



## **SYSTEM DYNAMICS AND SYSTEM CONTROLS USING ALTAIR ACTIVATE**

Patrick Goulding, Application Engineer

# Agenda

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**System Dynamics and System Controls using  
Altair Activate**

- 1 Activate Overview
- 2 Physical Component Modeling
- 3 Vehicle Dynamics
- 4 Vehicle Energy Management
- 5 Learning Resources

# WHAT IS ALTAIR ACTIVATE?

# Open and flexible integration platform



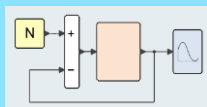
## MODELING LANGUAGES

### Scripts

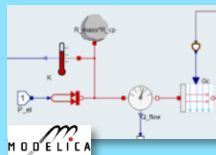


0D

### Signal blocks



### Physical components



1D

### Electric/ Electronics



spice

## CO-SIMULATION

### Multibody Dynamics



NATIVE (3D)

### Electro-magnetics



### Standards



3<sup>rd</sup> PARTIES  
(1D-3D)

# Open and flexible integration platform



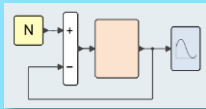
## MODELING LANGUAGES

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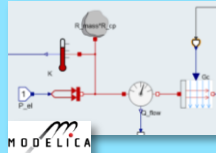


0D

### Signal blocks

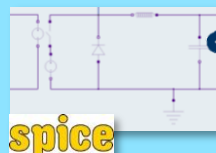


### Physical components



1D

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spice



### Multibody Dynamics



## CO-SIMULATION

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NATIVE (3D)

### Standards



3<sup>rd</sup> PARTIES  
(1D-3D)

0D

to

1D

to

3D

# Open and flexible integration platform

LINEARIZATION



Altair Activate™



OPTIMIZATION



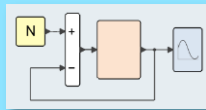
MODELING LANGUAGES

Scripts

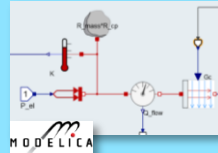


0D

Signal blocks

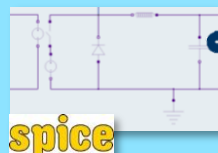


Physical components



1D

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Multibody Dynamics



NATIVE (3D)

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Standards



3rd PARTIES  
(1D-3D)

0D

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# Open and flexible integration platform

LINEARIZATION



Altair Activate™



OPTIMIZATION

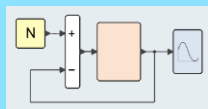


MODELING LANGUAGES

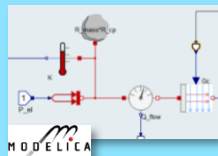
Scripts



Signal blocks



Physical components



Electric/Electronics



Multibody Dynamics



Electro-magnetics



Standards



0D

1D

NATIVE (3D)

3rd PARTIES  
(1D-3D)

