ME40064: System Modelling & Simulation
ME50344: Engineering Systems Simulation
Lecture 17

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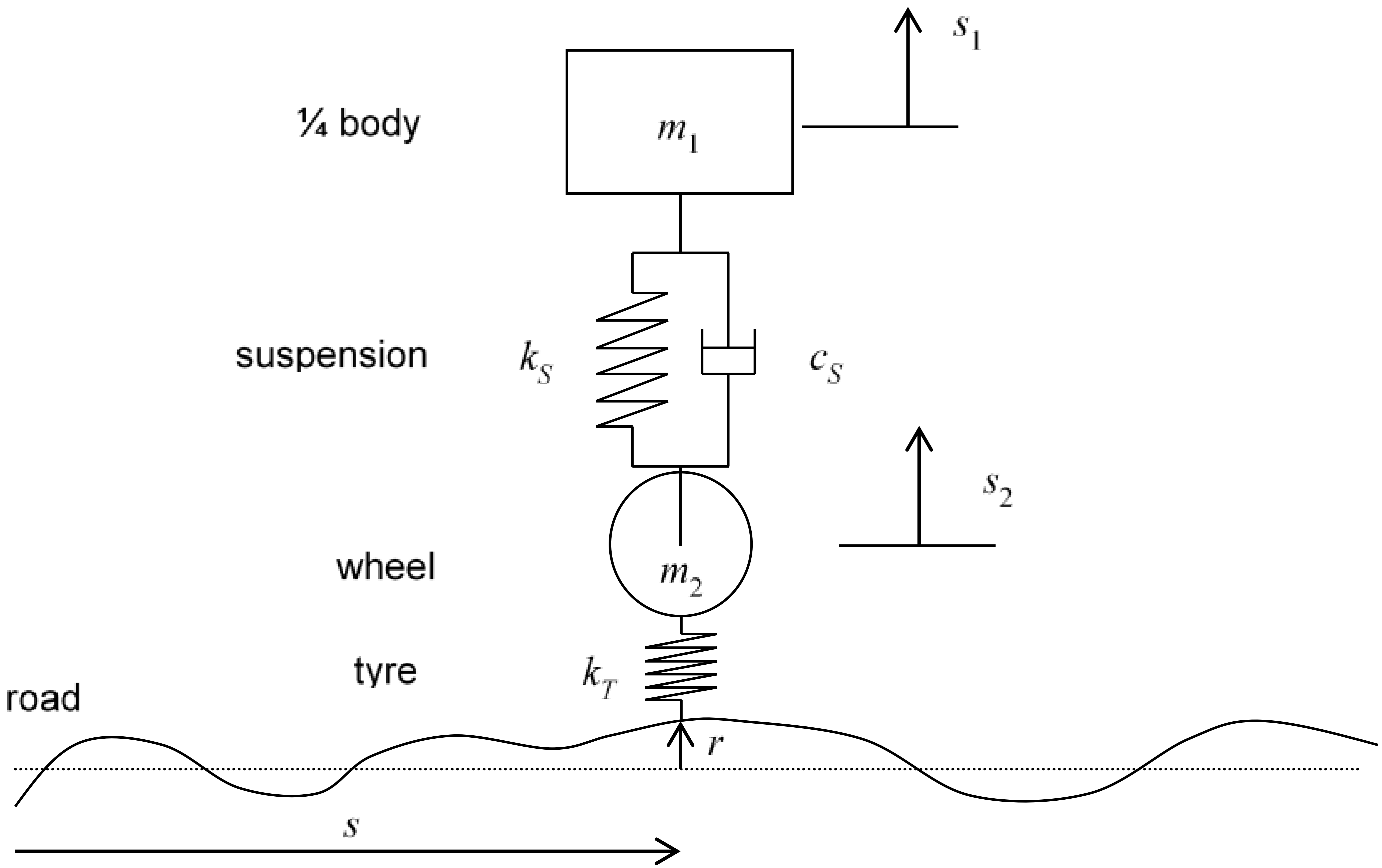
University of Bath, 2019-20

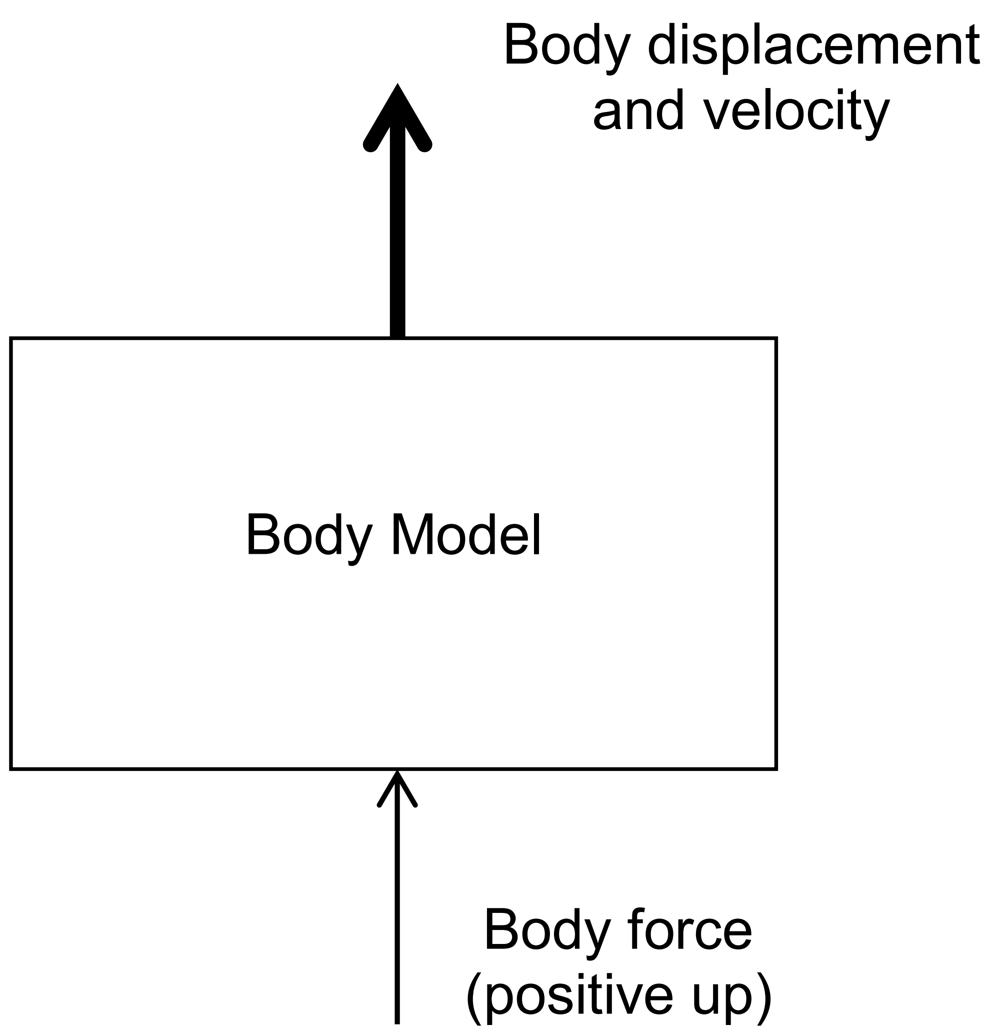
LECTURE 17
Verification Of Simulink Models

- Introduce 1/4 car model
- Reiterate importance of verification
- Understand how to use theoretical methods for verification
- Appreciate advanced tools for verification provided by Simulink

