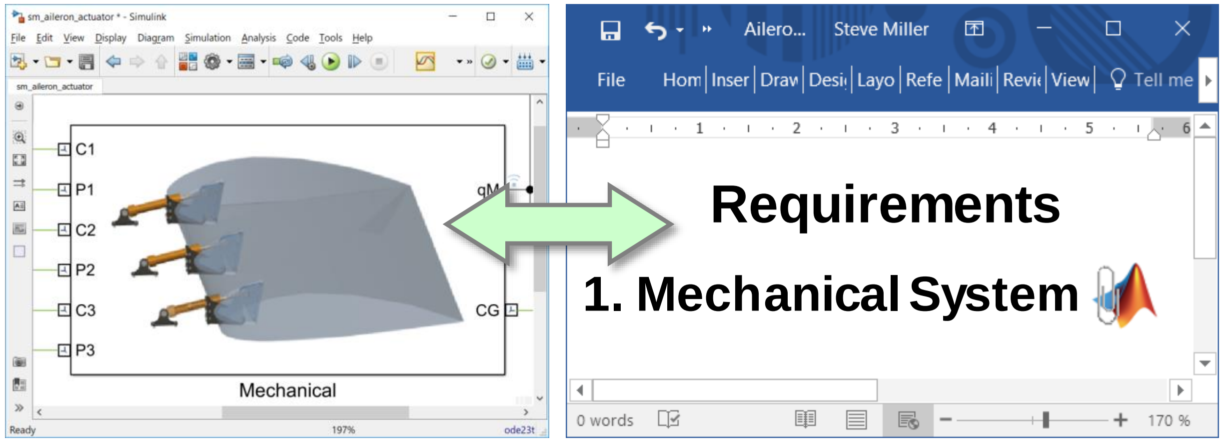
MATLAB EXPO 2018

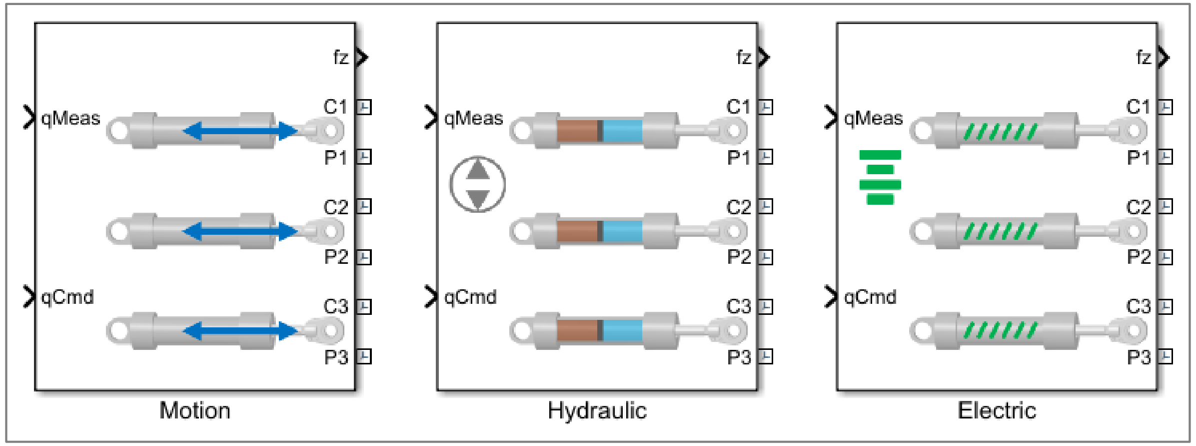
Master Class: Diseño de Sistemas Mecatrónicos

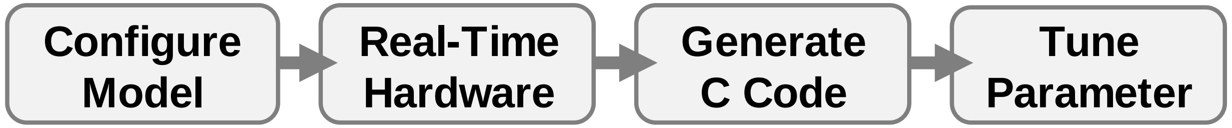
Luis López

Key Points

- Create intuitive models that all teams can share
- Simulate system in one environment to
  - Perform tradeoff studies
  - Optimise system performance
- Test without prototypes





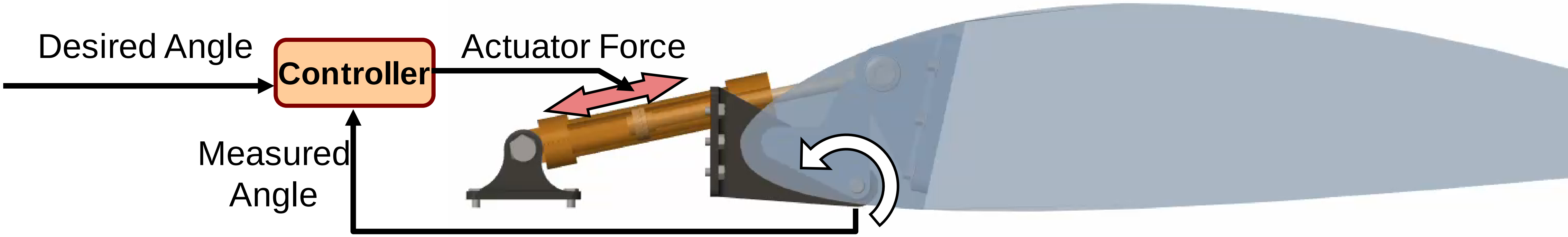


Agenda

- Example: Flight actuation system
  - Benefits of Model-Based Design
- Actuator design
  - Modeling the mechanical system
  - Determining actuator requirements
  - Testing Electrical and Hydraulic Designs
  - Tradeoff studies
- Optimizing System-Level Design
- HIL testing

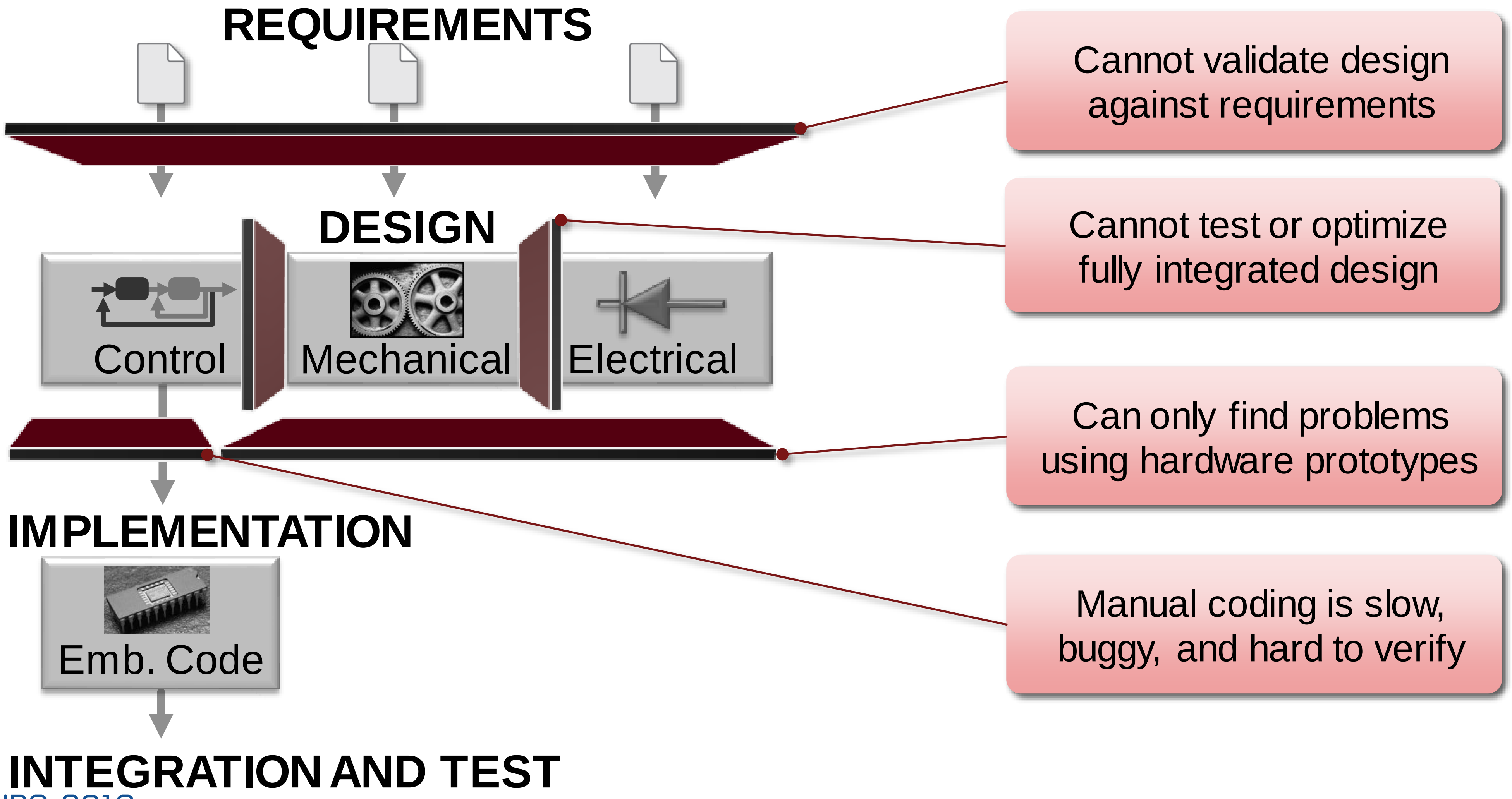
Example: Aileron Actuation System

- System

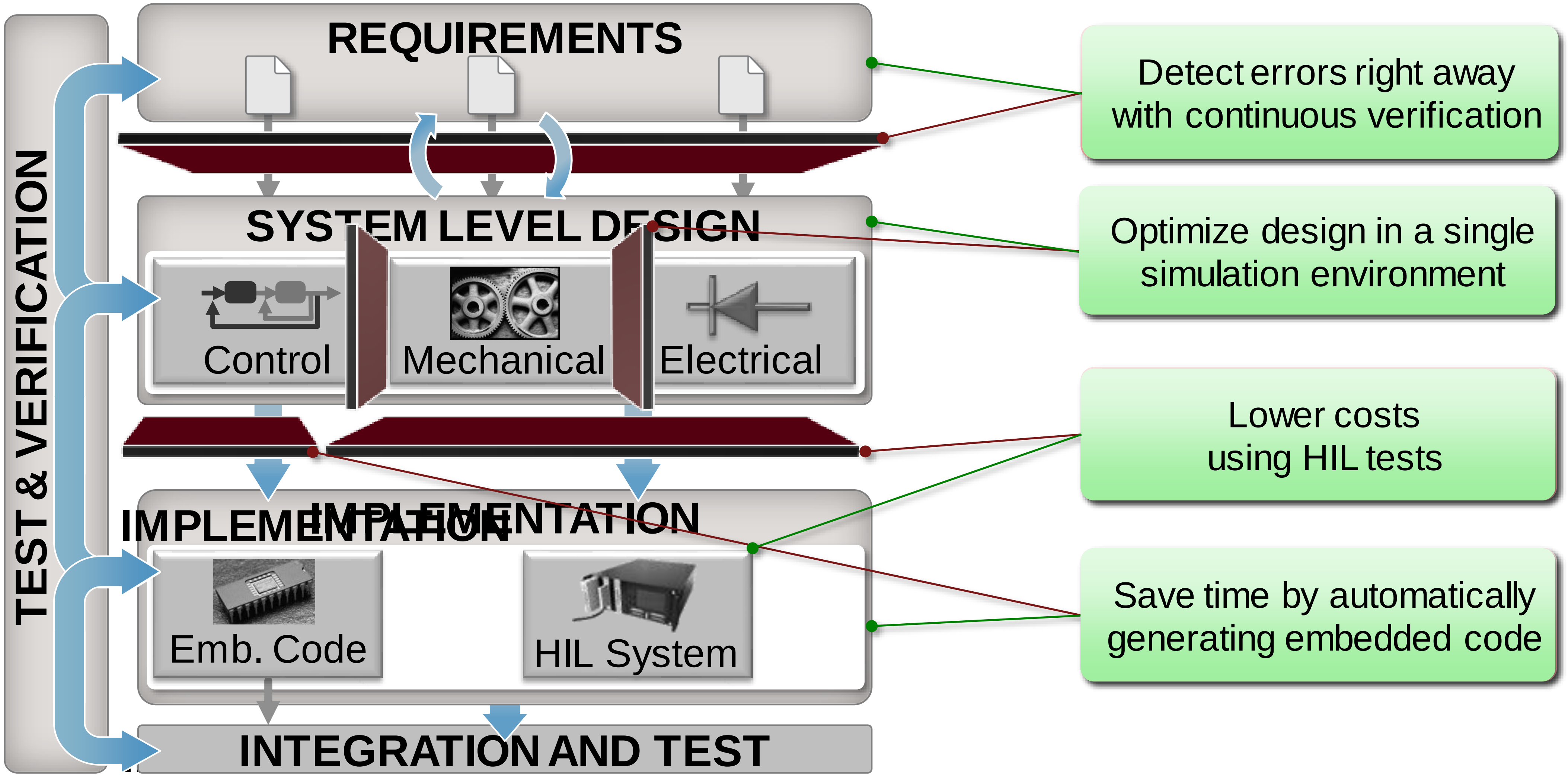


- Simulation goals
  1. Determine requirements for actuation system
  2. Test actuator designs
  3. Optimise system performance
  4. Run simulation on real-time hardware for HIL tests