0D

to

1D

to

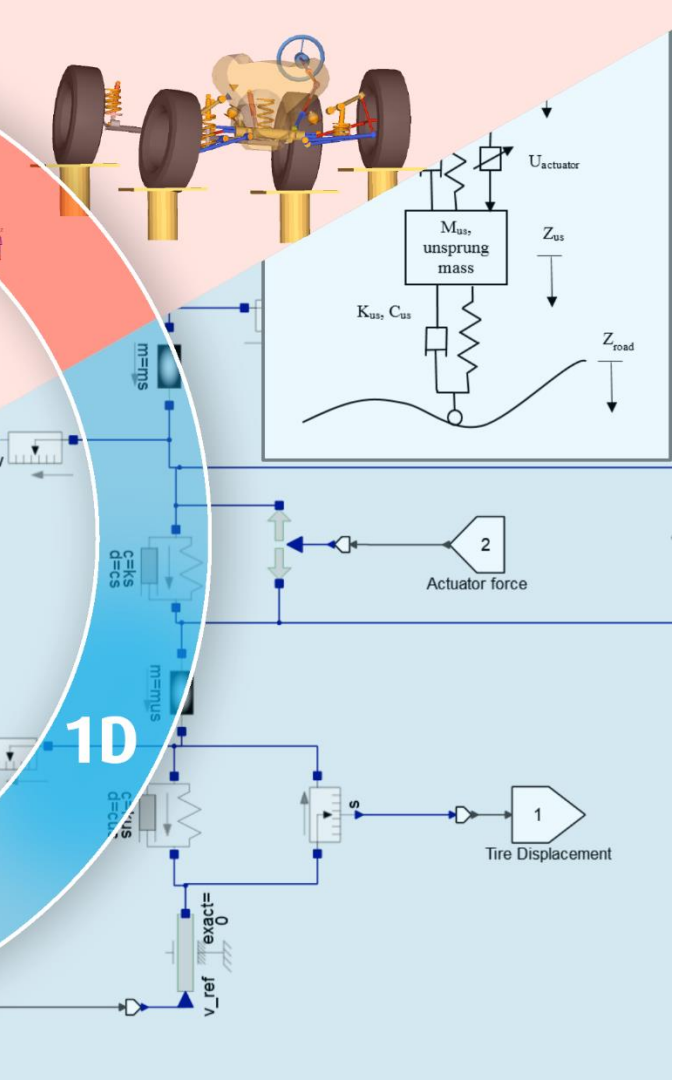
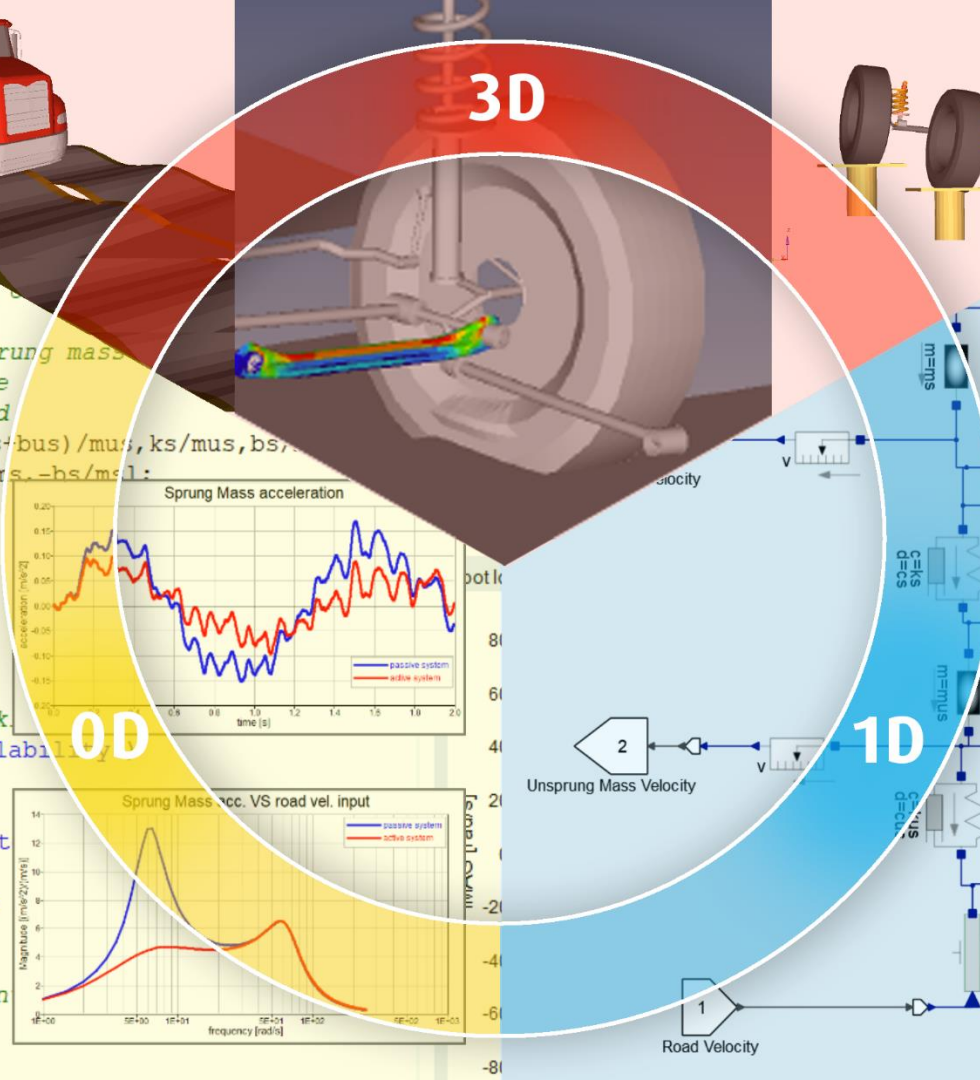
3D



```

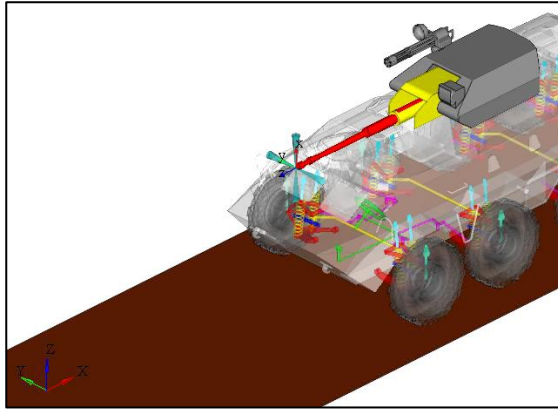
3  m
4  mus = 3000;
5  kus = 30000;
6  ks = 30000;
7  bs = 3000; %N/(m/s)
8  bus = 0; %N/(m/s)
9
10 %=====not
11 %x(1) = tire deflection
12 %x(2) = velocity of unsprung mass
13 %x(3) = suspension stroke
14 %x(4) = sprung mass speed
15 A = [0,1,0,0;-kus/mus,-(bs+bus)/mus,ks/mus,bs/mus;
16       0,-1,0,1;0,bs/ms,-ks/ms,-bs/ms];
17 Br = [-1;bus/mus;0;0];
18 C = eye(size(A));
19 D = 0;
20
21 sys = ss(A,Br,C,D);
22 p = pole(sys);
23
24 %=====check
25 printf(' checking controllability\n');
26 pause()
27 if isctrb(sys)
28     disp('Controllable system')
29 else
30     disp('Not controllable')
31 end
32
33 %=====con
34
35 Bu=[0;1/mus;0;-1/ms];