THE 1/4 CAR MODEL
The System

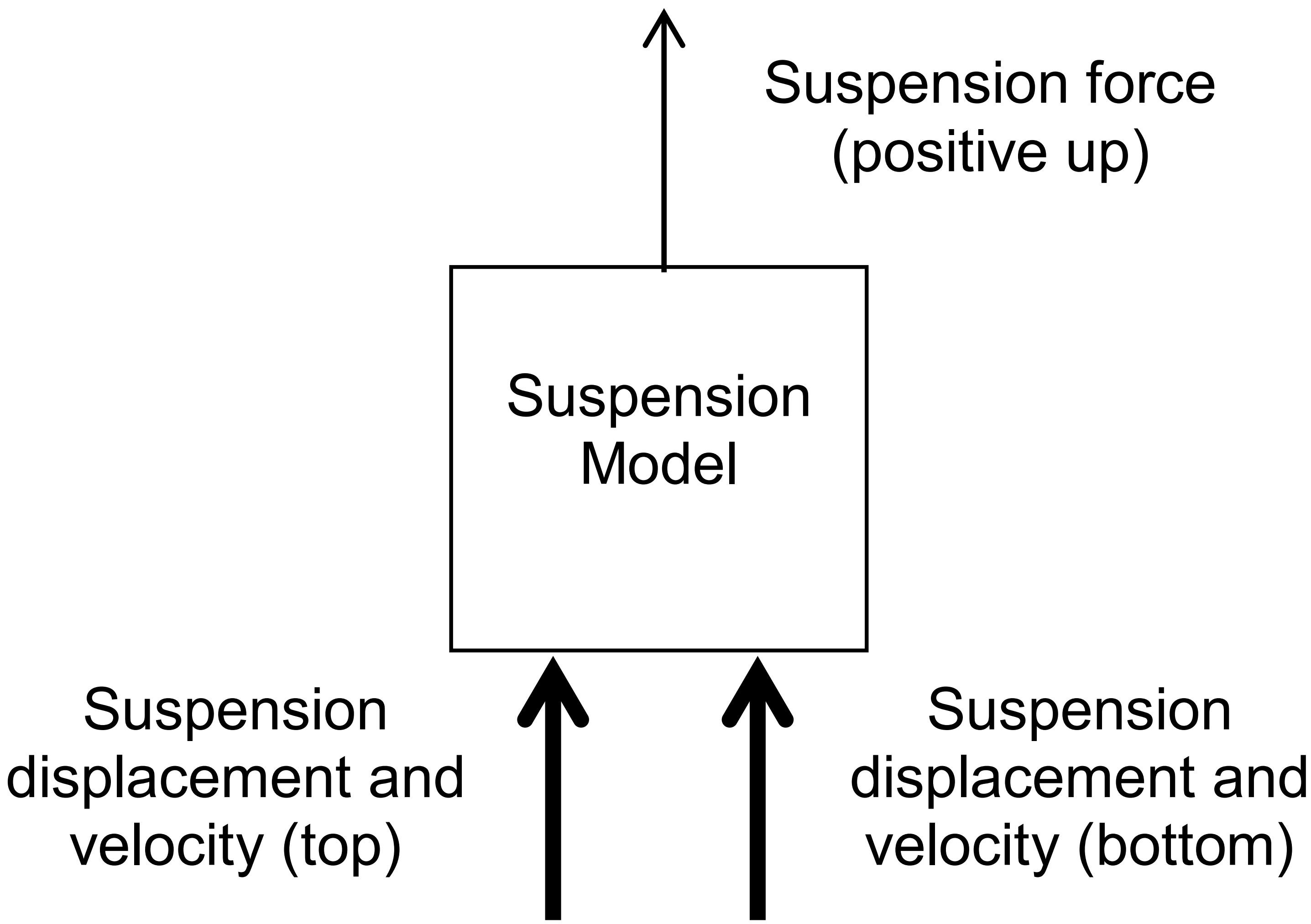


THE 1/4 CAR MODEL
Body Model Subsystem



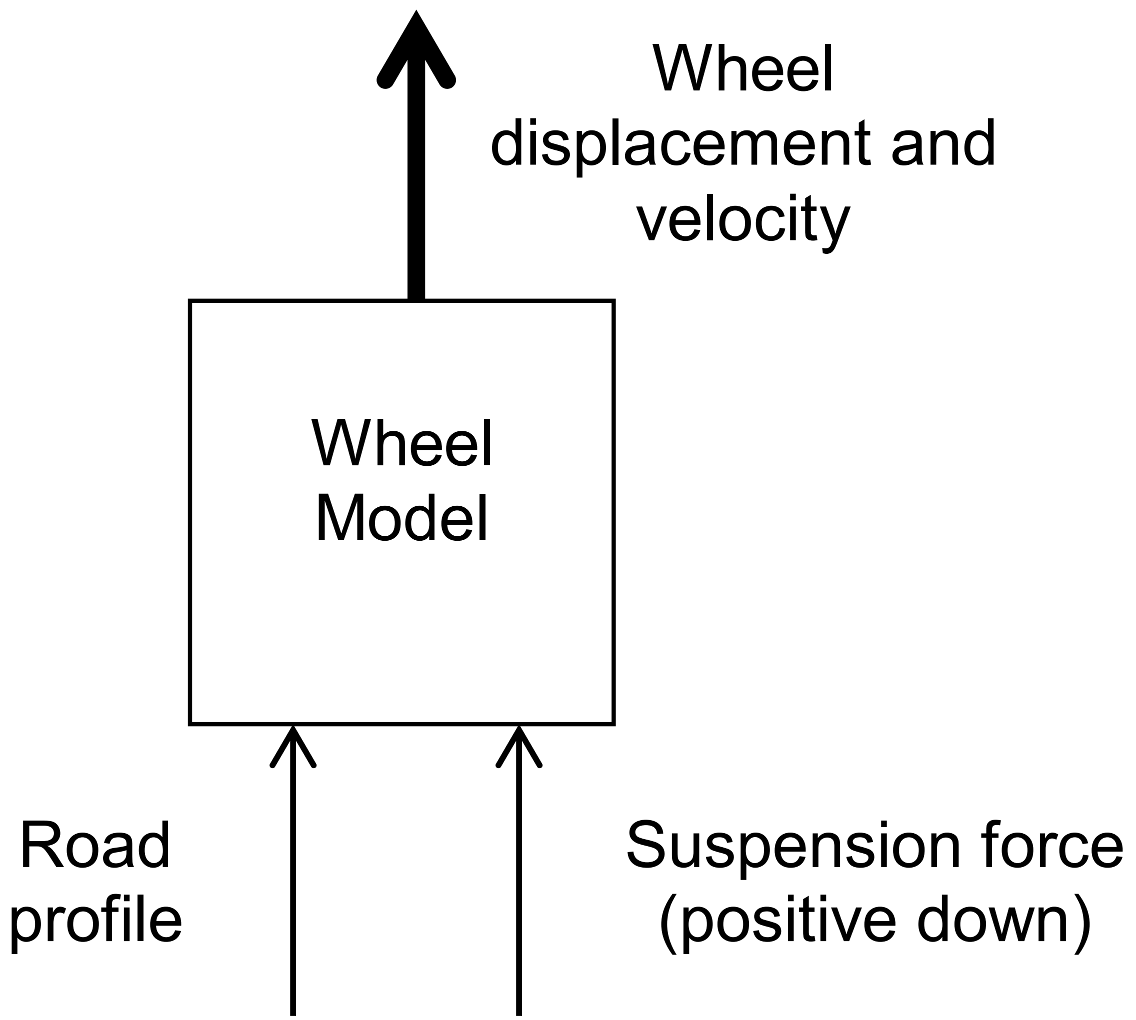
$$m_1 \ddot{s}_1 = F - m_1 g$$

THE 1/4 CAR MODEL
Suspension Model Subsystem



$$F = -k_S(s_1 - s_2) - c_S(\dot{s}_1 - \dot{s}_2)$$

THE 1/4 CAR MODEL
Tyre Model Subsystem

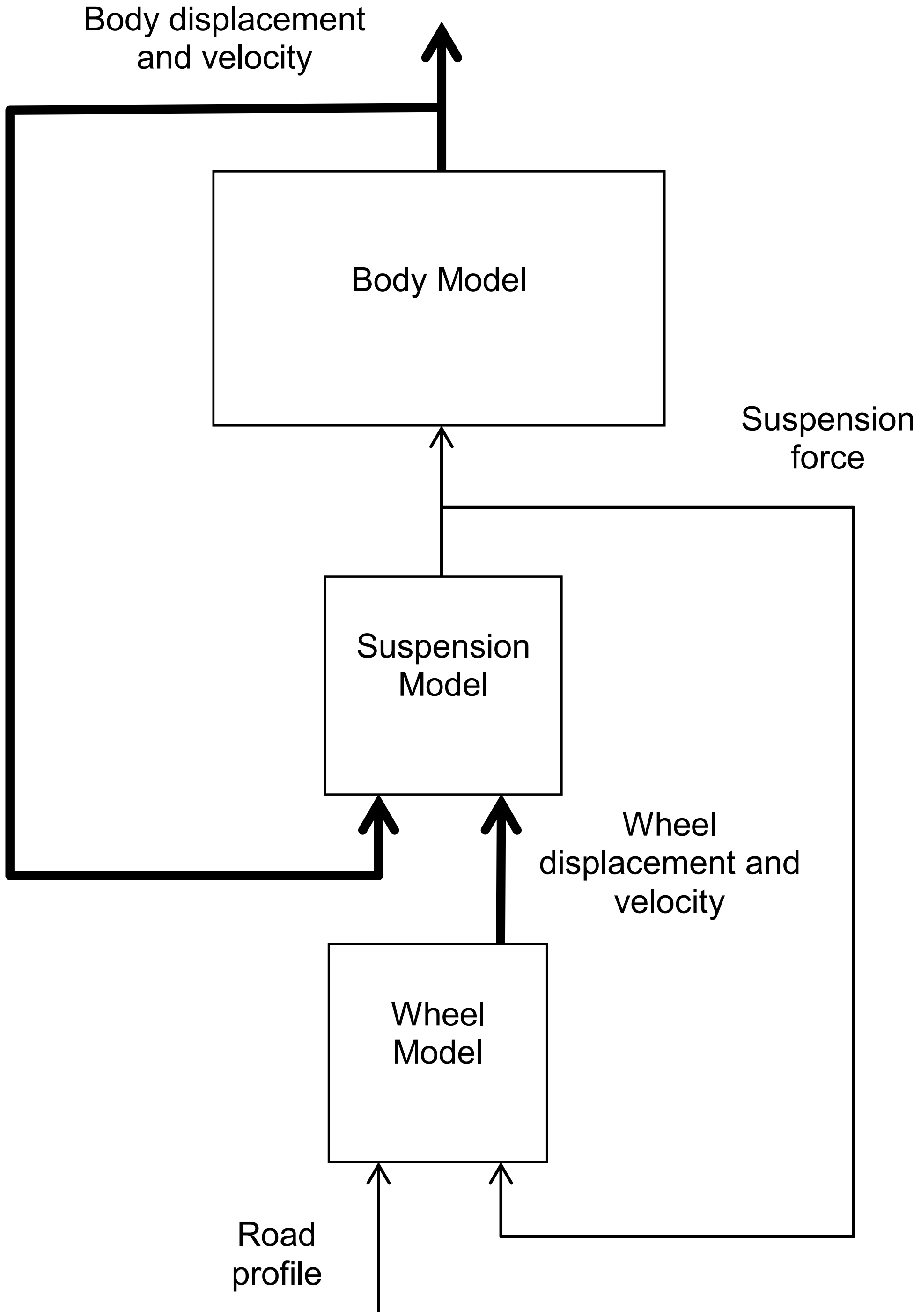


$$m_2\ddot{s}_2 = -F + k_T(r - s_2) - m_2 g$$

THE 1/4 CAR MODEL
Coupled Together For Whole System

Coupled 1/4 Car Model System

- Note the series and feedback
- The model layout relates to the "physical" model
- As presented, the model is linear
- Could be modified to have nonlinear elements
  - Different bump/rebound rates in the suspension
  - Tyre forces can be due to compression only



The Challenge