Traditional Design Process



Model-Based Design



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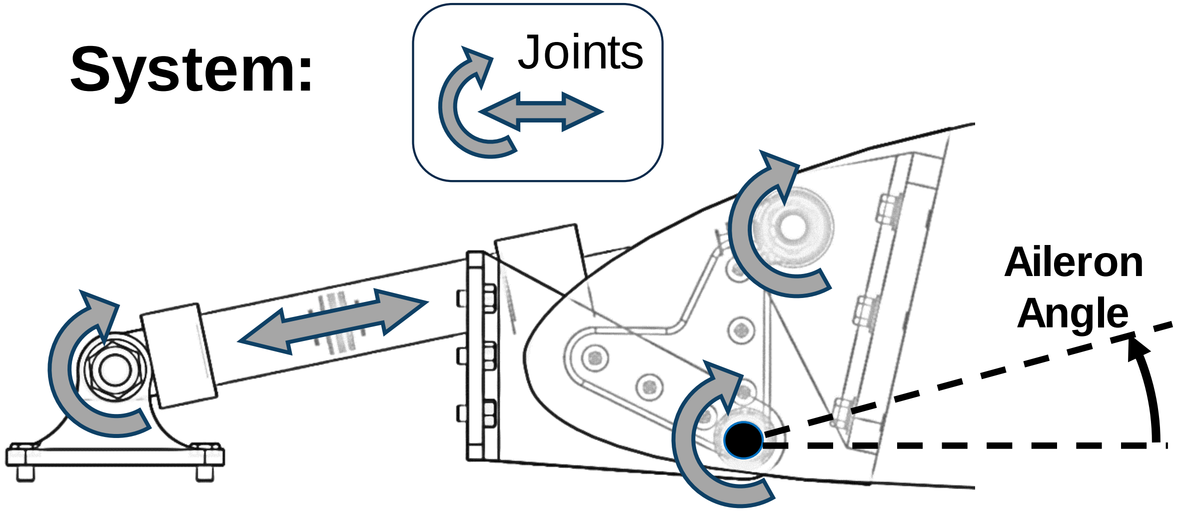
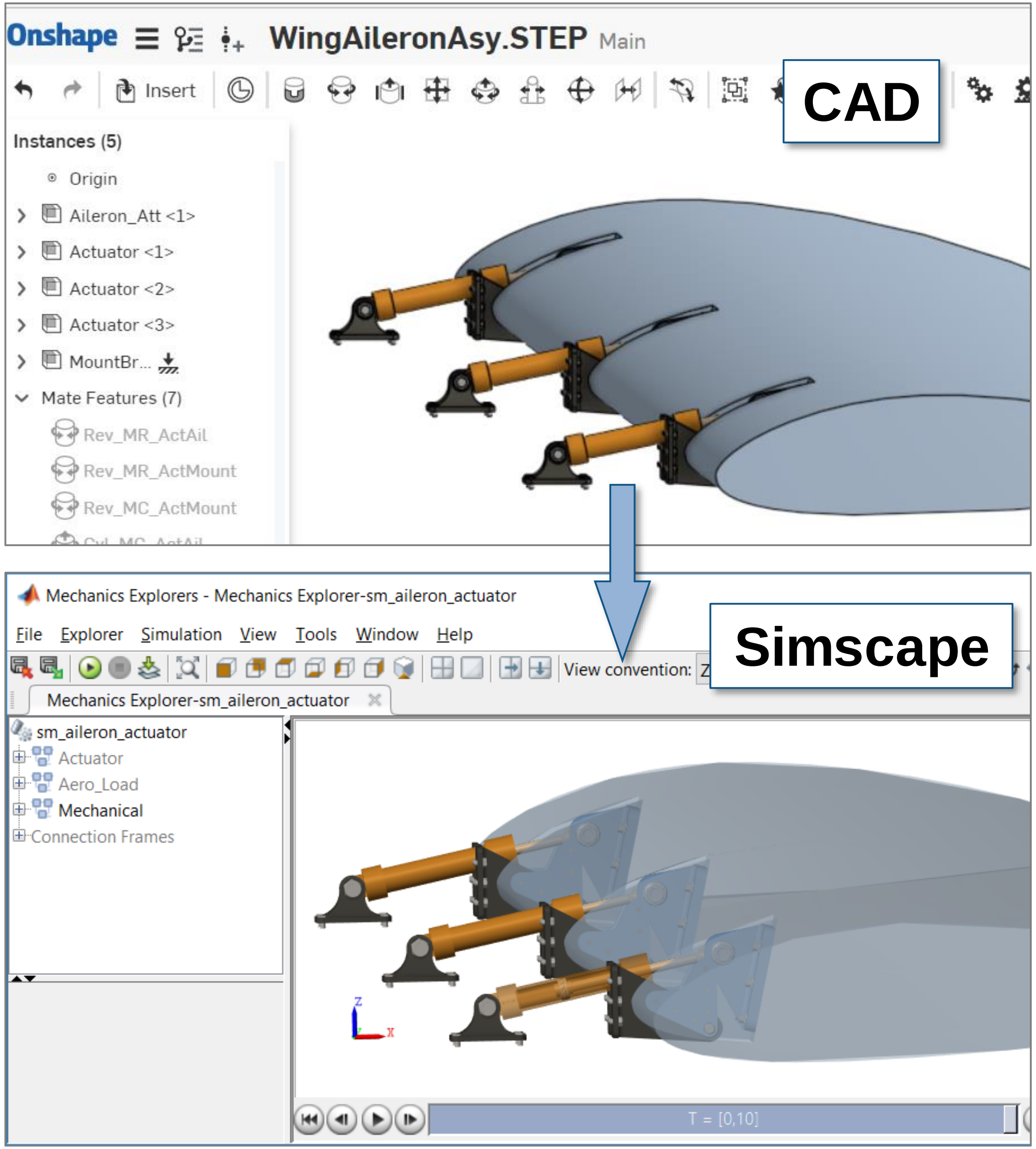
Modeling the Mechanical System

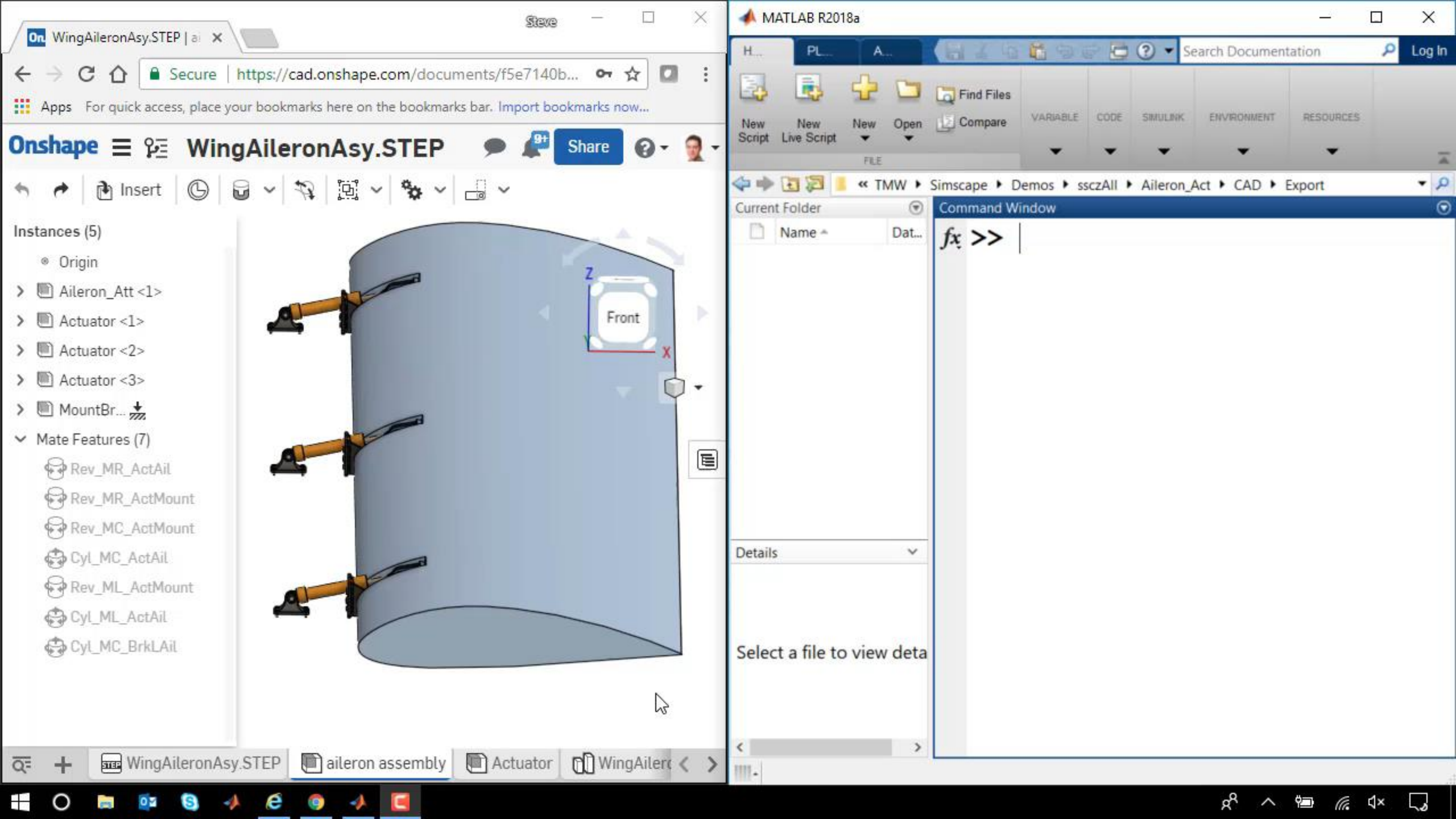
System:





Problem: Model the mechanical system within Simulink

Solution: Import the mechanical model from CAD into Simscape Multibody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Apps
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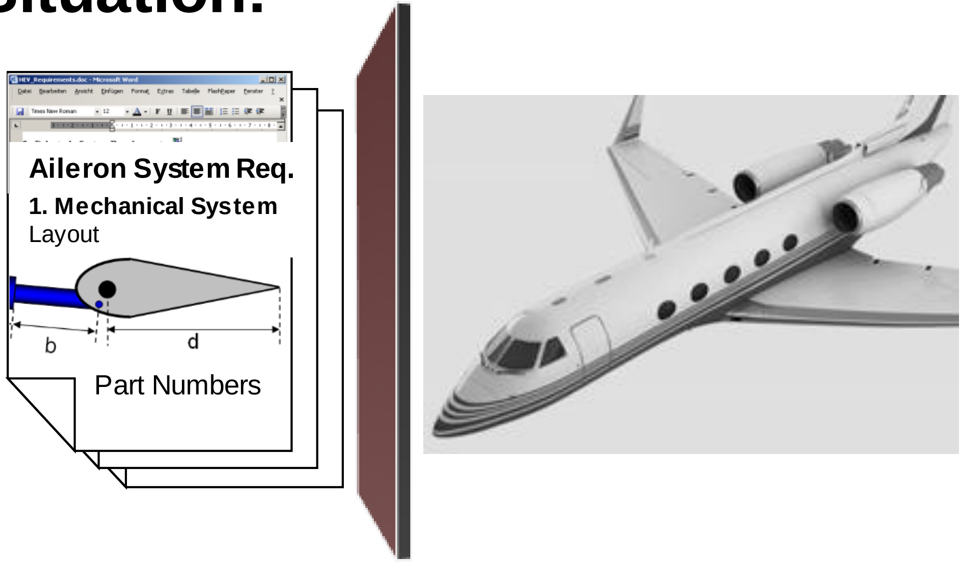
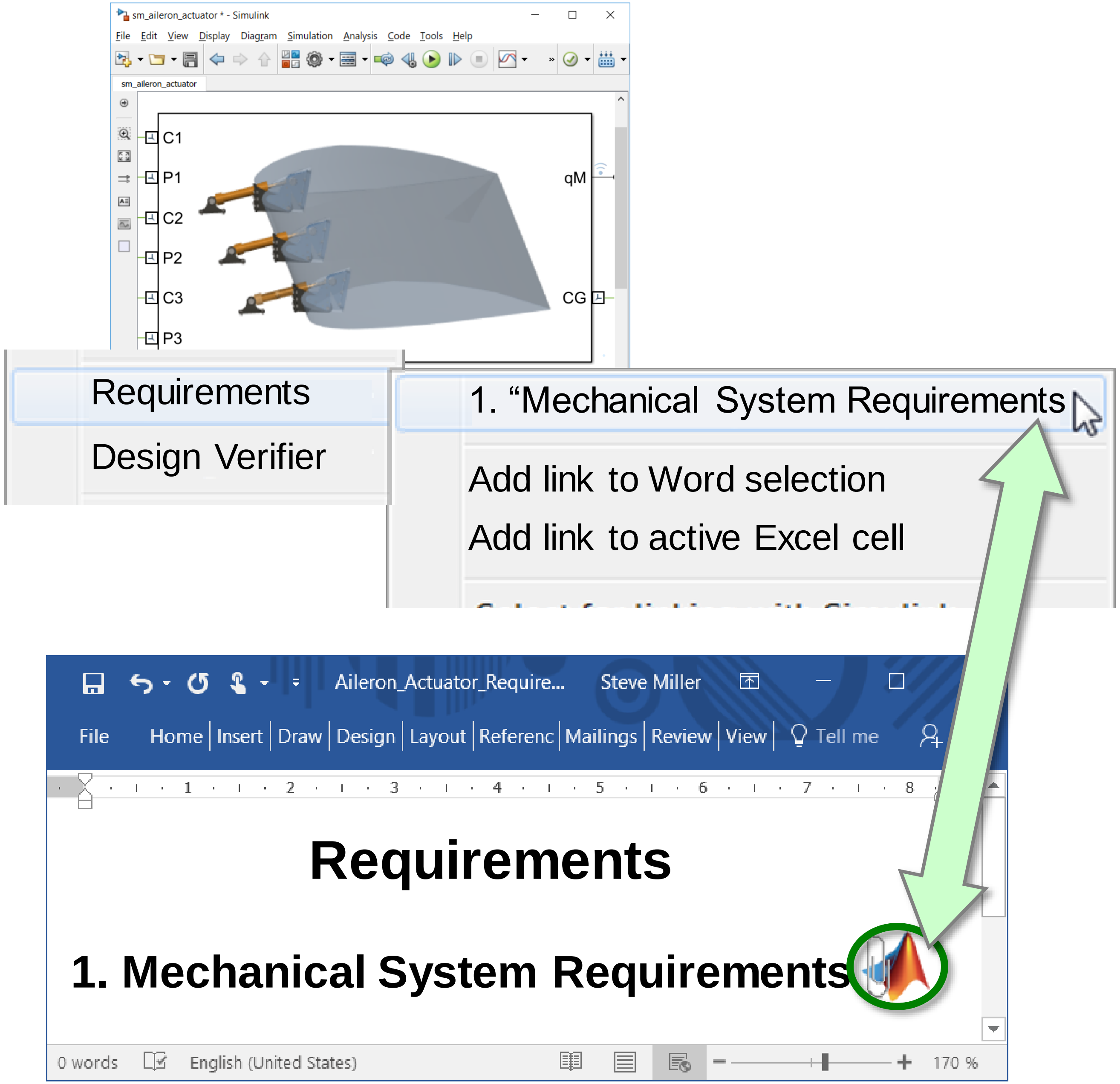
Link Specification and Design

Situation:



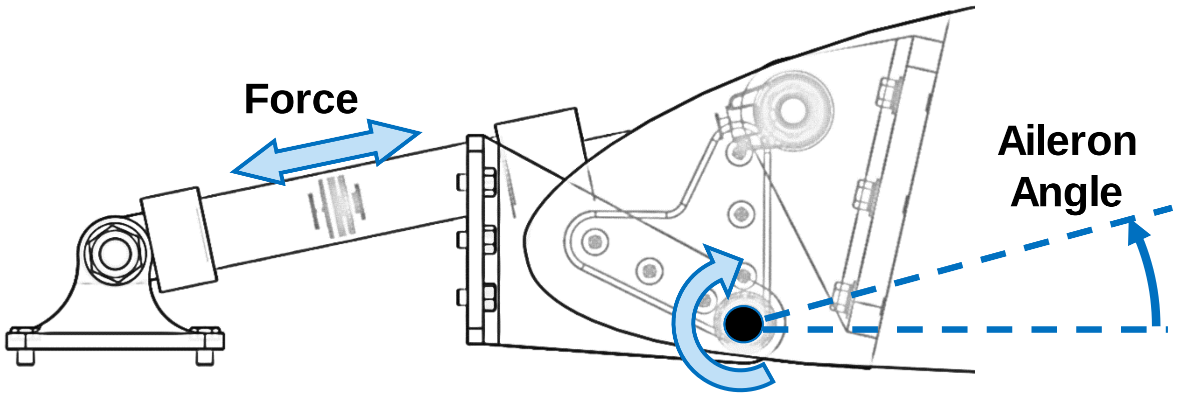
Problem: Difficult to check design against specification.

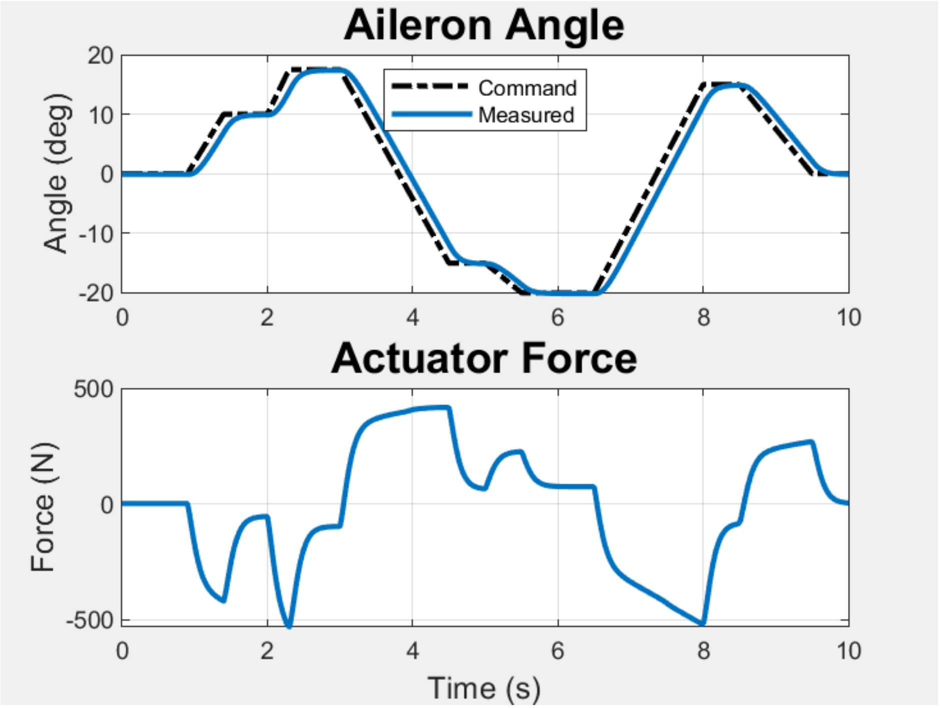
Solution: Link design and specification using Simulink Requirements



Determining Actuator Requirements

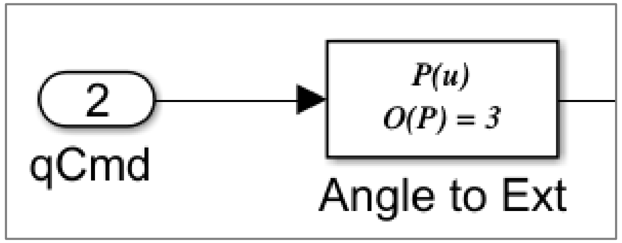
Model:

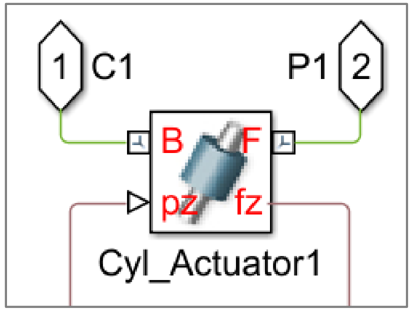




Problem: Determine the requirements for an aircraft aileron actuator

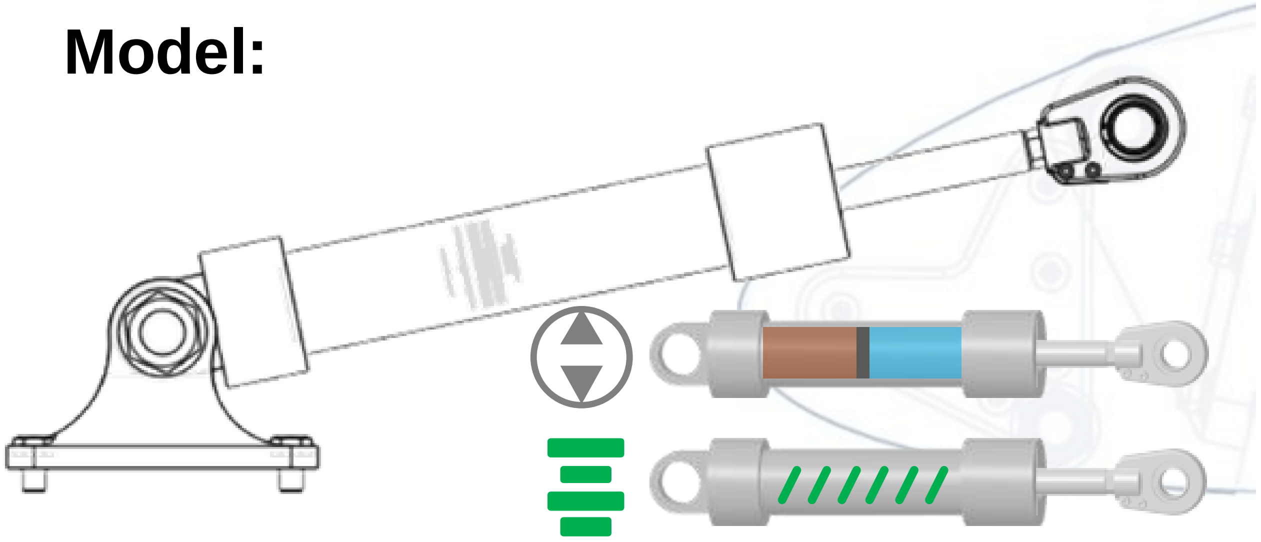
Solution: Use Simscape Multibody to model the aileron and use inverse dynamics to determine the required force