```

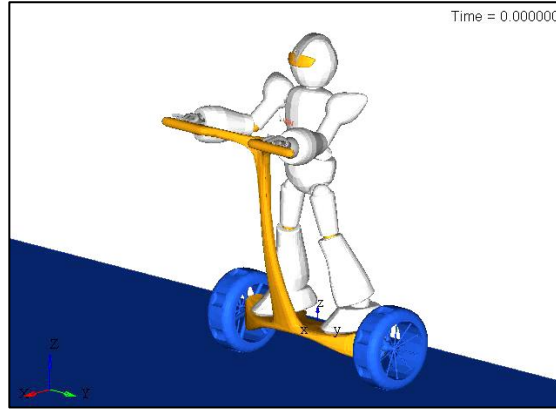




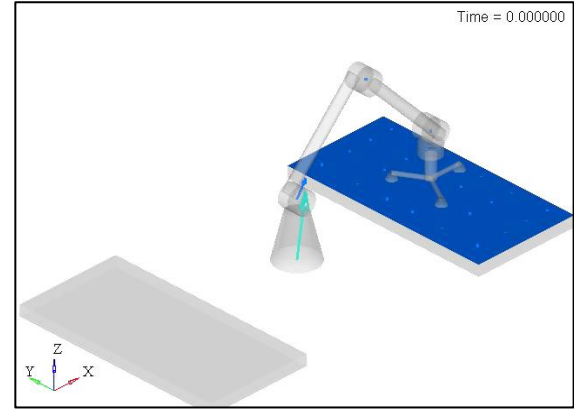
# Examples of Multi-Disciplinary System Simulations (3D+1D+0D)



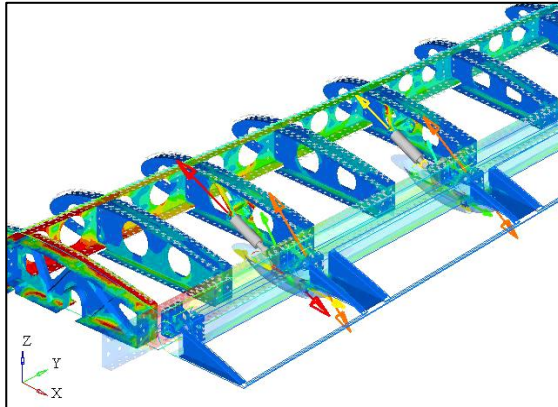
Multi-body, Controls



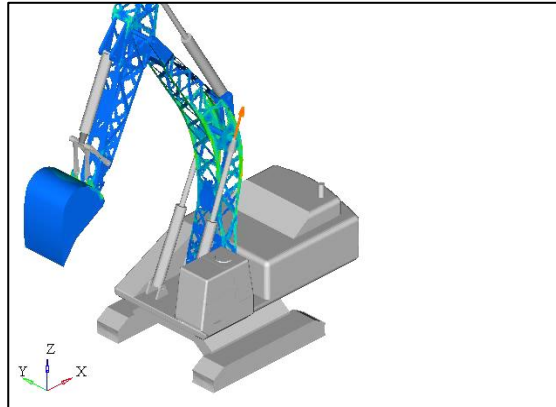
Motors, Multi-body, Controls



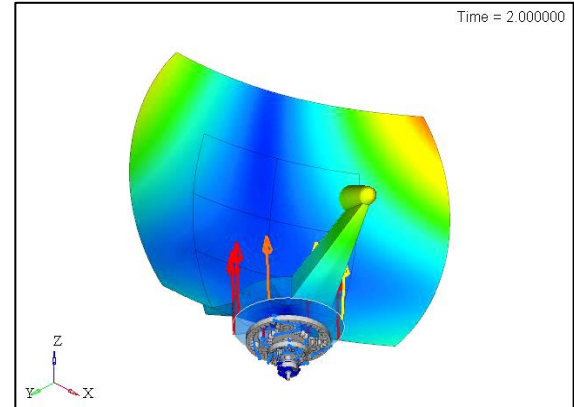
Structural, Motors, Multi-body, Controls



