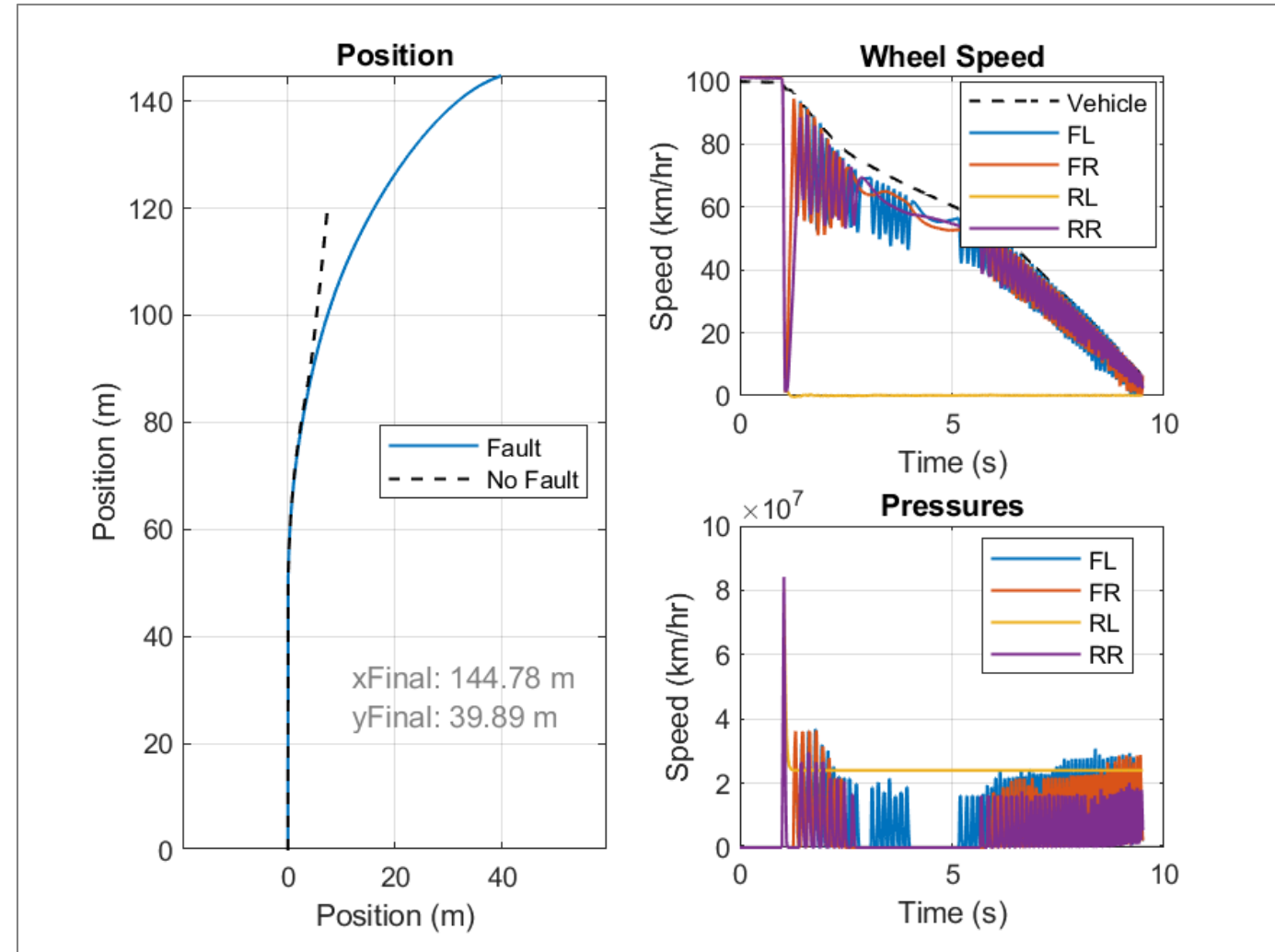
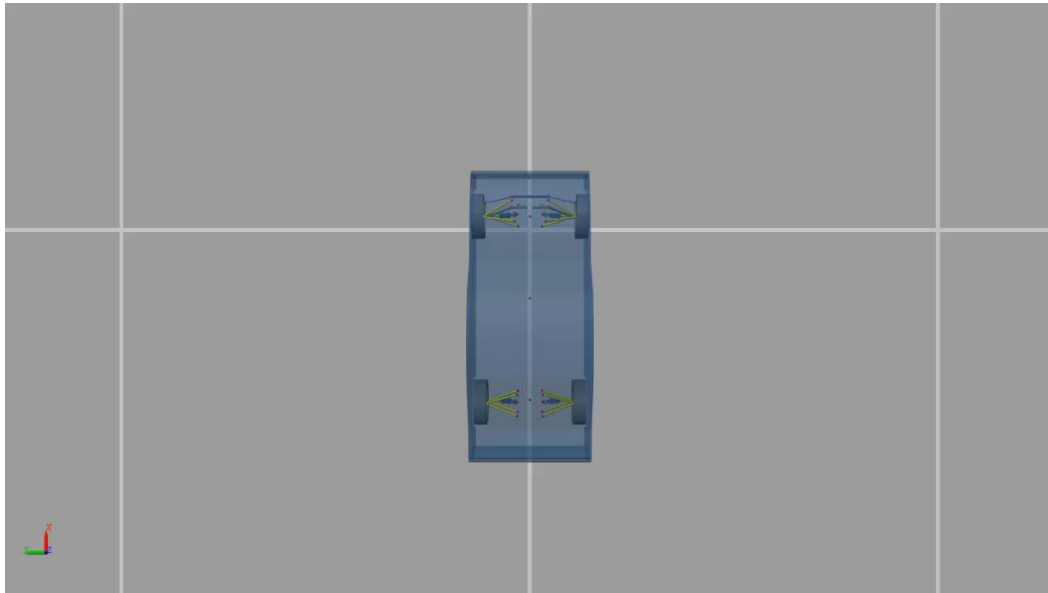
- 阀常开、常闭等等
- 可让不同系统功能的阀失效