As you can see the GOOD thing about Simulink is how easy its graphical method makes it to build complex models

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The BAD thing about Simulink is how easy its graphical method makes it to build complex models

SIMULINK VERIFICATION
The Aims

Verify that subsystem models and the complete model deliver the correct solutions. As far as possible, test them to show that:

- Solutions are accurate to a desired level. This will depend on the particular time-stepping routine used and associated specifications of relative and absolute tolerances

- All mathematical and logic errors have been eliminated. This is possible by thorough checking of code and assessing the model predictions arising from particular forms of all inputs

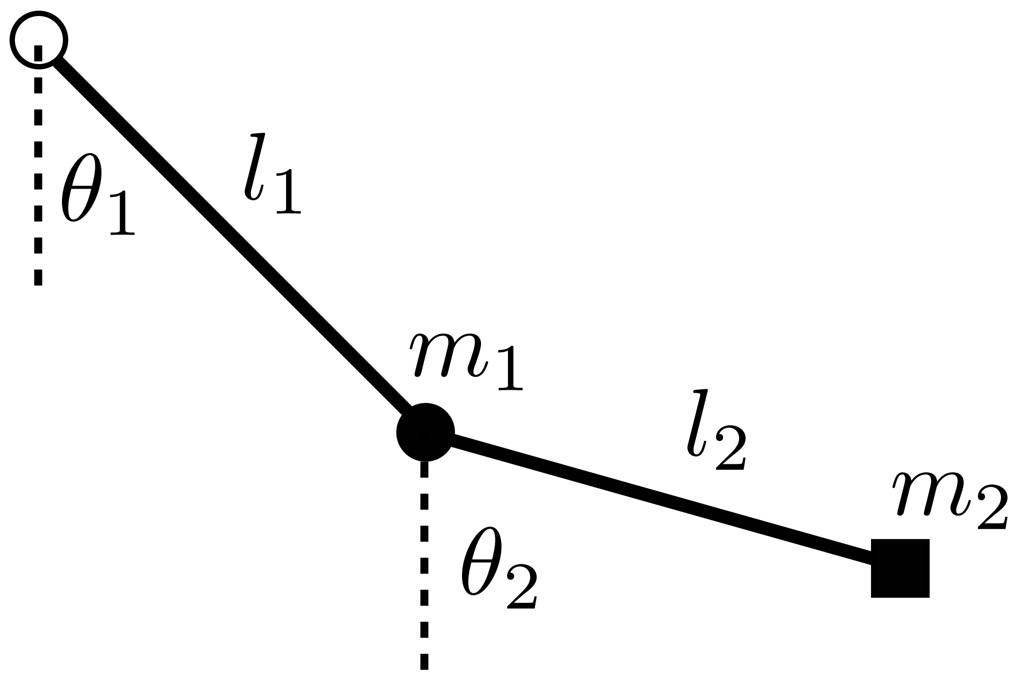
SIMULINK VERIFICATION
What Can We Do?