Light-weighting, Structural, Multi-body



Hydraulics, Light-weighting, Structural, Multi-body



CFD, EMag, Structural, Motors, Multi-body, Controls



# Multi-Body: Different levels of fidelity



Altair Activate

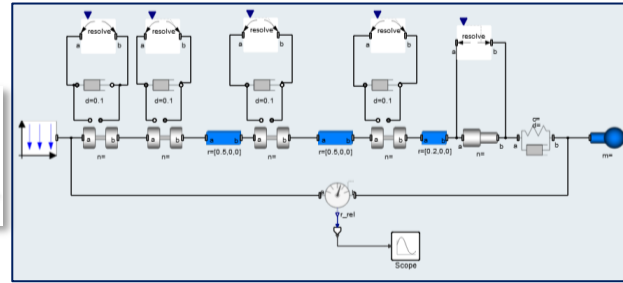
Altair Compose

```

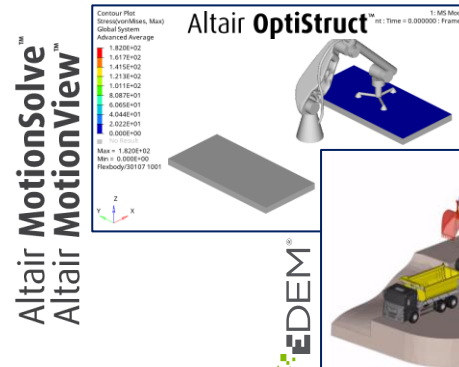
clc,clear,close all;
%-----system parameters
ms = 750; %kg
mus = 75; %kg
kus = 300000; %N/m
ks = 30000; %N/m
bs = 3000; %N/(m/s)
bus = 0; %N/(m/s)
A = [0,1,0,0,-kus/mus,-(bs+bus)/mus,ks/mus,bs/mus;...
     0,-1,0,1,0,bs/ms,-ks/ms,-bs/ms];
Br = [-1;bus/mus;0;0];
C = eye(size(A));
D = 0;

sys = ss(A,Br,C,D);
p = pole(sys);
  