模块失效定义

零件失效

- 测试: 加压阀, 左后轮
 - 只能关闭 50%
 - 左后轮锁死



模块失效定义

传感器失效

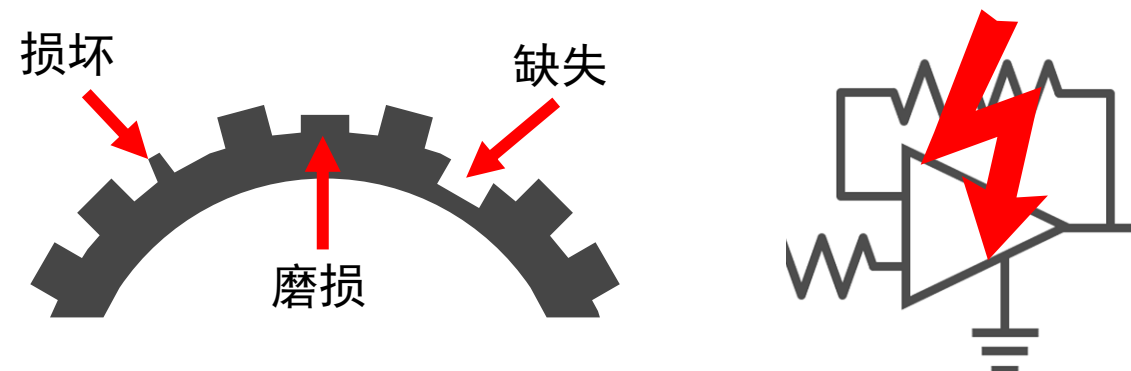
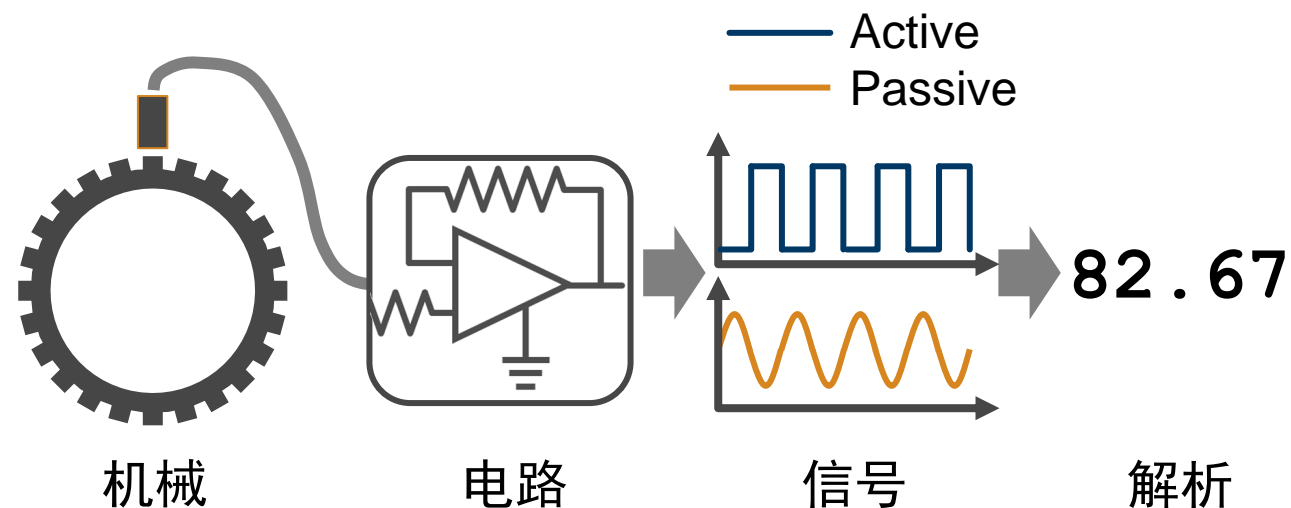
轮速传感器