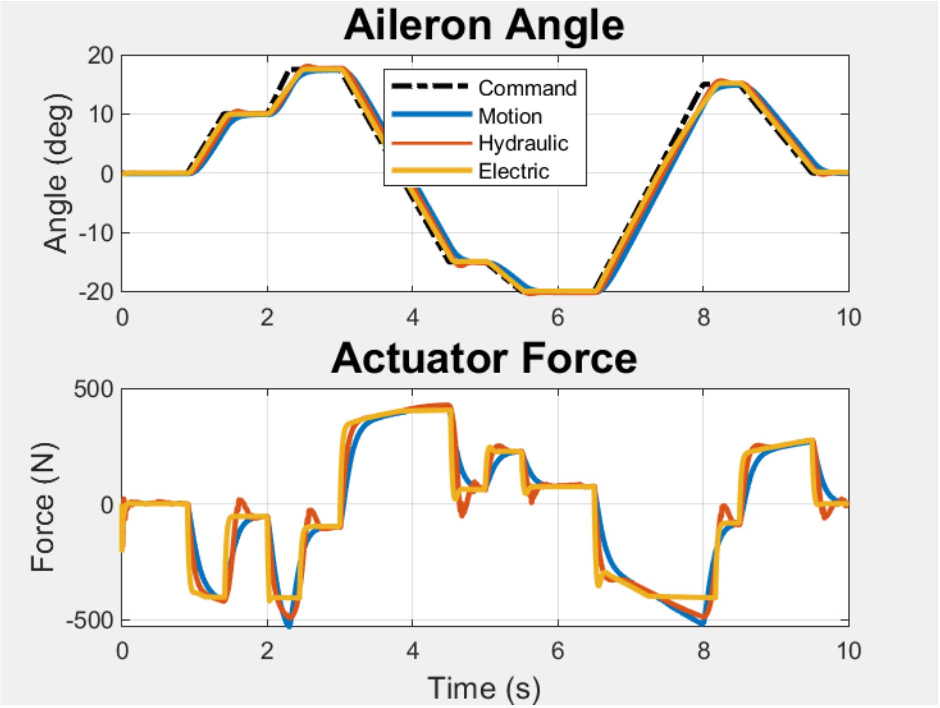




Testing Electrical and Hydraulic Designs

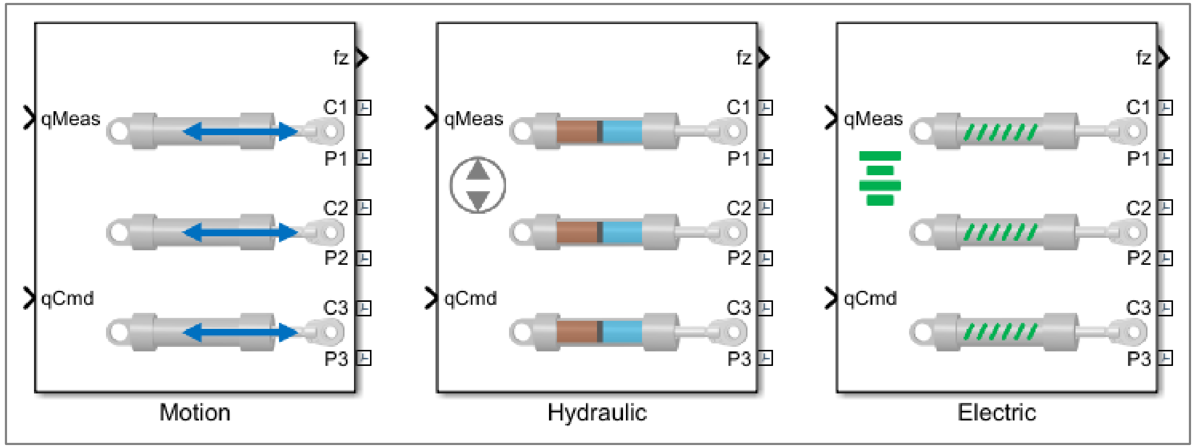
Model:





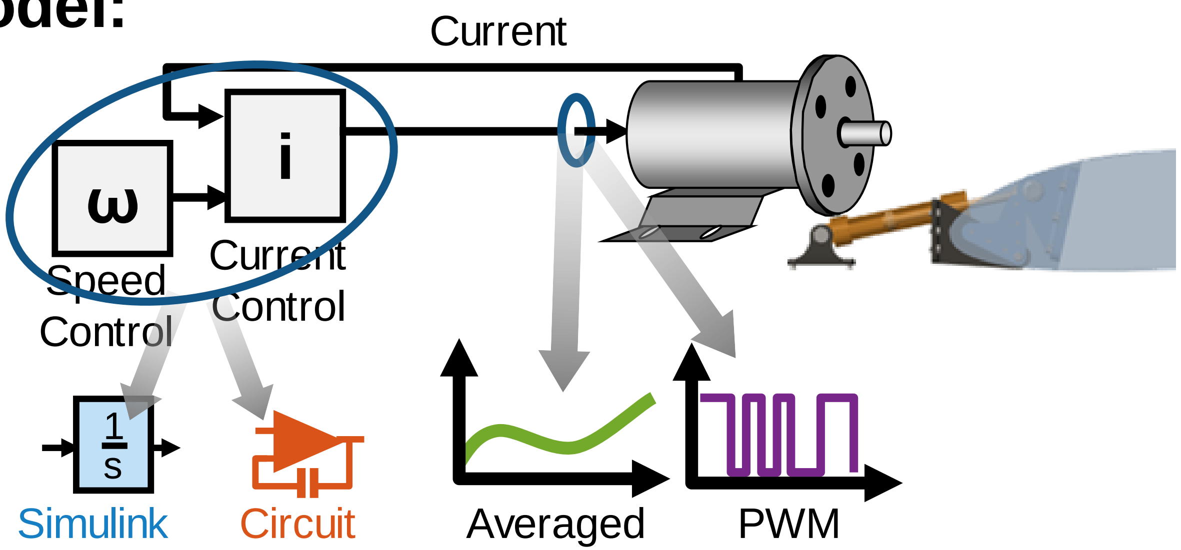
Problem: Select type of actuator based on system-level requirements

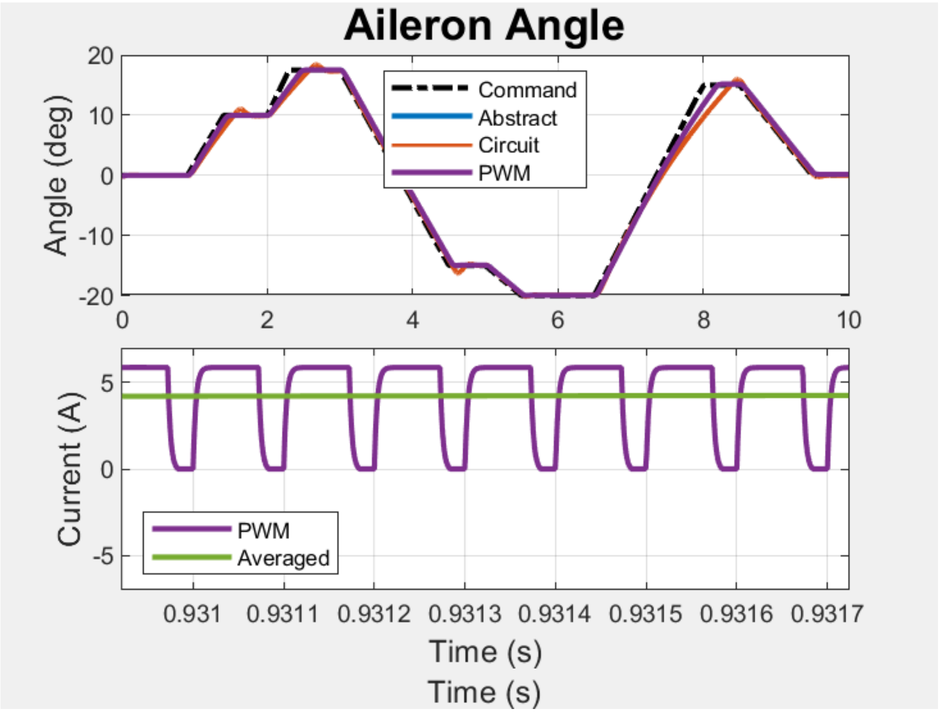
Solution: Use Simscape Fluids and Simscape Electronics to model the actuators, and variant subsystems to test them



Balancing the Tradeoff of Model Fidelity and Simulation Speed

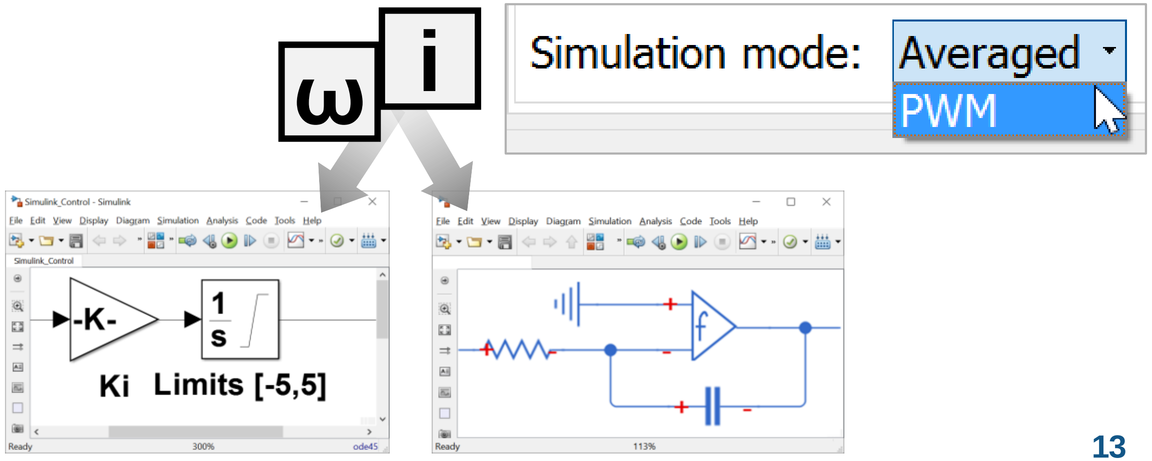
Model:





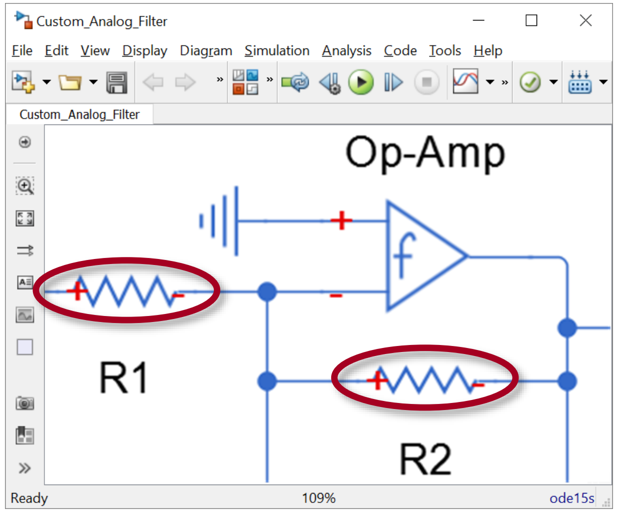
Problem: Add implementation details to the model and test system performance

Solution: Use Simscape Electronics to add analog circuit implementation and PWM



Model Custom Physical Components in Simscape

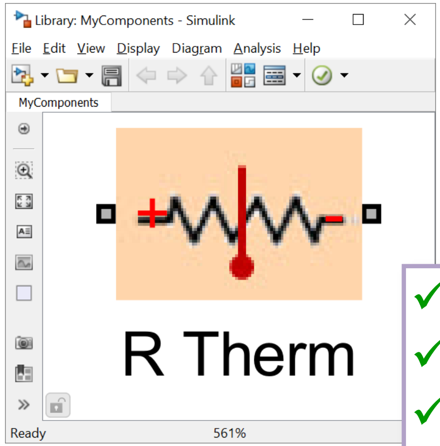
Model:



Temperature
250K – 350K

Problem: Add custom equation to model thermal effect on resistor

Solution: Use MATLAB and Simscape to model the component.



- ✓MATLAB based
- ✓Object-oriented
- ✓Define implicit equations (DAEs and ODEs)

$$v = r_0 * (1 + \alpha * (T - T_0)) * i$$

```
parameters
   R  = { 1, 'kOhm' };       % Nomi
   a  = { 0.001, '1/K' };    % Temp
   T0 = { 300, 'K' };        % Refe
   T  = { 300, 'K' };        % Curr
end
```

```
equations
   v == R*(1+a*(T-T0))*i;
end
```

Extend and Create Libraries

EDITOR VIEW

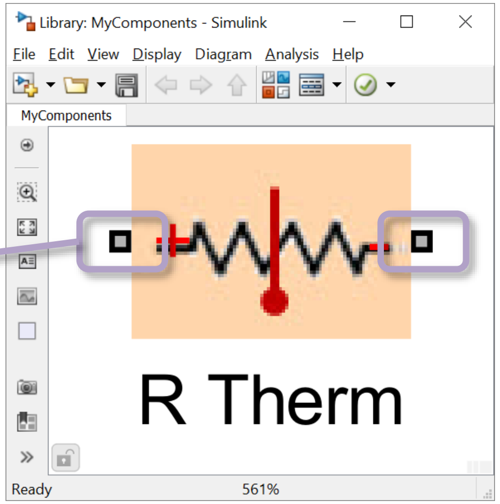
MyResistor.ssc

```
component MyResistor
% R Therm
% Resistor with temperature dependence defined by V = R(1+alpha*(T-T0))
% where R is the nominal resistance at the reference temperature in ohms
% and alpha is the temperature coefficient.

% Copyright 2005-2016 The MathWorks, Inc.

  nodes
    p = foundation.electrical.electrical; % +:left
    n = foundation.electrical.electrical; % -:right
  end
  variables
    i = { 0, 'A' };
```

```
nodes
  p = foundation.electrical.electrical; % +:left
  n = foundation.electrical.electrical; % -:right
end
```

```
    if R < 0
        pm_error('simscape:GreaterThanOrEqualToZero','Resistance')
    end
  end
  branches
     i: p.i -> n.i;
  end
  equations
     v == p.v - n.v;
     v == R*(1+a*(T-T0))*i;
  end
end
```