1. Checking against conservation laws

2. Running simple parameter cases where behaviour can be predicted from simple calculations or analytical solutions

3. Simulink’s testing tools

SIMULINK VERIFICATION
Conservation Of Energy Example



Potential Energy + Kinetic Energy = Constant

$$m_1 g y_1 + m_2 g y_2 + 1/2 m_1 v_1^2 + +1/2 m_2 v_2^2 = Constant$$

SIMULINK VERIFICATION
Using 1/4 Car As An Example

Default data:

$$m_1 = 250\,\text{kg}, m_2 = 20\,\text{kg}, k_S = 2\times10^4\ \text{N/m}, c_S = 1000\,\text{Ns/m}, k_T = 14\times10^4\ \text{N/m}$$

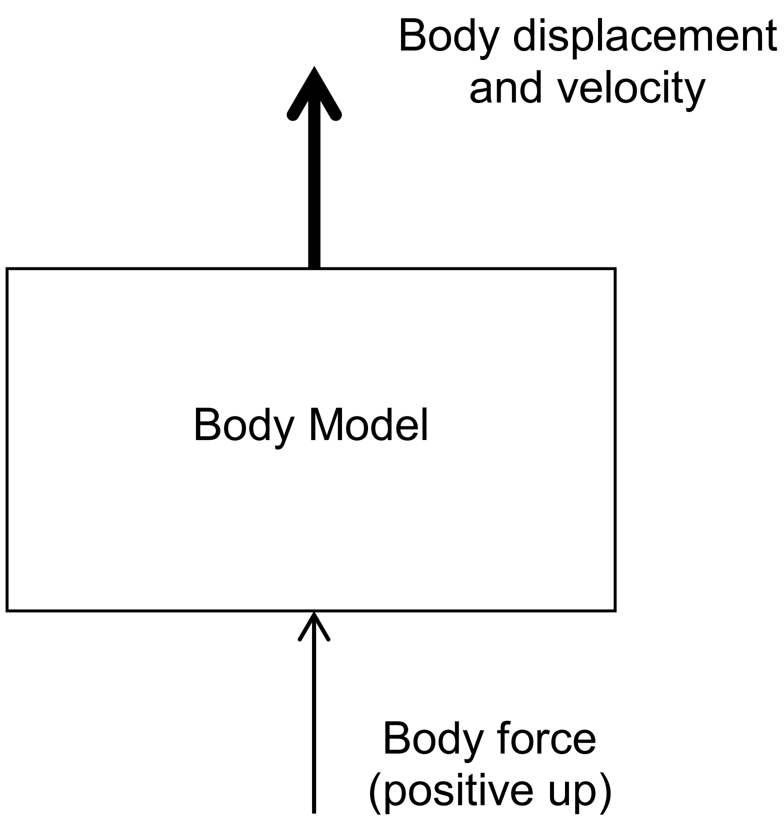
As part of the verification process, we are at liberty to change these parameters for particular tests

We have shown how to write the system in terms of three sub-models
- can test each sub-model individually

Assume linear components

SIMULINK VERIFICATION
Car Body Subsystem

1. Apply zero force as input with zero initial conditions. The expected output is that the body will fall under gravity with a negative parabolic trajectory for body displacement and a corresponding linearly decreasing negative velocity

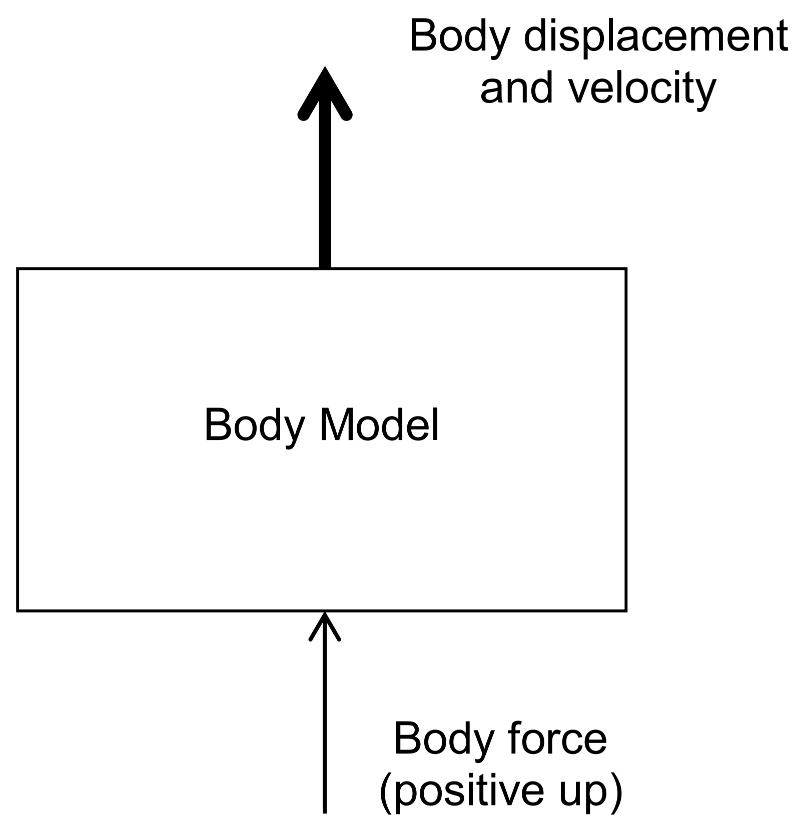


$$m_1 \ddot{s}_1 = F - m_1 g$$

SIMULINK VERIFICATION
Car Body Subsystem

1. Apply zero force as input with zero initial conditions. The expected output is that the body will fall under gravity with a negative parabolic trajectory for body displacement and a corresponding linearly decreasing negative velocity

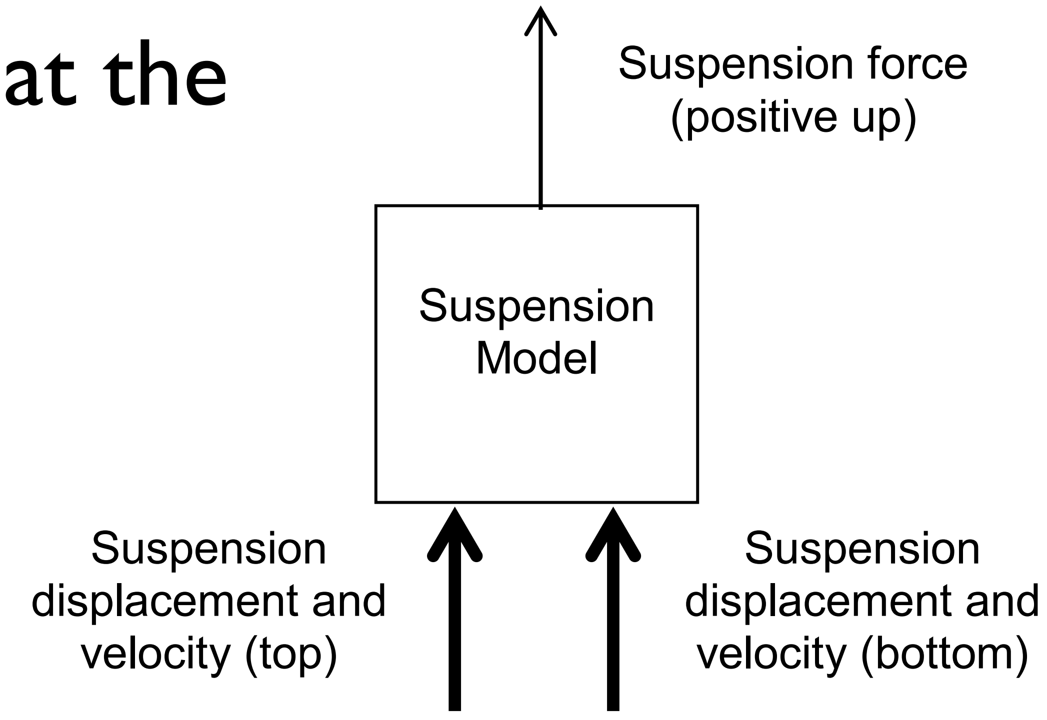
2. With zero initial conditions, apply a force input that is equal and opposite to the body weight. The expected output is that both displacement and velocity should be zero