- 旋转齿产生脉冲信号
- 脉冲数和转速相关

失效原因

- 机械原因: 磨损, 安装问题, 胎压过低 (affects radius)
- 电气原因: 热, 噪音影响

- 仿真 ABS 所使用的传感器信号失效, 并评估对车辆控制效果的影响

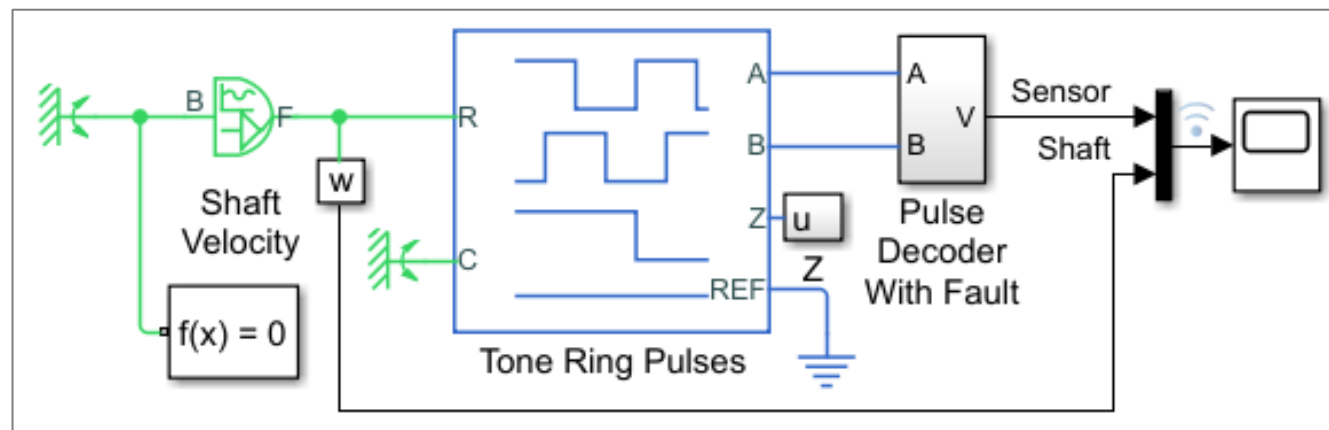


模块失效定义

传感器失效

- 轮速传感器

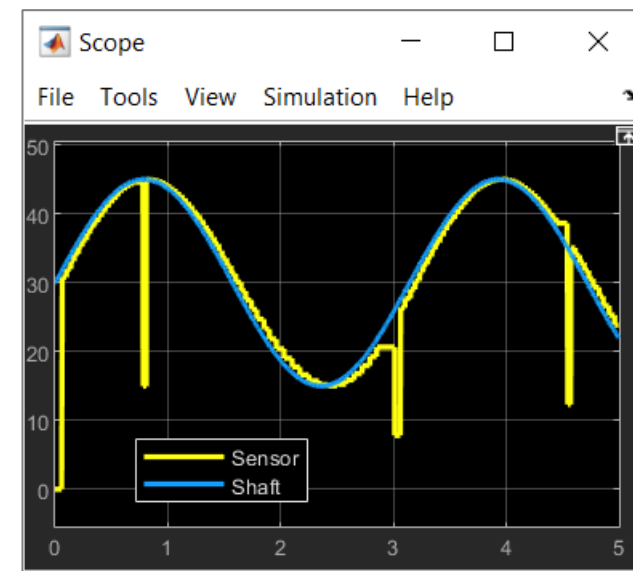
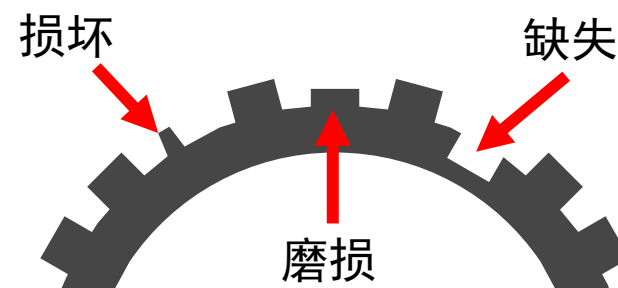