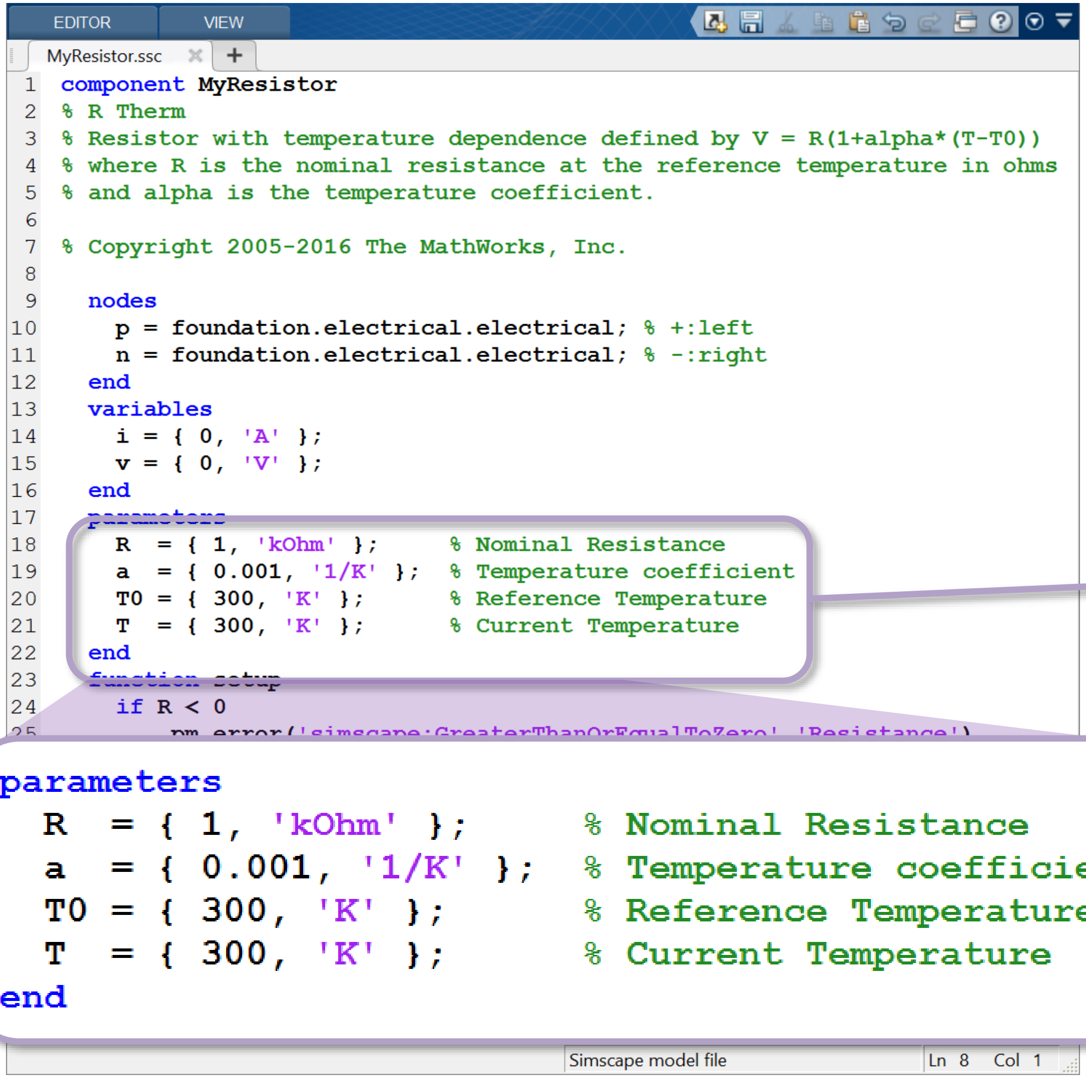
Simscape model file | Ln 8 Col 1



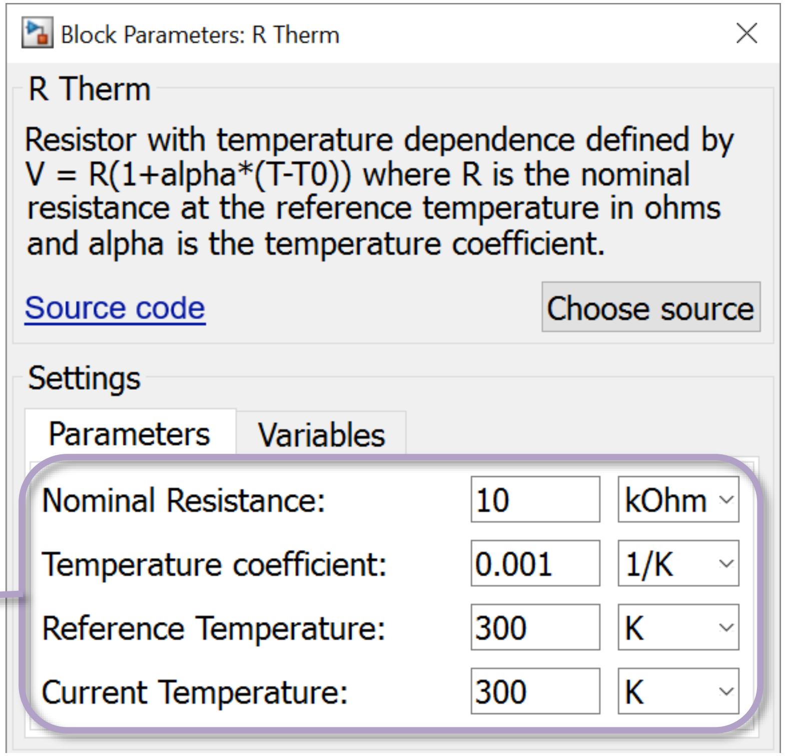
Define the physical network ports for the Simscape block

- Reuse existing physical domains to extend libraries
- Define new physical domains

Define User Interface




```
parameters
  R  = { 1, 'kOhm' };       % Nominal Resistance
  a  = { 0.001, '1/K' };    % Temperature coefficient
  T0 = { 300, 'K' };        % Reference Temperature
  T  = { 300, 'K' };        % Current Temperature
end
```



Parameters, units, default values, and dialog box text are all defined in the Simscape file (extension .ssc).

Leverage MATLAB

EDITOR VIEW

MyResistor.ssc

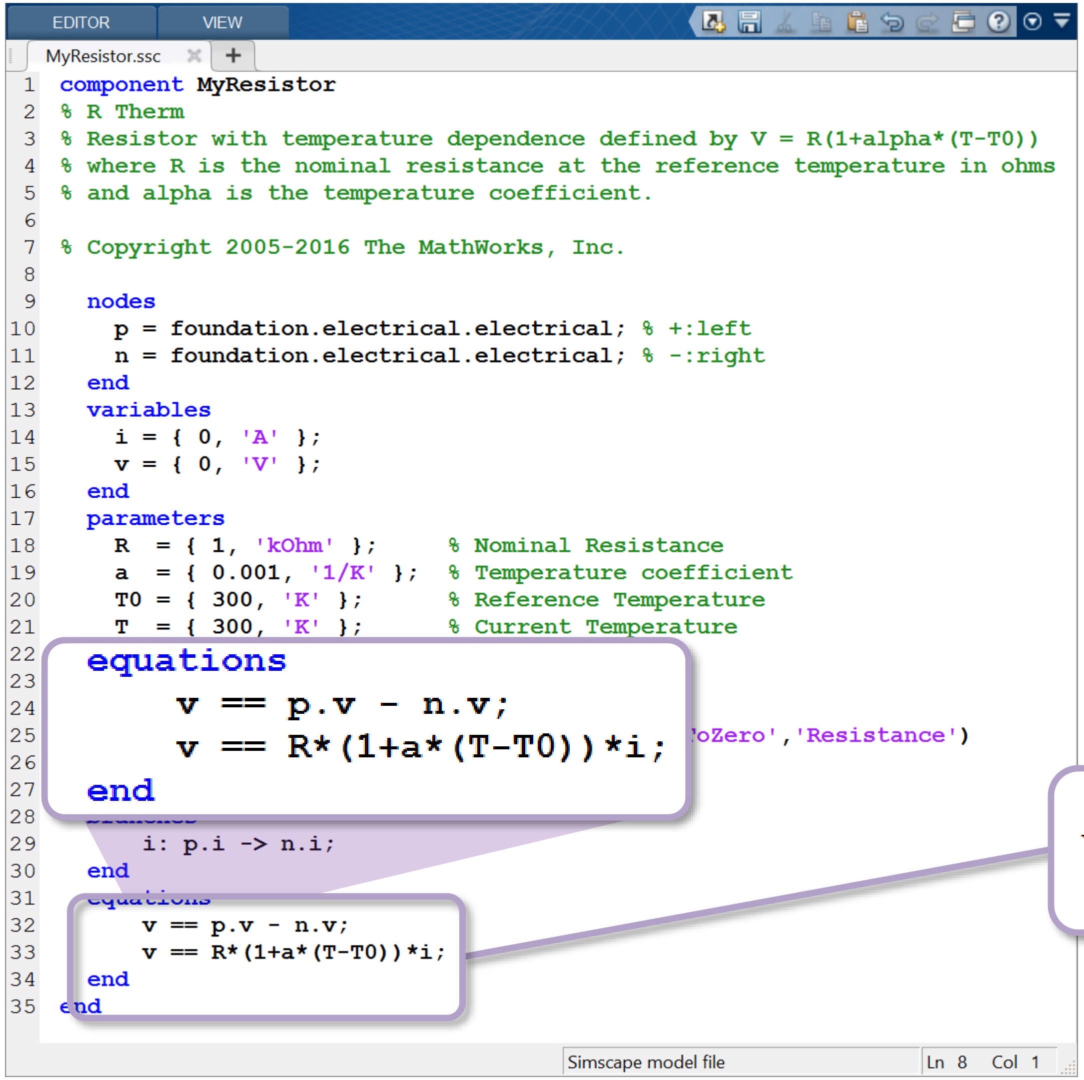
```
component MyResistor
% R Therm
% Resistor with temperature dependence defined by V = R(1+alpha*(T-T0))
% where R is the nominal resistance at the reference temperature in ohms
% and alpha is the temperature coefficient.

% Copyright 2005-2016 The MathWorks, Inc.

  nodes
    p = foundation.electrical.electrical; % +:left
    n = foundation.electrical.electrical; % -:right
  end
  variables
    i = { 0, 'A' };
    v = { 0, 'V' };
  end
  parameters
    R  = { 1, 'kOhm' };      % Nominal Resistance
    a  = { 0.001, '1/K' };   % Temperature coefficient
    T0 = { 300, 'K' };       % Reference Temperature
    T  = { 300, 'K' };       % Current Temperature
  end
  function setup
    if R < 0
        pm_error('simscape:GreaterThanOrEqualToZero','Resistance')
    end
  end
  branches
      i: p.i -> n.i;
```


```
function setup
  if R < 0
      pm_error('simscape:GreaterThanOrEqualToZero','Resistance')
  end
end
```


Use MATLAB functions and expressions for typical physical modeling tasks:

- Analyzing parameters
- Performing preliminary computations

Create Reusable Components



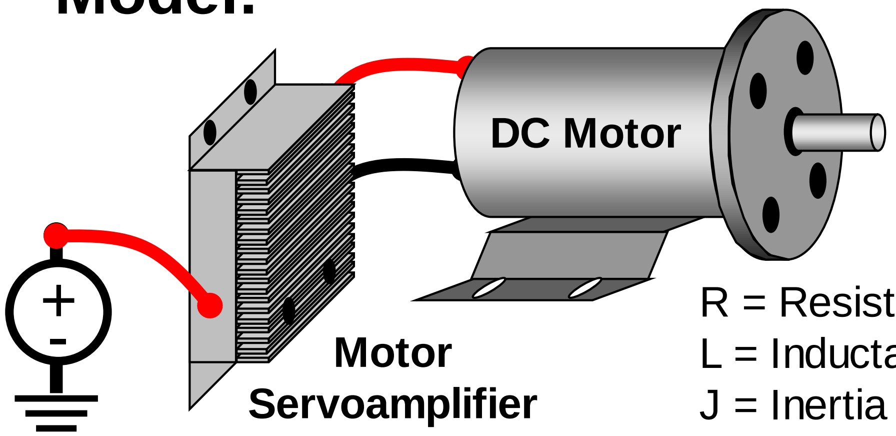
$$v = r_0 * (1 + \alpha * (T - T_0)) * i$$