```

EQUATIONS



DIAGRAMS



CAD

• Requirements specification

0D

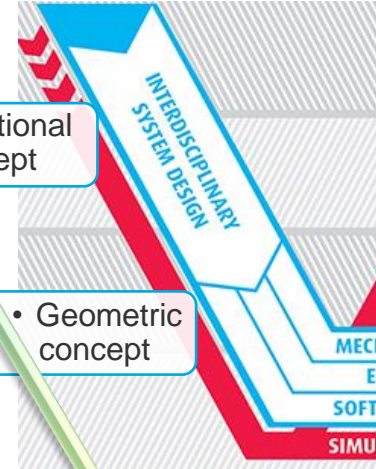
• Functional concept

(0D)-1D

• Geometric concept

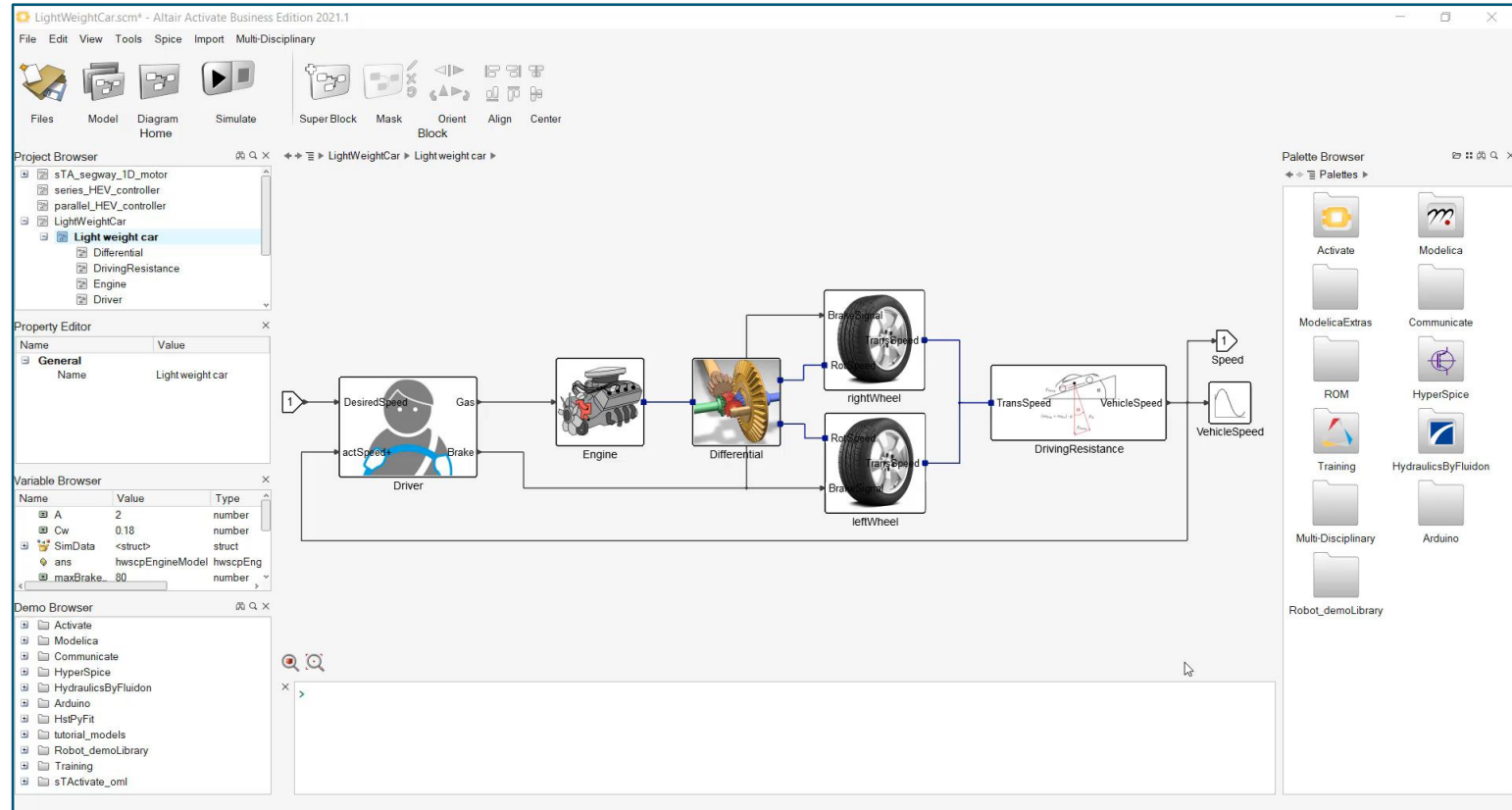
• Detailed Design, Optimization

(0D-1D)-3D  
co-simulation



# Altair Activate

## Tour of the User Interface



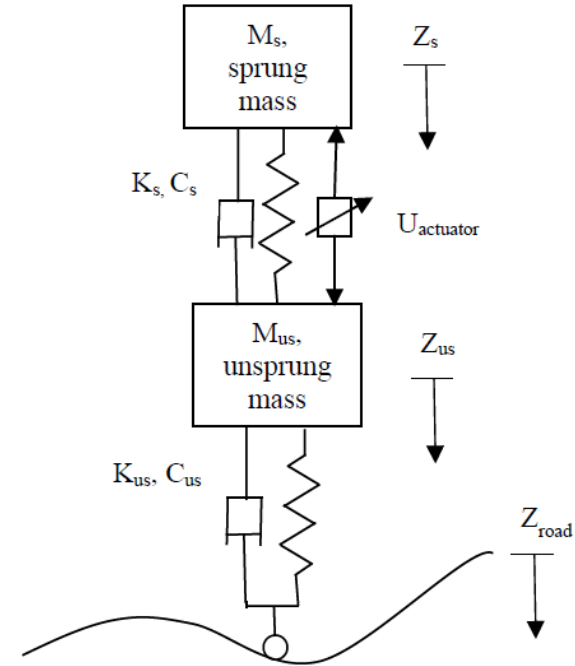
# MECHANICAL MODELING EXAMPLE

## Example: Active Suspension

Quarter-car: passive system only

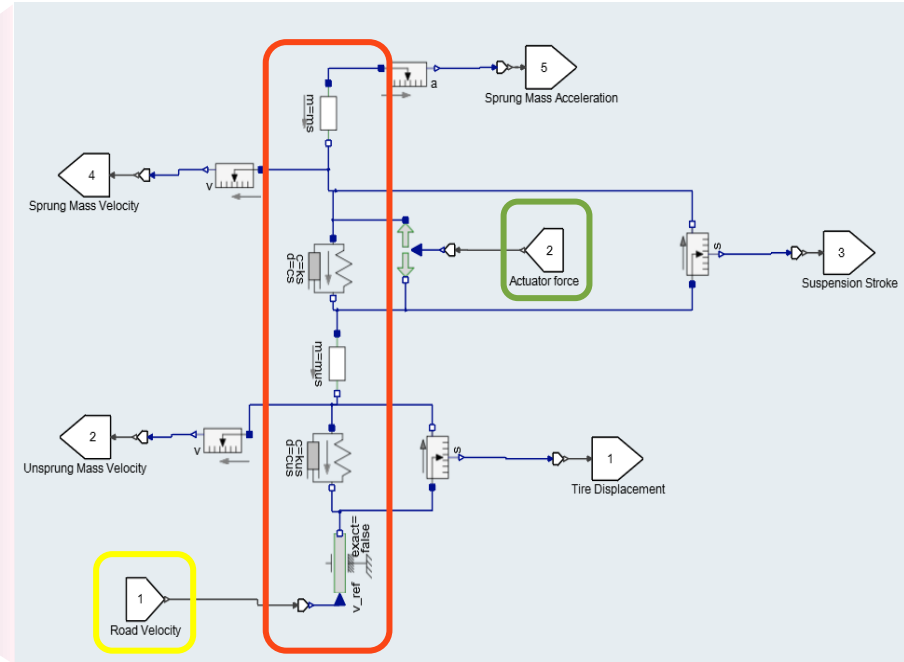
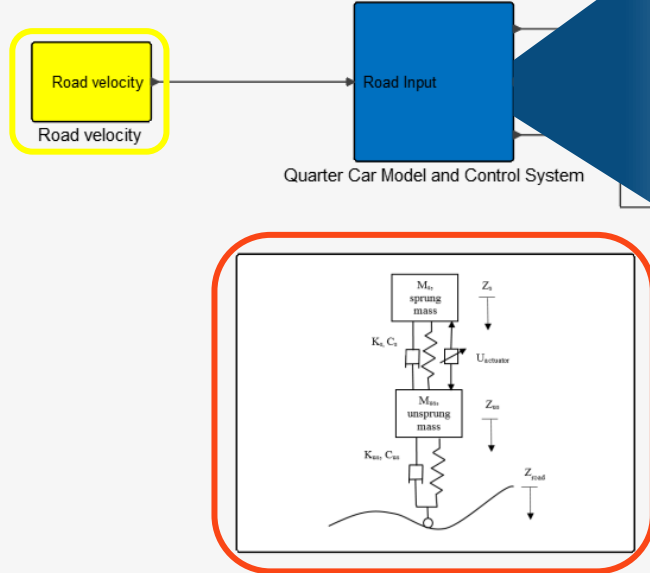
Description of system states:

- Tire deflection:  $Z_{us} - Z_{road}$
- Unsprung mass velocity:  $d(Z_{us})/dt$
- Suspension stroke:  $Z_s - Z_{us}$
- Sprung mass velocity:  $d(Z_s)/dt$



# Example: Active Suspension (modeling with Modelica)

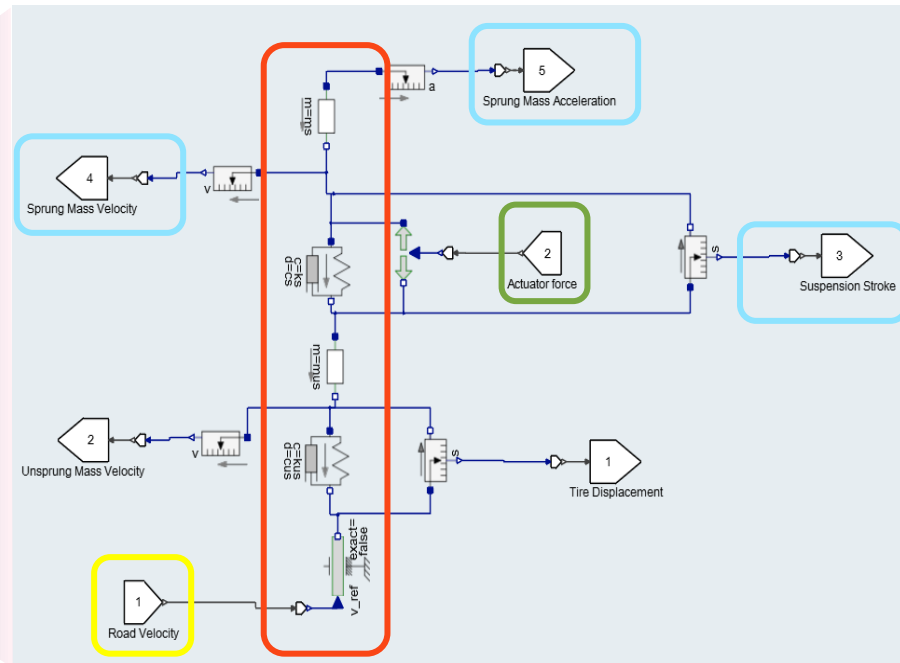
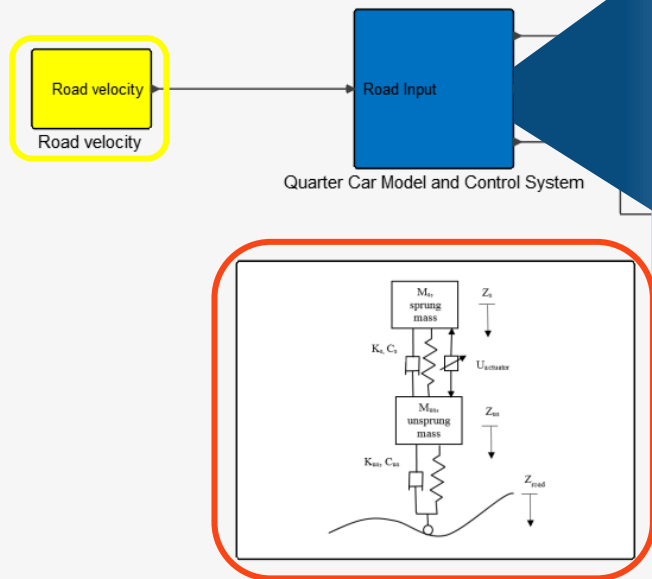
Quarter Car with Active Suspension