- 旋转齿产生脉冲信号
- 脉冲数和转速相关



- 失效原因

- 机械原因: 磨损, 安装问题, 胎压过低 (affects radius)
- 电气原因: 热, 噪音影响

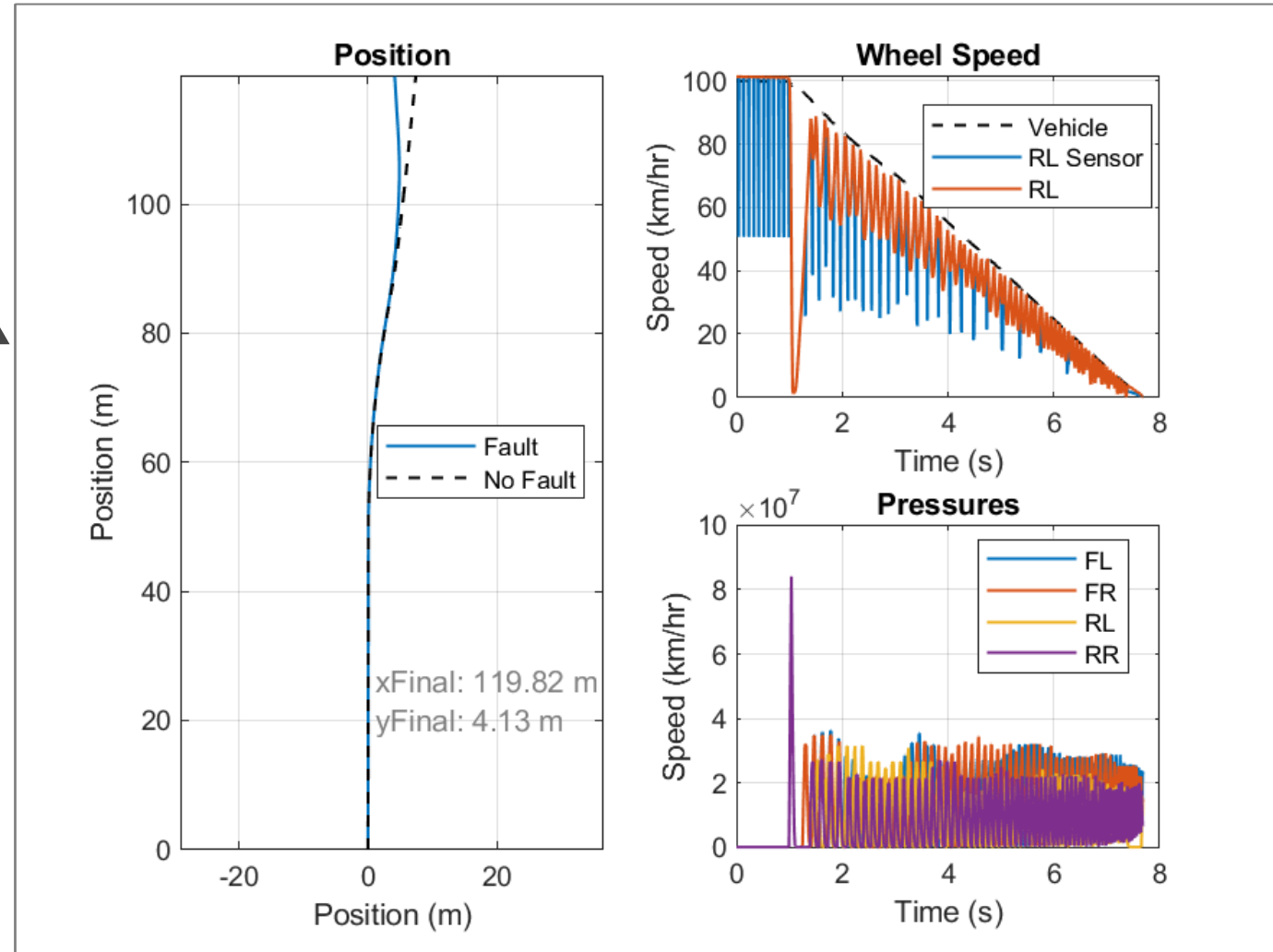
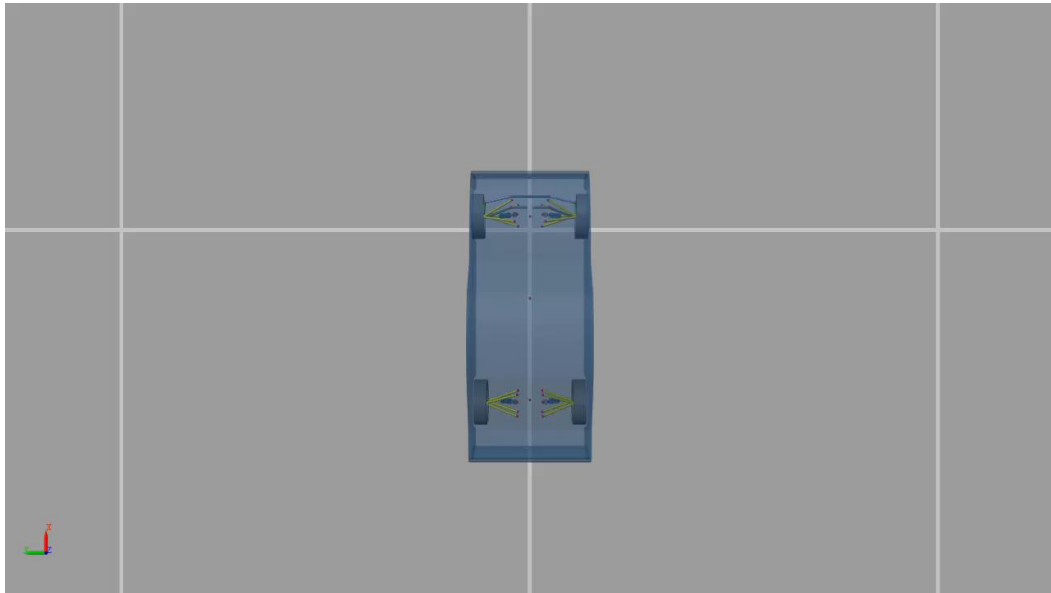
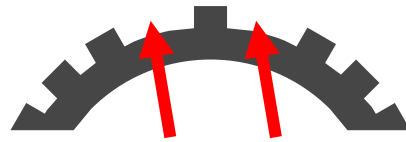
- 仿真 ABS 所使用的传感器信号失效, 并评估对车辆控制效果的影响