Equations defined in a text-based language

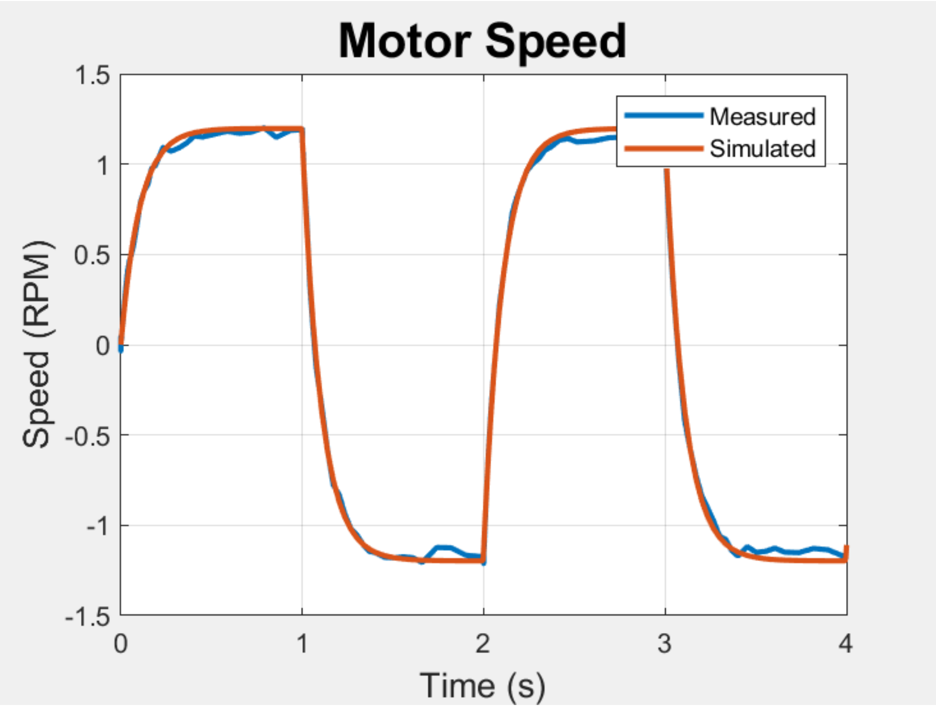
- Based on variables, their time derivatives, parameters, etc.
- Define simultaneous equations
  - Can be DAEs, ODEs, etc.
  - Assignment not required
  - Specifying inputs and outputs not required

Estimating Parameters Using Measured Data

Model:



R = Resistance
L = Inductance
J = Inertia
B = Friction
K = Back EMF Constant



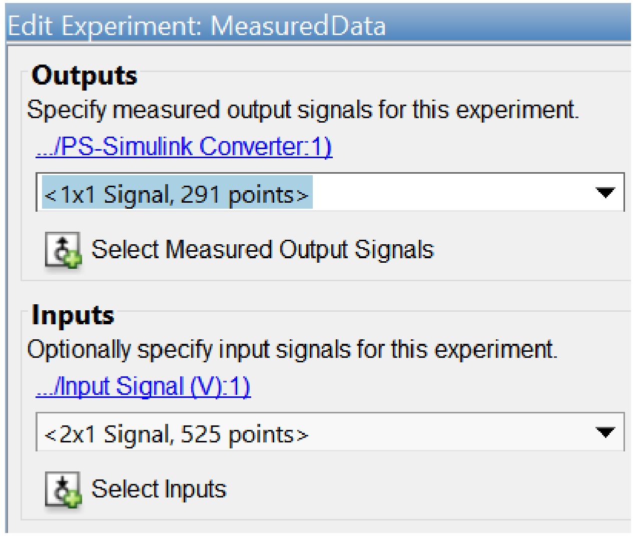
Problem: Simulation results do not match measured data because model parameters are incorrect

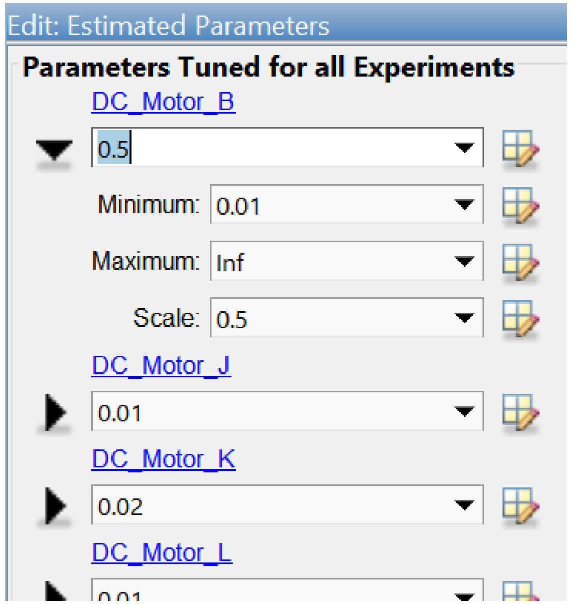
R	L	J	K	B
4.03	1e-4	0.11	0.45	1.07

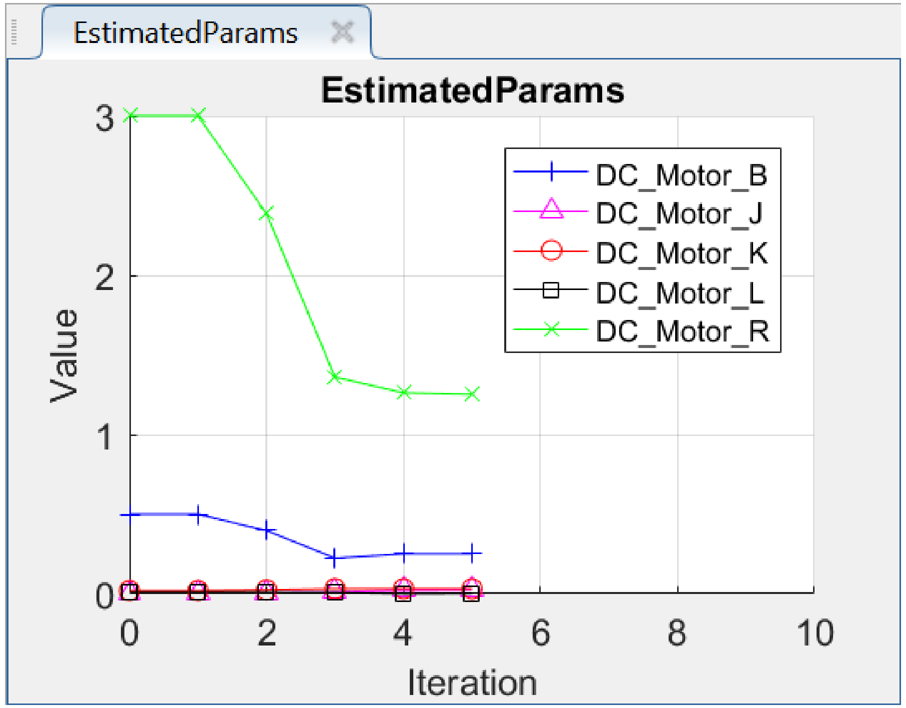
Solution: Use Simulink Design Optimization to automatically tune model parameters

Estimating Parameters Using Measured Data

- Steps to Estimating Parameters
  1. Import measurement data and select estimation data
  2. Identify parameters and their ranges
  3. Perform parameter estimation

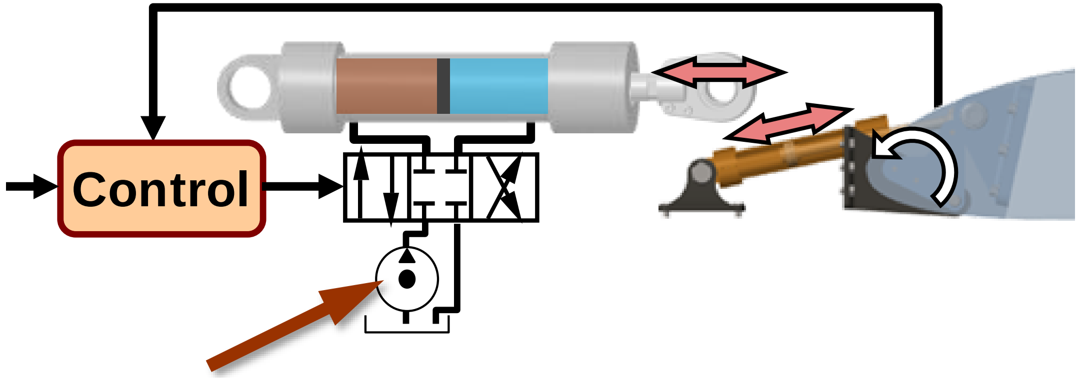


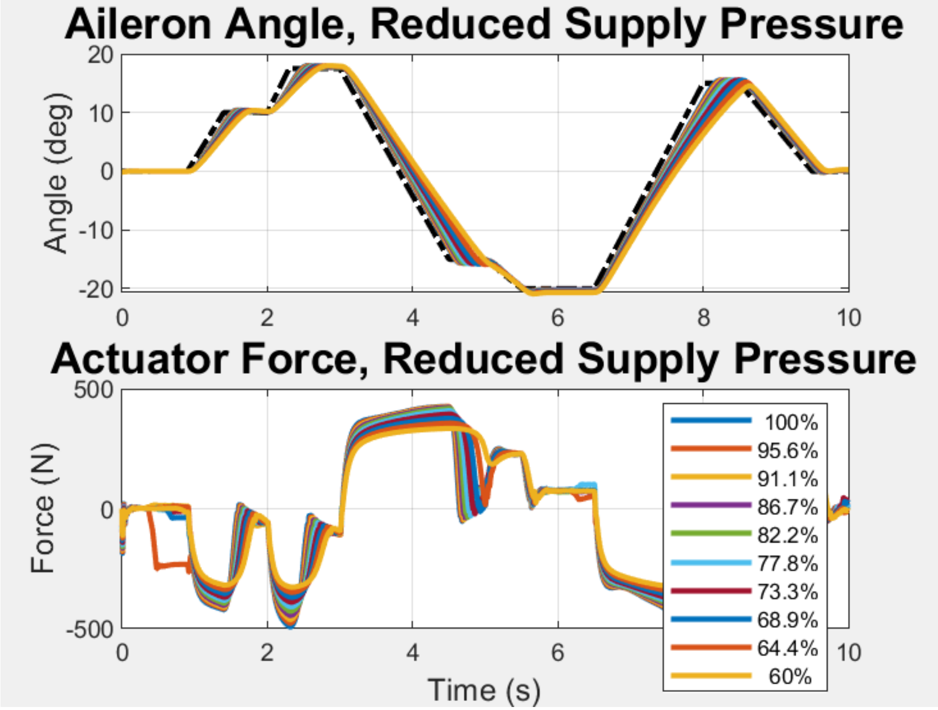




Parameter Sweep Using Parallel Computing

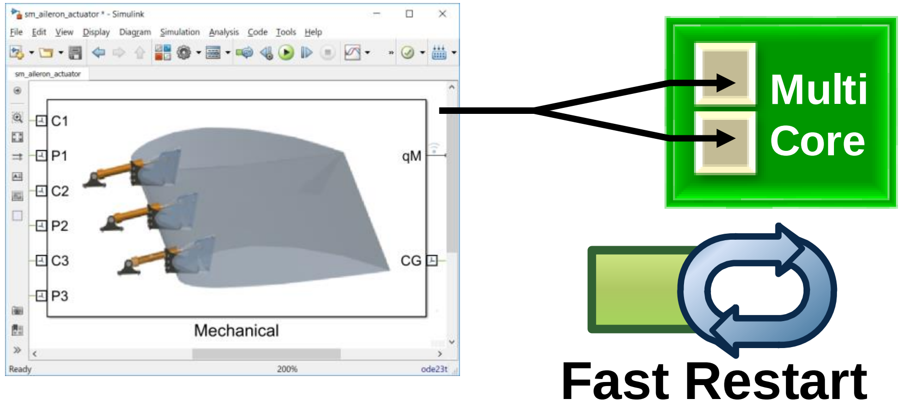
Model:





Problem: Measure degradation in system performance as supply pressure drops

Solution: Use Parallel Computing Toolbox to speed up the parameter sweep



Parameter Sweep Using Parallel Computing

- Steps to compare simulation methods

1. Open pool of MATLAB sessions

```
>> parpool 2
```

2. Generate parameter sets

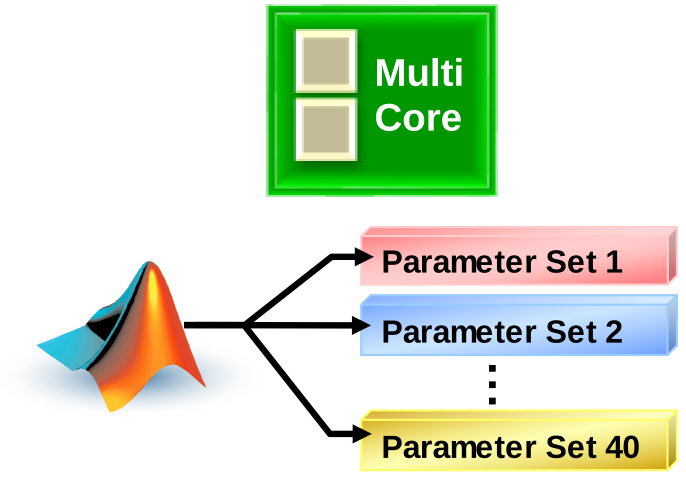
```
Kp_array = [0.25:0.5:19.75];
Generate_Sim_Settings
```

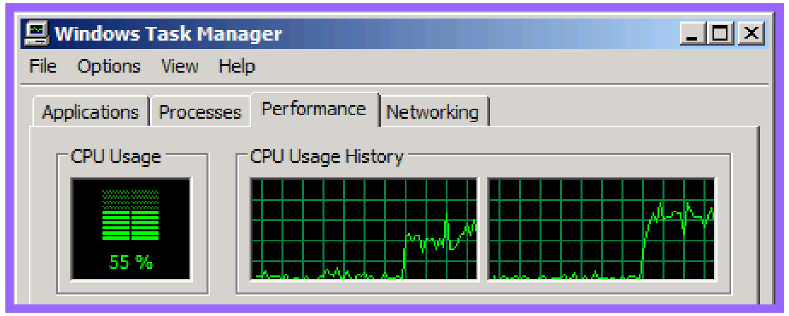
3. Run simulations **serially**

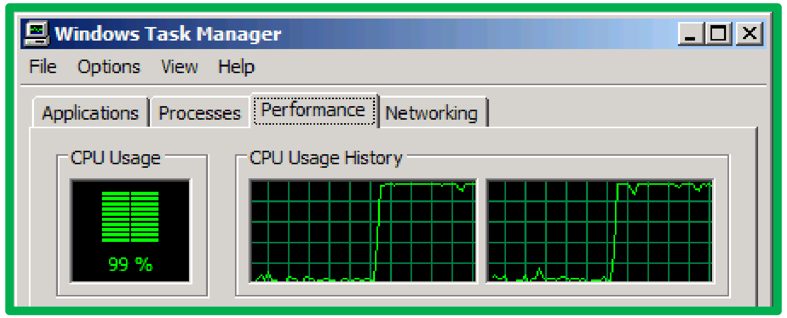
```
simOut  =
sim(simInput,'ShowProgress','on','UseFastRestart',
'on');
```

4. Run simulations in **parallel**

```
simOut =
parsim(simInput,'ShowProgress','on','UseFastRestart
','on','TransferBaseWorkspaceVariables','on');
```







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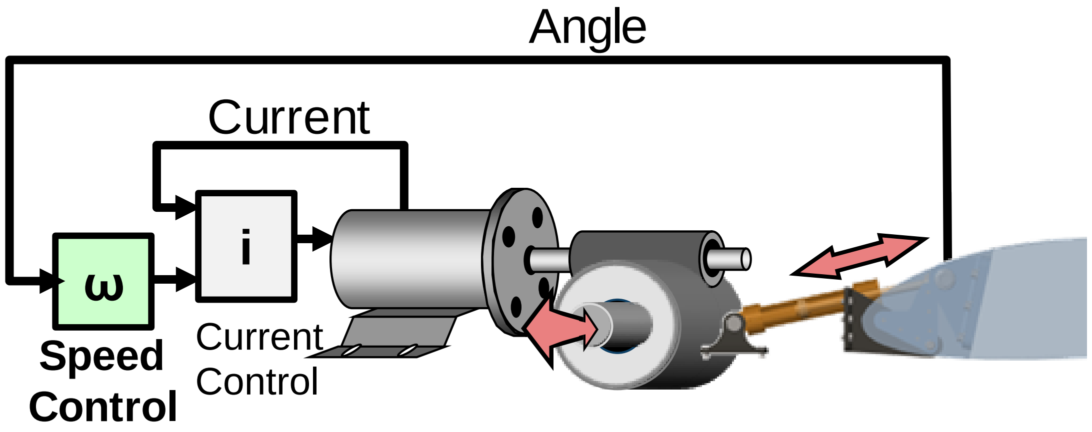
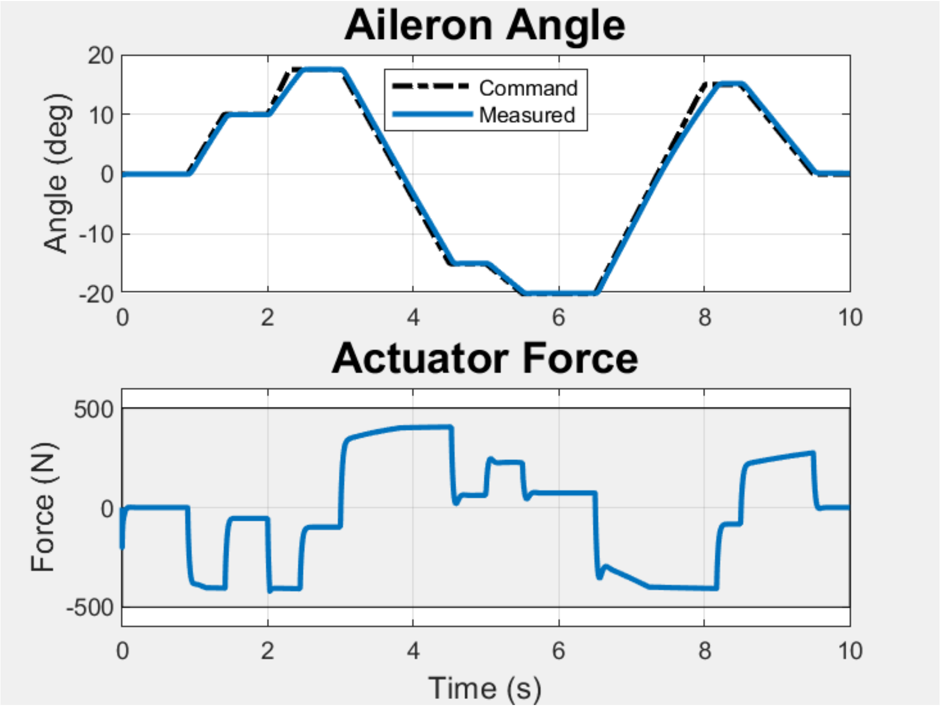
Optimizing System Performance

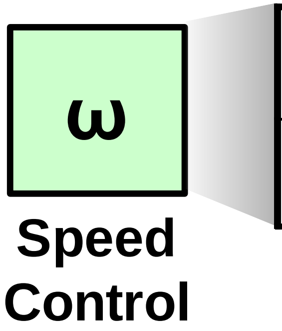
Model:



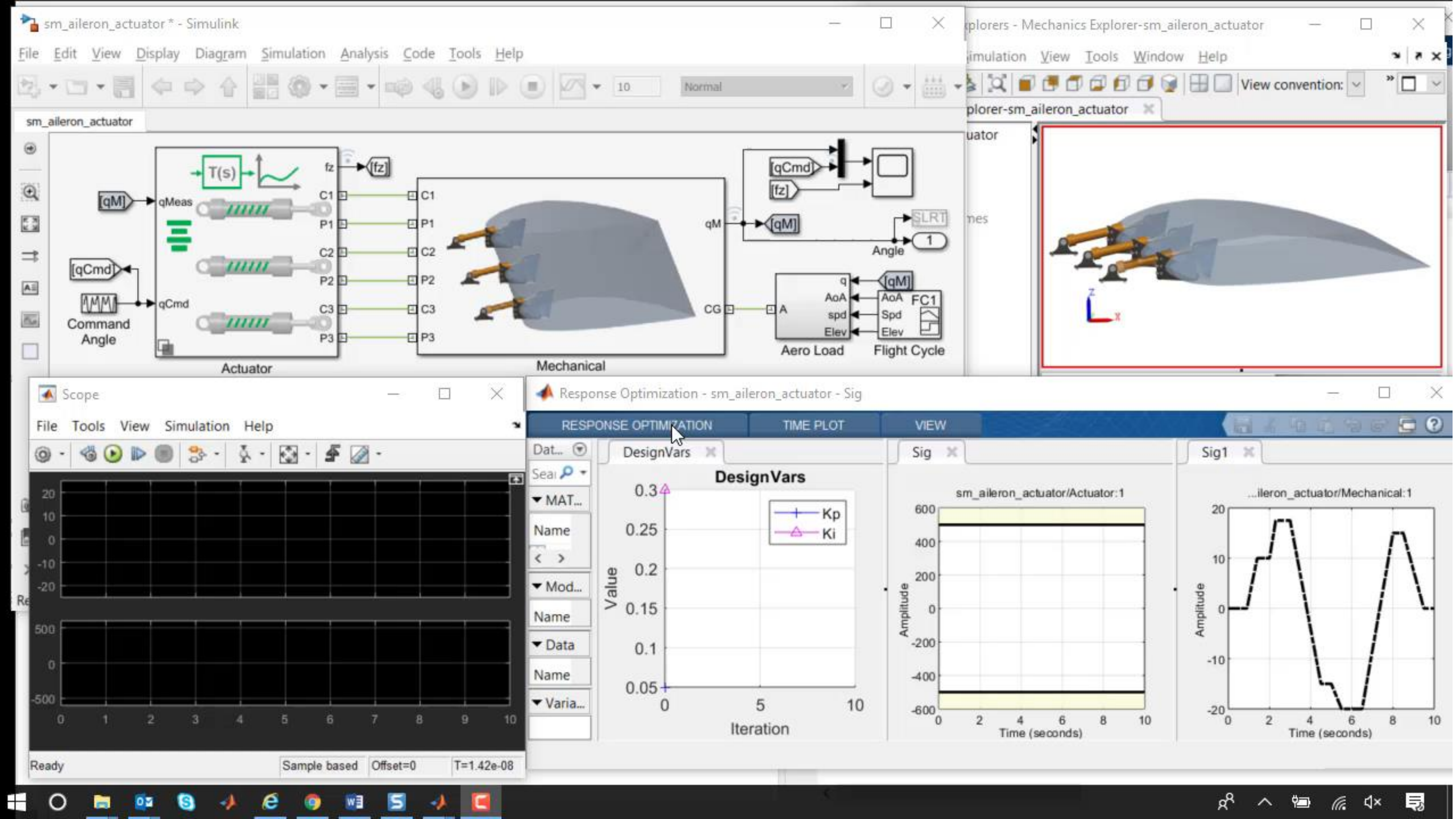


Problem: Optimize the speed controller to meet system requirements

Solution: Tune controller parameters with Simulink Design Optimization



K_p	K_i
0.62	0.29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Elev
FC1
Flight Cycle
Mechanics Explorer-sm_aileron_actuator
Simulation View Tools Window Help
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Amplitude
Time (seconds)

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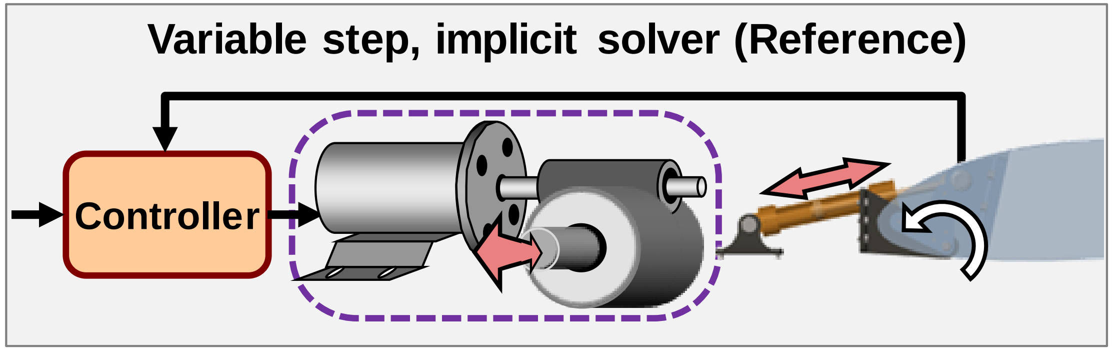
Configuring an Electrical Actuator for HIL Testing