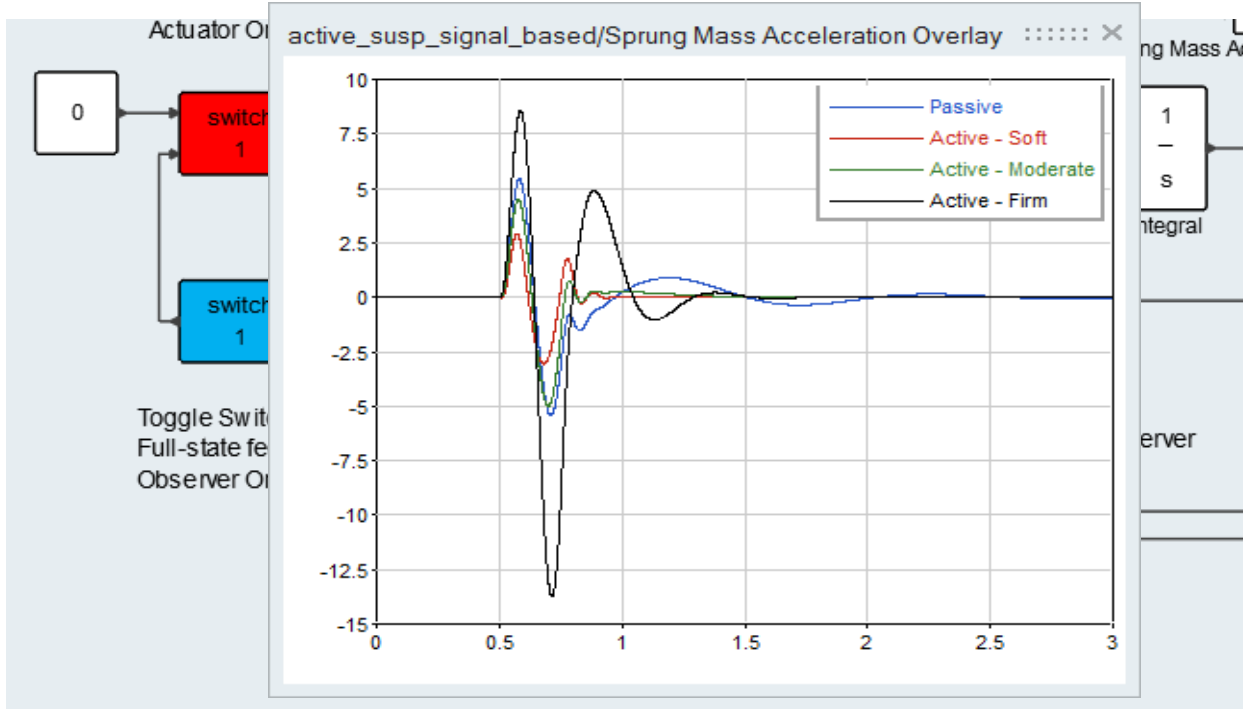


# Example: Active Suspension (modeling with Modelica)

Quarter Car with Active Suspension



# Example: Active Suspension (Controls)



Linear Quadratic Regulator (LQR) control using *LQR()* function in Control library

```
//suspension tuning choice
choice = 'soft'
choice = 'moderate'
choice = 'firm'

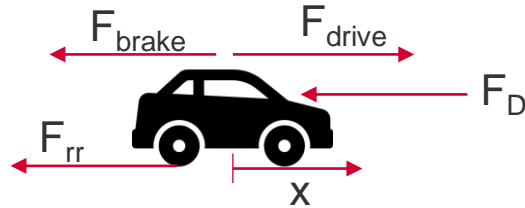
if choice == 'soft' then
    print("soft ride")
    Q = C'*C // need square matrix
    Q(1,1) = 1E3; // weight for tire deflection
    Q(2,2) = 10; //velocity of unsprung mass
    Q(3,3) = 10; // suspension stroke
    Q(4,4) = 1E2; //sprung mass speed
    R = 1; // weight for input force
```



# VEHICLE DYNAMICS

# Vehicle Dynamics

Simple car dynamics:



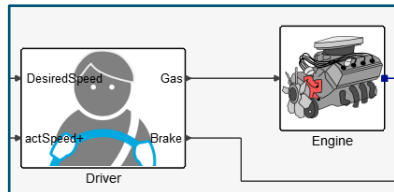
$$m\ddot{x} = F_{drive} - F_{brake} - F_{rr} - F_D$$