模块失效定义

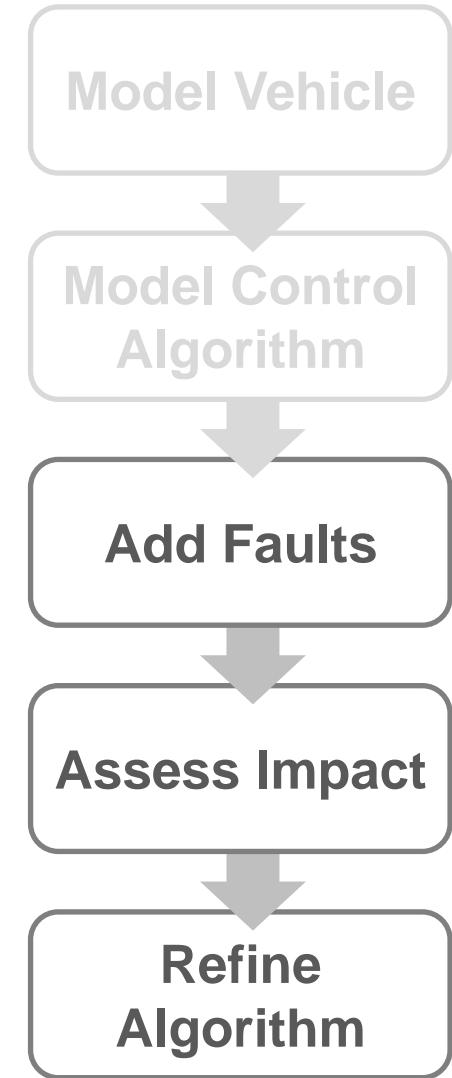
传感器失效

- 测试: 缺2个齿, 左前轮
 - 低速尖峰
 - 最小化影响



零件失效对 ABS 控制的影响分析