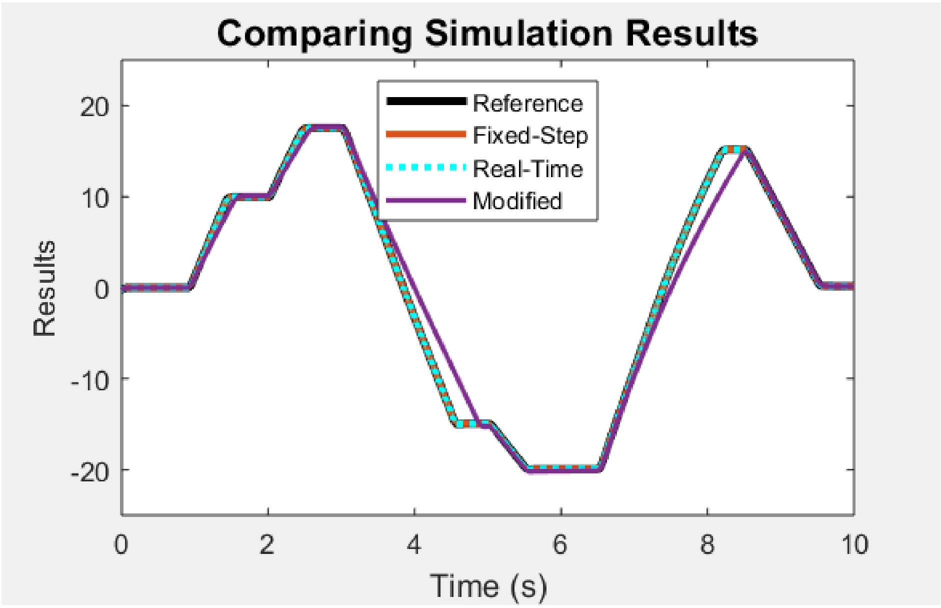
Model:

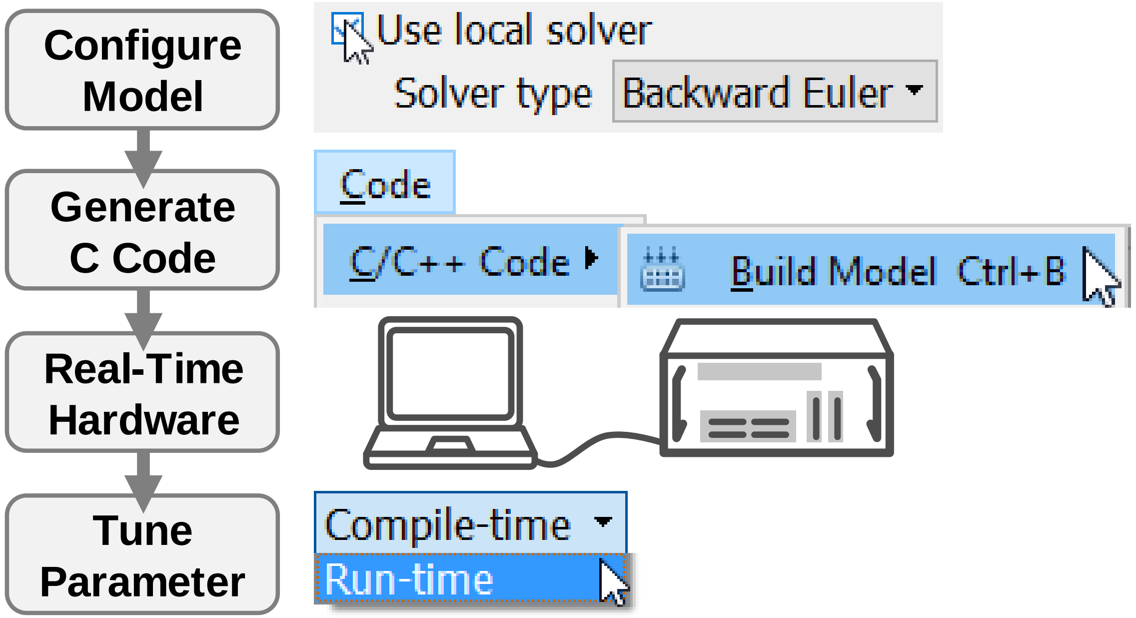


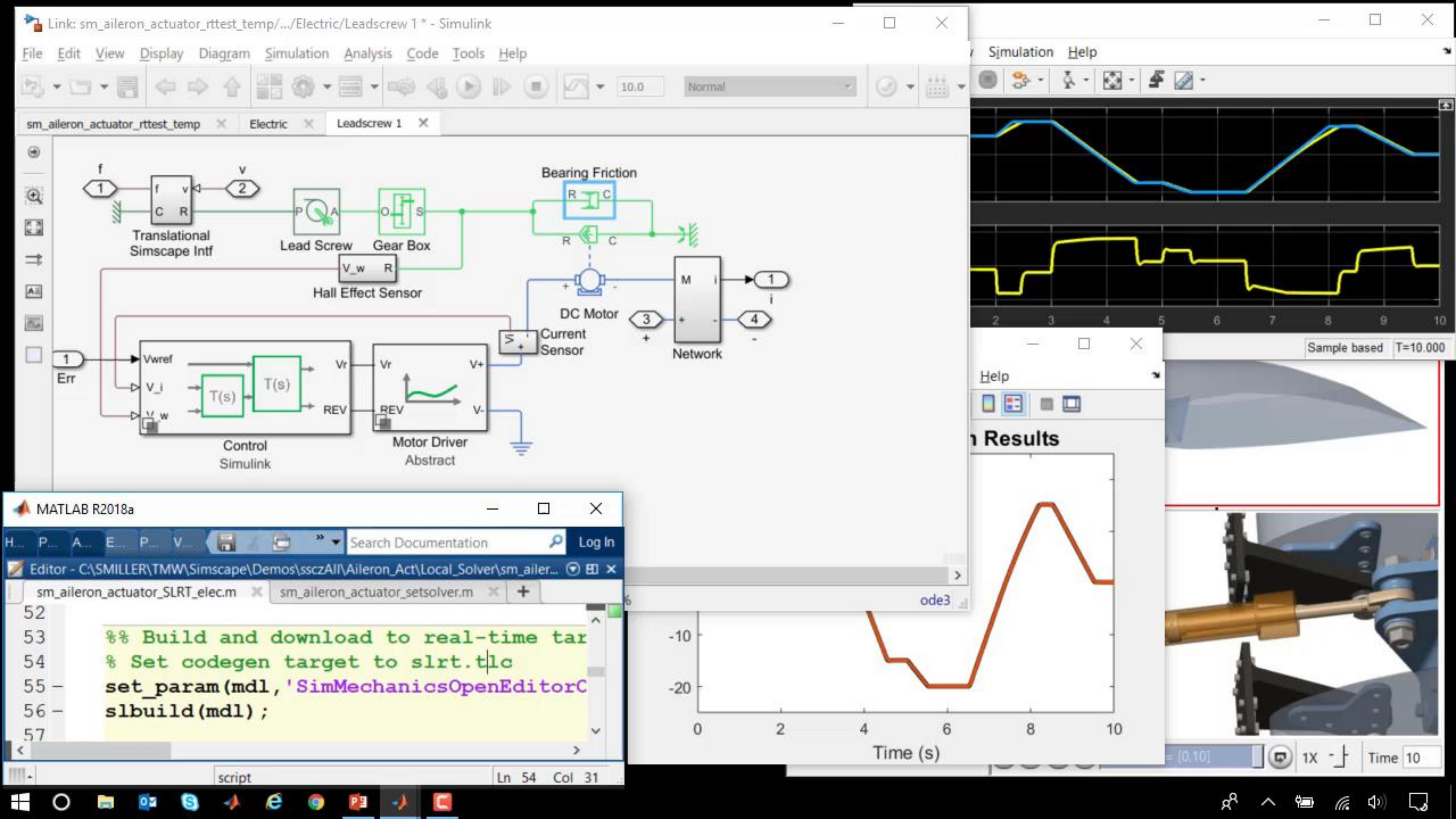
Numerically
Stiff System

Problem: Configure solvers to minimize computations and convert to C code for real-time simulation

Solution: Use Simscape local solvers on stiff physical networks and Simulink Coder™ to generate C code






Link: sm_aileron_actuator_rttest_temp/.../Electric/Leadscrew 1 * - Simulink
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Normal
sm_aileron_actuator_rttest_temp
Electric
Leadscrew 1
f
v
Bearing Friction
Translational Simscape Intf
Lead Screw
Gear Box
Hall Effect Sensor
DC Motor
Network
Current Sensor
Err
Vwref
V_i
V_w
T(s)
Vr
REV
V+
V-
Control
Simulink
Motor Driver
Abstract
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Simulation Help
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Help
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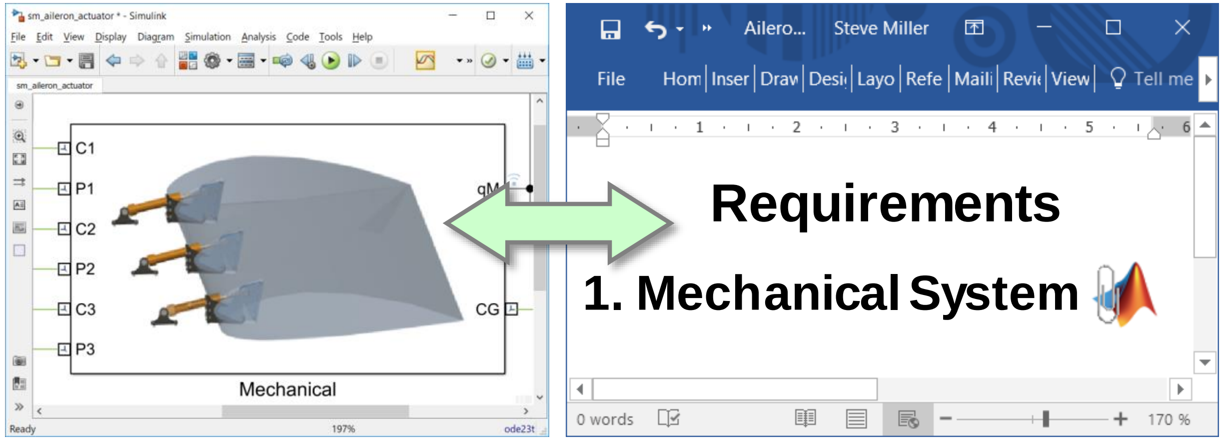
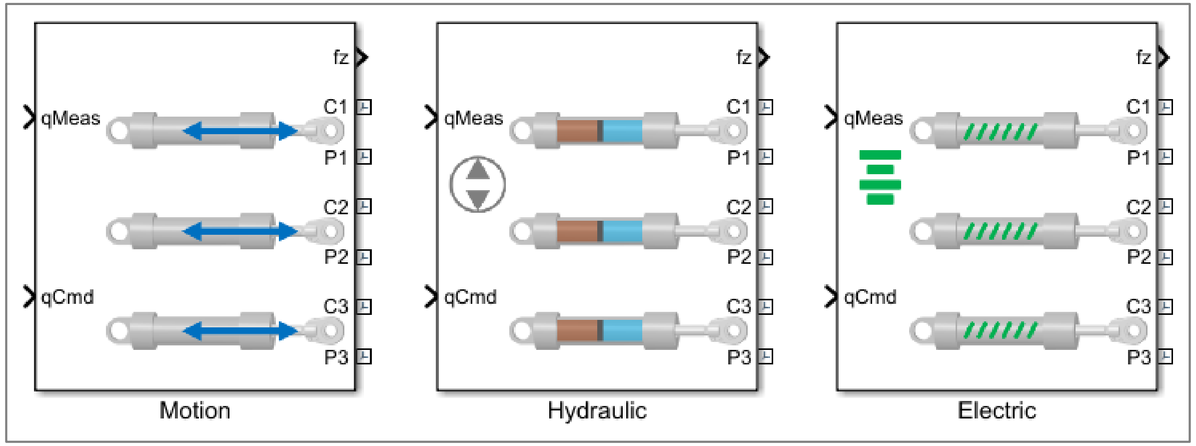
Time (s)
MATLAB R2018a
Search Documentation
Log In
Editor - C:\SMILLER\TMW\Simscape\Demos\ssczAll\Aileron_Act\Local_Solver\sm_ailer...
sm_aileron_actuator_SLRT_elec.m
sm_aileron_actuator_setsolver.m
52
53 %% Build and download to real-time tar
54 % Set codegen target to slrt.tlc
55 – set_param(mdl,'SimMechanicsOpenEditorC
56 – slbuild(mdl);
57
script
Ln 54 Col 31
1X
Time 10

Key Points

- Create intuitive models that all teams can share
- Simulate system in one environment to
  - Perform tradeoff studies
  - Optimise system performance
- Test without prototypes





Configure Model → Real-Time Hardware → Generate C Code → Tune Parameter