Driving force:

$$F_{drive} = \frac{1}{r} * M_{drive}$$

Drive torque :  $M_{drive} = 0$  to  $200$  Nm

Wheel radius:  $r = 0.275$  m



Brake force:

$$F_{brake} = \beta \frac{1}{r} * M_{brake}$$

Braking torque :  $M_{brake} = 3500$  Nm

Brake pedal position :  $\beta = 0$  to  $1$

Rolling friction:

$$F_{rr} = \mu_{rr} * m * g$$

Car mass :  $m = 1350$  kg

Rolling friction coefficient :  $\mu_{rr} = 0.015$

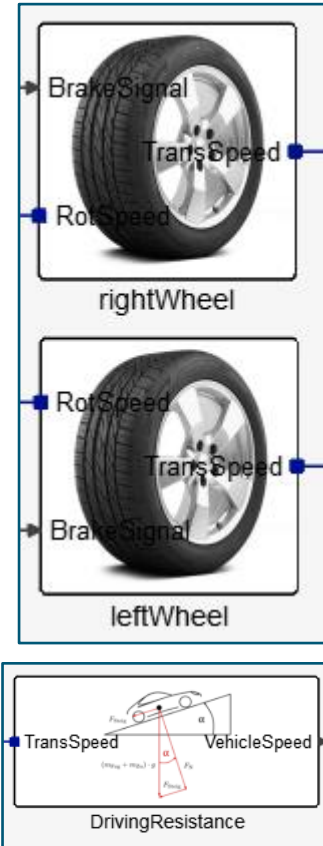
Drag:

$$F_D = \frac{1}{2} A * \rho * c_w * \dot{x}^2$$

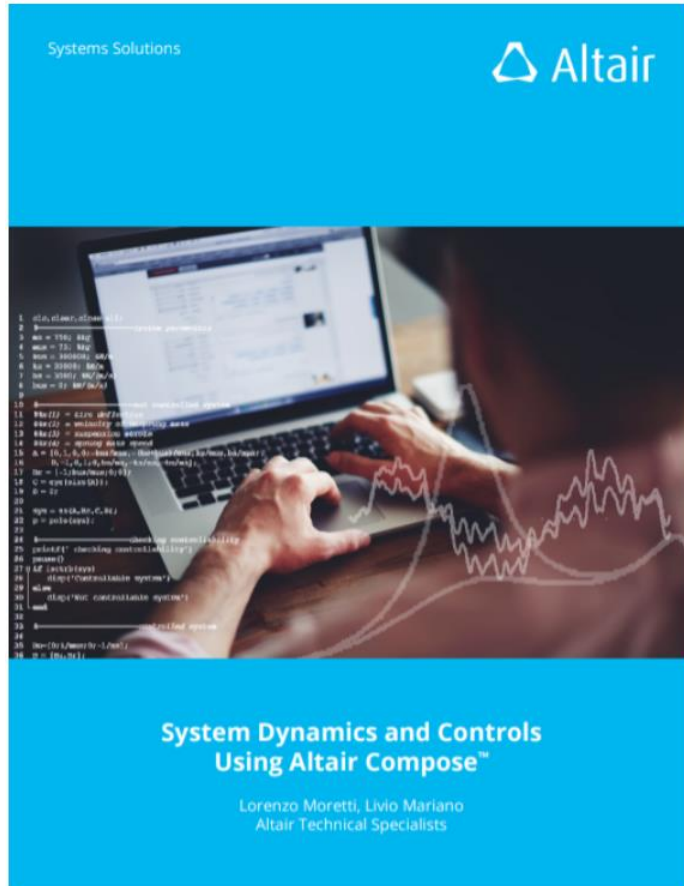
Cross sectional area :  $A = 2,14$  m<sup>2</sup>

Drag coefficient :  $c_w = 0.33$

Density of air :  $\rho = 1,204$  kg /m<sup>3</sup>



# E-book for System Dynamics and Controls Using Altair Compose



## Contents:

Introduction

System Dynamics

Linear and Nonlinear Systems

Continuous and Discrete Dynamics

Time-variant and Time-invariant

SISO, SIMO, MIMO, MISO

Continuous Dynamics

System Analysis

Control Theory

Discrete Dynamics

Discretization and State-Space Representation

Natural and Forced Response

Eigenvalues and Eigenvectors

Stability

z Transform

Initial and Final Value Theorems

z Transfer Function

Discretization of Continuous Transfer Function

Appendix

Asymptotic Bode Plot

Proportional-Integral-Derivative (PID) GUI

Transformation from s-Domain to z-Domain

Available for **free** download at **Altair University**

<https://altairuniversity.com/>

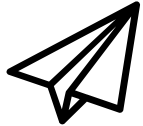




## Unique Tools for Systems Modeling

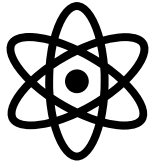
- Open
- Easy-to-use
- Seamlessly move from 0D/1D to 3D
- Leverage Altair's business model

[www.altair.com/systems-modeling-applications](http://www.altair.com/systems-modeling-applications)



## Products download

[www.altairuniversity.com](http://www.altairuniversity.com) | [www.connect.altair.com](http://www.connect.altair.com)



## Learning Center

<https://www.altair.com/learning-center/>



## Altair Forum

<https://community.altair.com>







# THANK YOU

[altair.com](https://altair.com)



#ONLYFORWARD