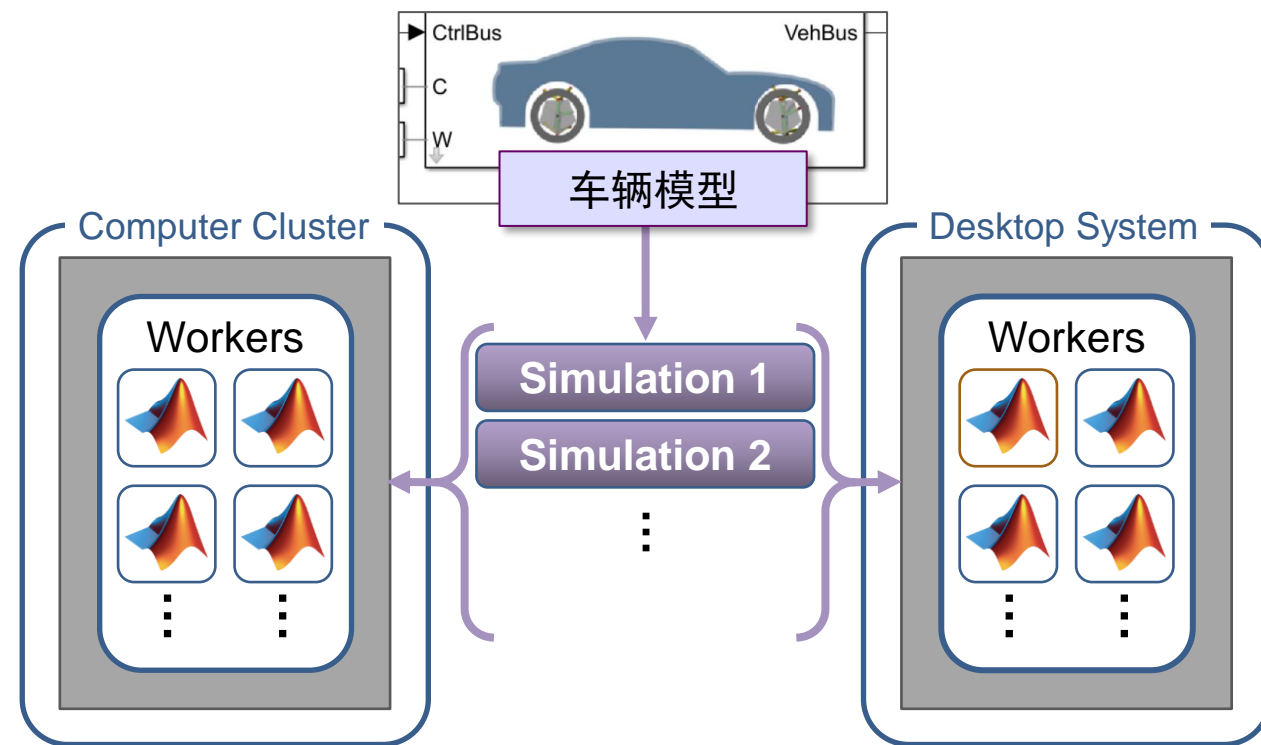
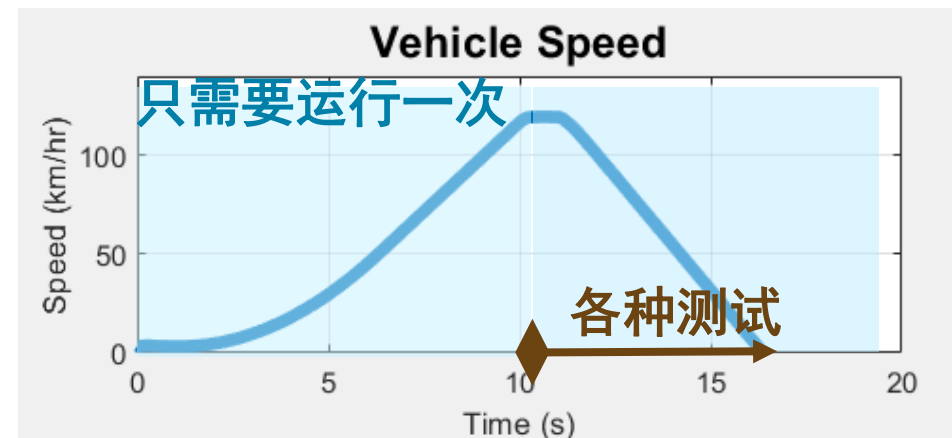
- 虚拟车辆模型
 - 子系统细化
 - 控制逻辑
- 模块失效定义
 - 零件失效
 - 传感器失效
- 失效影响分析