$$m_1 \ddot{s}_1 = F - m_1 g$$

SIMULINK VERIFICATION
Suspension Subsystem

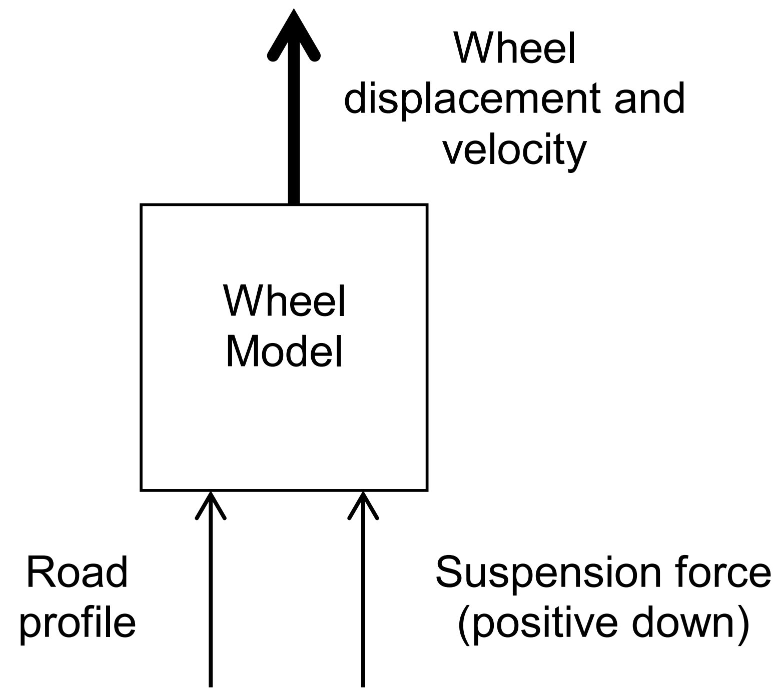
1. Apply unit values to each displacement and velocity input in turn, checking that the output force values are as expected



$$F = -k_S(s_1 - s_2) - c_S(\dot{s}_1 - \dot{s}_2)$$

SIMULINK VERIFICATION
Wheel Subsystem

1. With $k_T = 0$, similar tests as for the car body subsystem could be applied

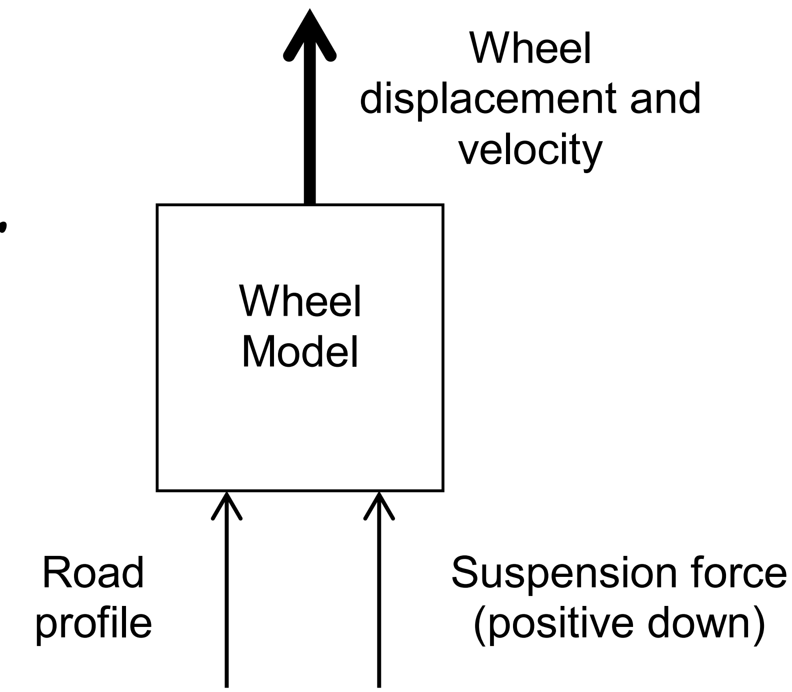


$$m_2\ddot{s}_2 = -F + k_T(r - s_2) - m_2 g$$

SIMULINK VERIFICATION
Wheel Subsystem

1. With $k_T = 0$, similar tests as for the car body subsystem could be applied

2. With $k_T \neq 0, F = 0, g = 0$, a step input in r from 0 to 1 should result in oscillations at an angular frequency $\sqrt{k_T / m_2}$, the mean value of s_2 being 1 and the mean value of $\dot{s}_2$ being 0



$$m_2 \ddot{s}_2 = -F + k_T (r - s_2) - m_2 g$$

Note: ordinary frequency $f = \dfrac{\omega}{2\pi}$

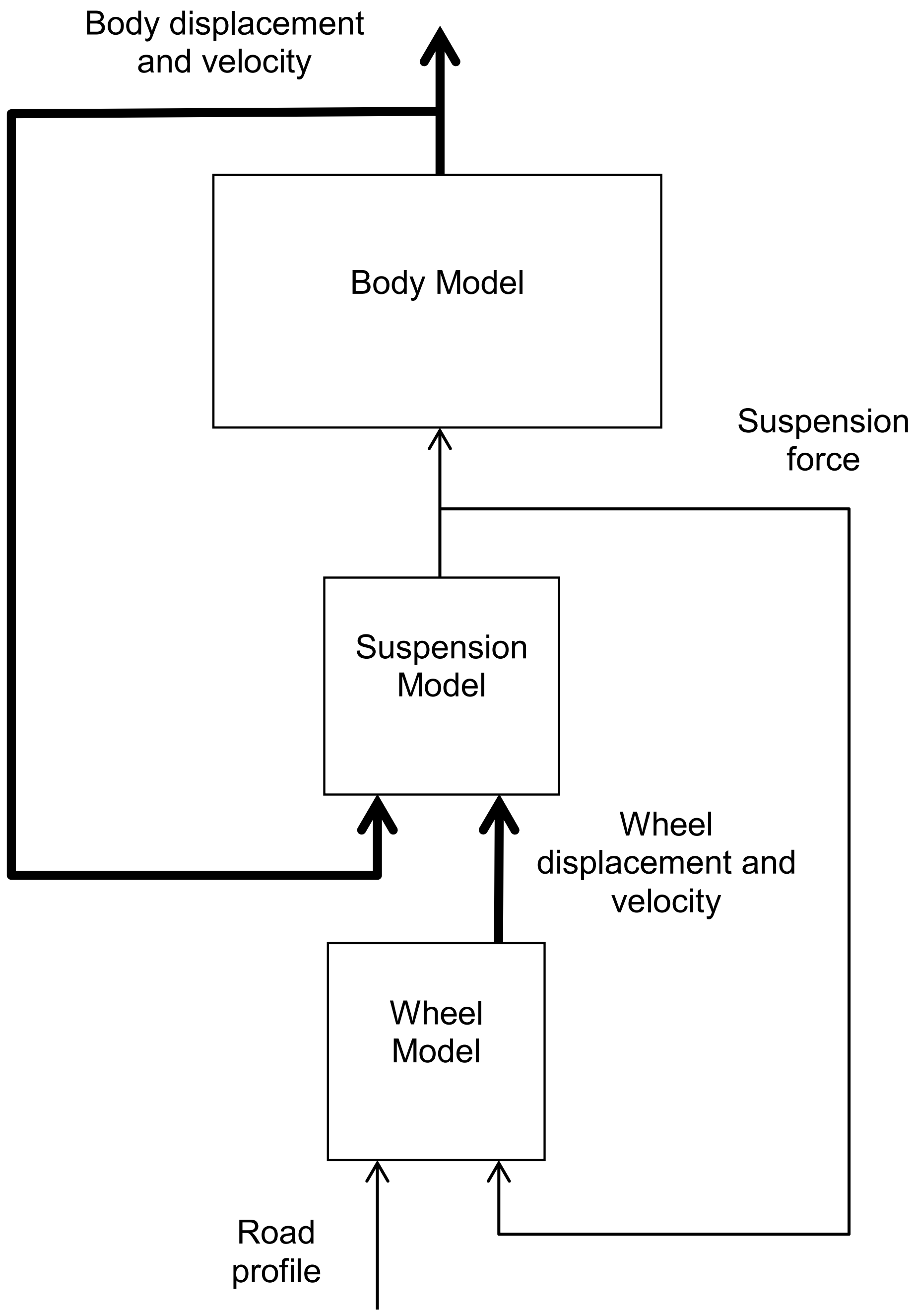
SIMULINK VERIFICATION
Complete 1/4 Car Model