失效影响评估

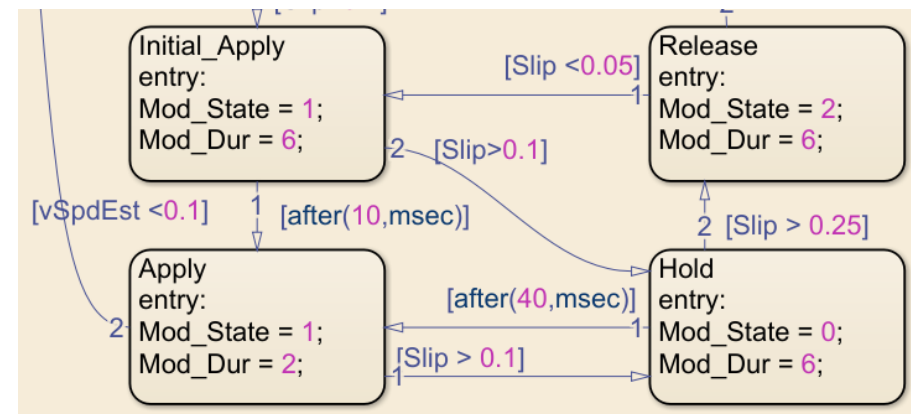
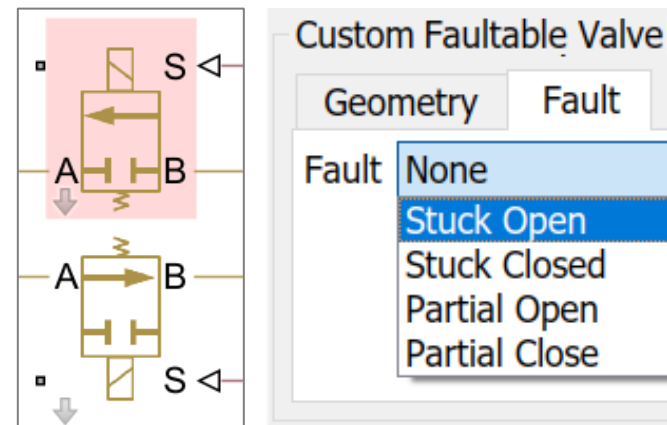
- 各种不同的测试用例
 - 失效类型, 失效程度, 失效位置
 - 各种不同路况以及驾驶逻辑
- 缩短测试时间
 - 起始工况点记录和复用
 - 使用脚本进行自动配置
 - 并行运算

```
set_fault mdl, 'Valve FL')
out = parsim(mdl);
```

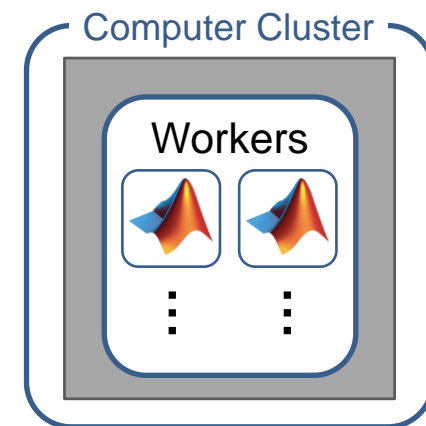


要点

- MathWorks 为不同的仿真目的提供了多种建模方法
- 可以结合 Simscape 建立子系统物理模型，定义和分析零件功能失效对系统整体性能的影响
- 集成控制策略模型并利用并行加速仿真，能帮助我们快速测试和评估算法的有效性



```
set_fault mdl, 'Valve FL'
out = parsim mdl;
```



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谢谢！