1. With r=0, the wheel should settle to a displacement at which the tyre supports the whole vehicle weight:

$$s_2 = -(m_1 + m_2)g/k_T$$

2. The suspension spring should support the car body weight:

$$s_1 = -m_1 g/k_S + s_2$$

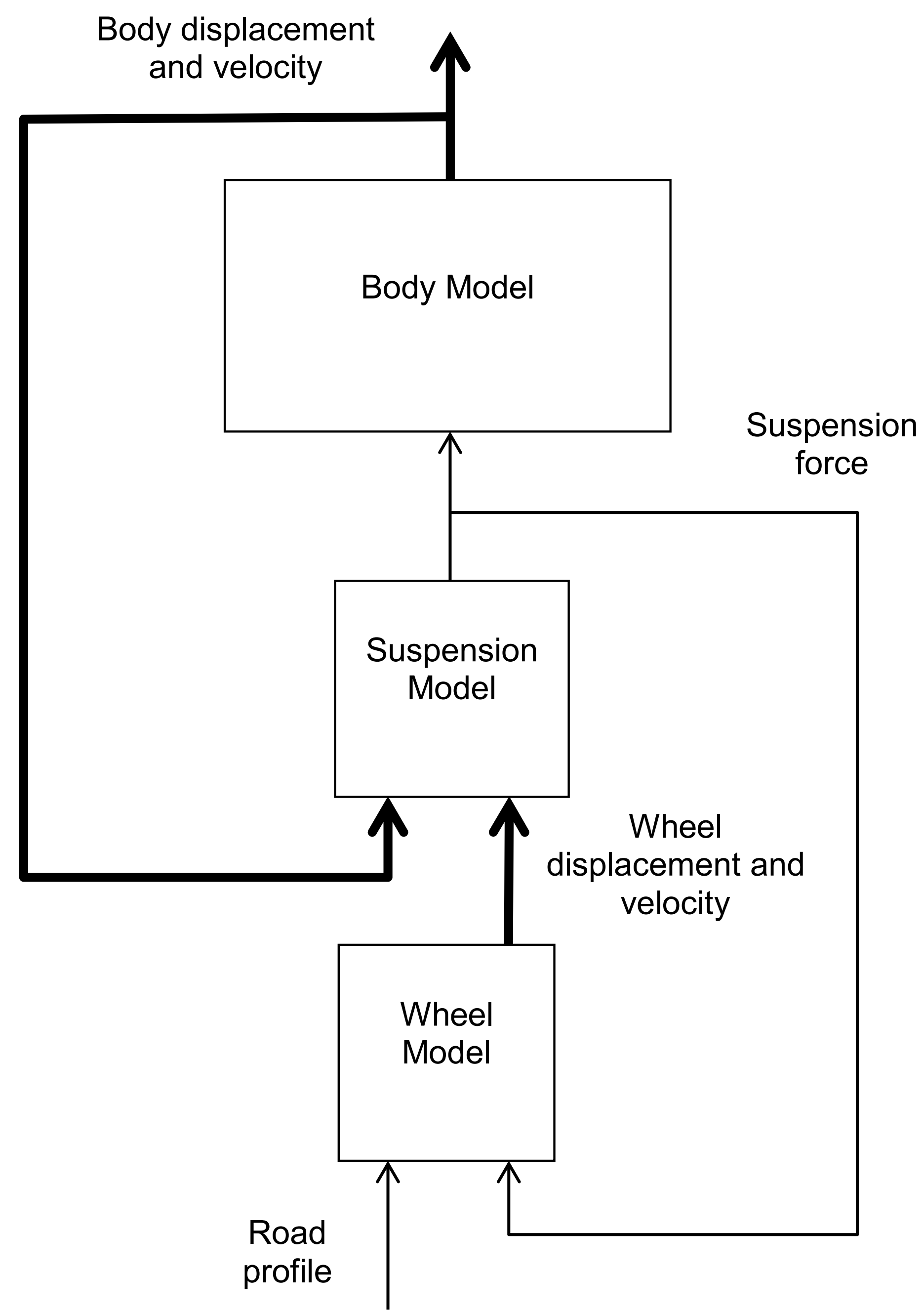


Complete 1/4 Car Model

1. Set k_S or c_S to be large values such that the body and wheel masses are effectively a single mass.

Under a step input in r from 0 to 1, both masses should oscillate with a peak amplitude of 1 at the natural frequency:

$$\sqrt{k_T/(m_1+m_2)}$$

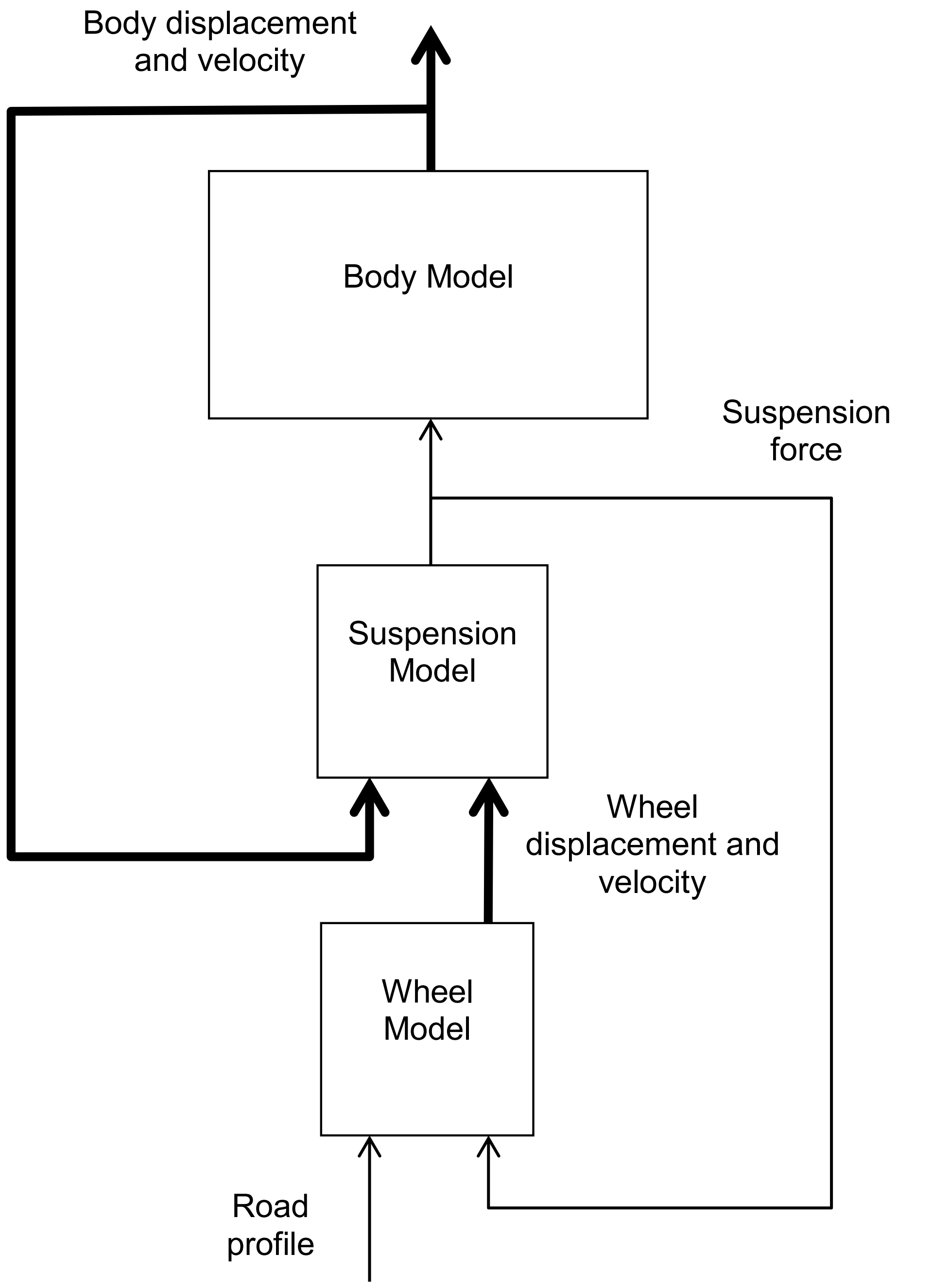


SIMULINK VERIFICATION
Complete 1/4 Car Model

1. Set k_T to be an abnormally high value and set m_2 to be very small (but non-zero). Under a step input in r from 0 to 1, the body mass should oscillate at the natural frequency $\sqrt{k_S/m_1}$ (if $c_s = 0$) with a peak amplitude of 1.

If a suspension damper has a non-zero rate, the oscillations should decay.

The wheel mass should follow closely the step input.



You could check these types of outputs manually or...

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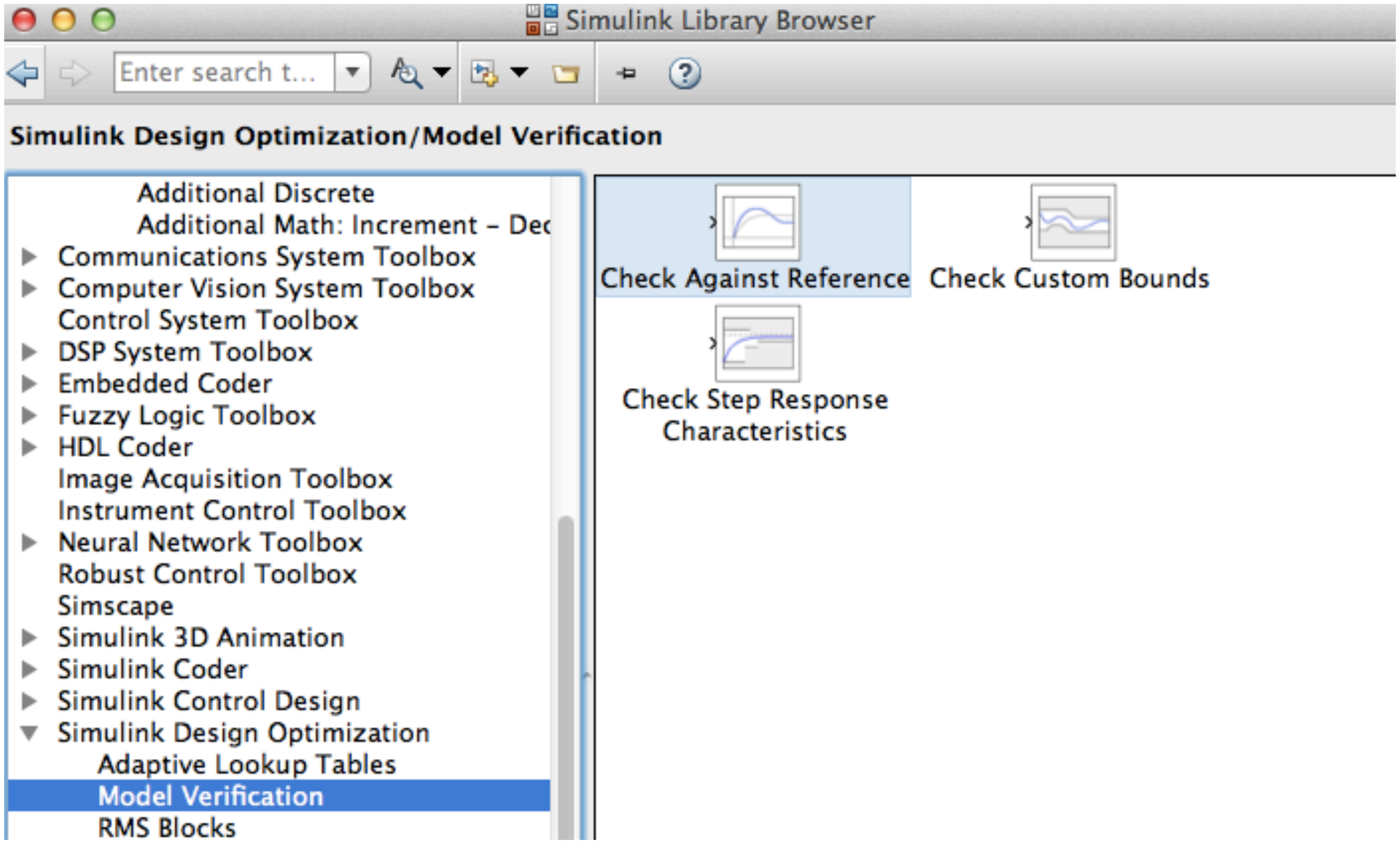
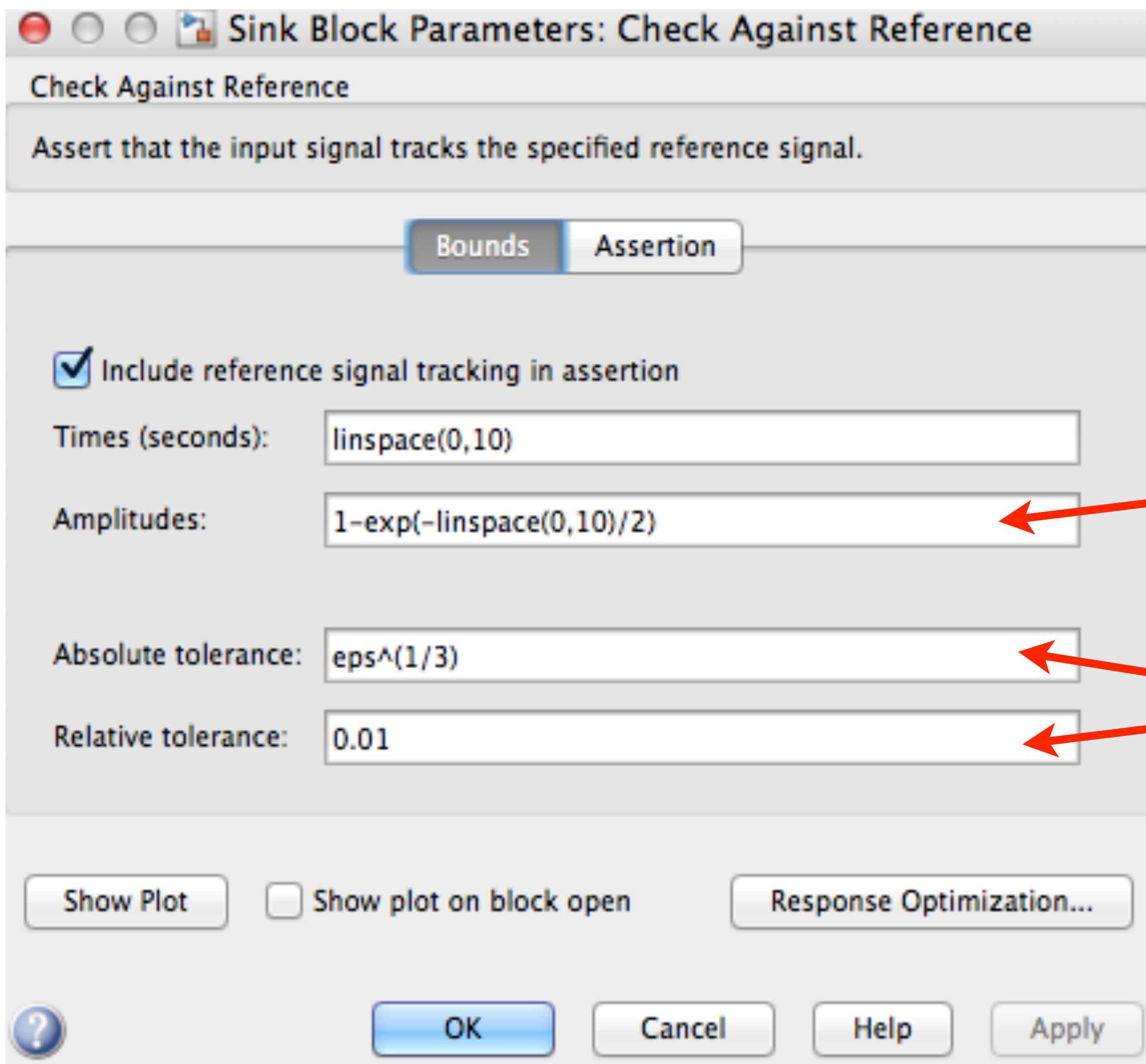
Simulink Design Optimisation
Model Verification



Model Verification

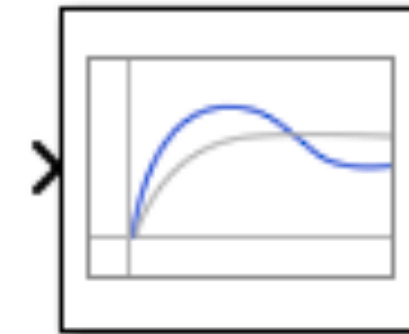
Check Against Reference

https://uk.mathworks.com/help/sldo/ref/checkagainstreference.html



Data to compare against

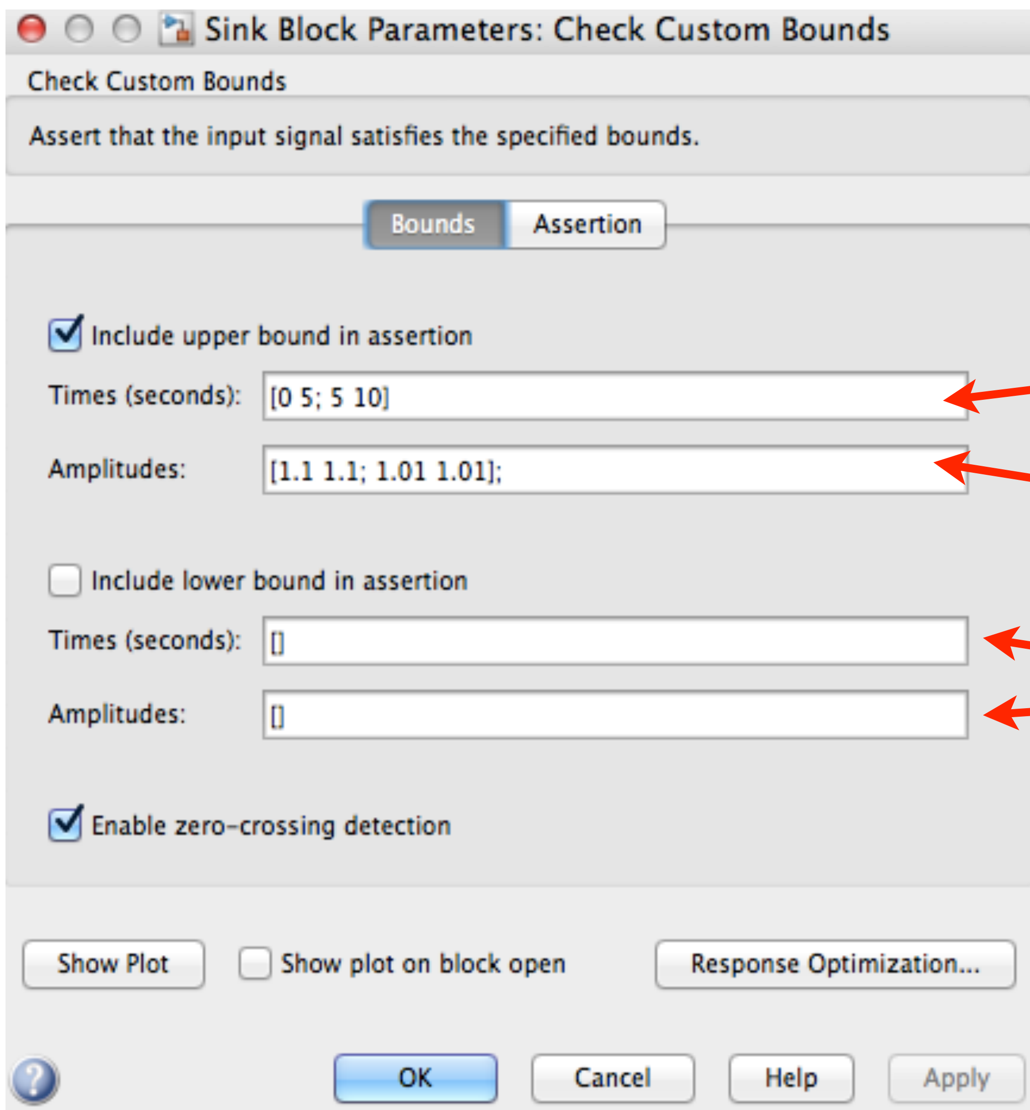
Tolerance settings

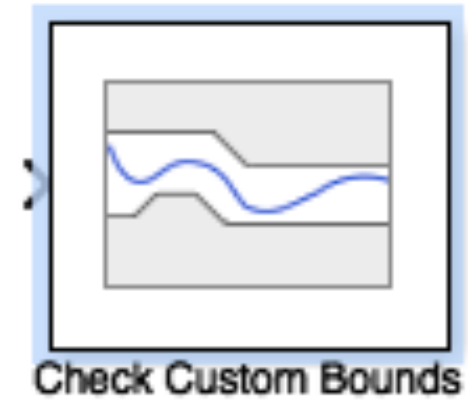


Check Against Reference

Model Verification
Check Custom Bounds

https://uk.mathworks.com/help/sldo/ref/checkcustombounds.html





Vector of time values for the bounds to hold

Bound values

Settings for lower bounds

SIMULINK VERIFICATION
Further Reading

Simulink Verification, Validation, and Test:

https://uk.mathworks.com/solutions/verification-validation.html

Using Unit Tests in Simulink:

https://uk.mathworks.com/help/sltest/ug/run-test-files-using-matlab-unit-test.html