

# MATLAB EXPO 2018

## How Simscape™ Supports Innovation for Cyber-Physical Systems

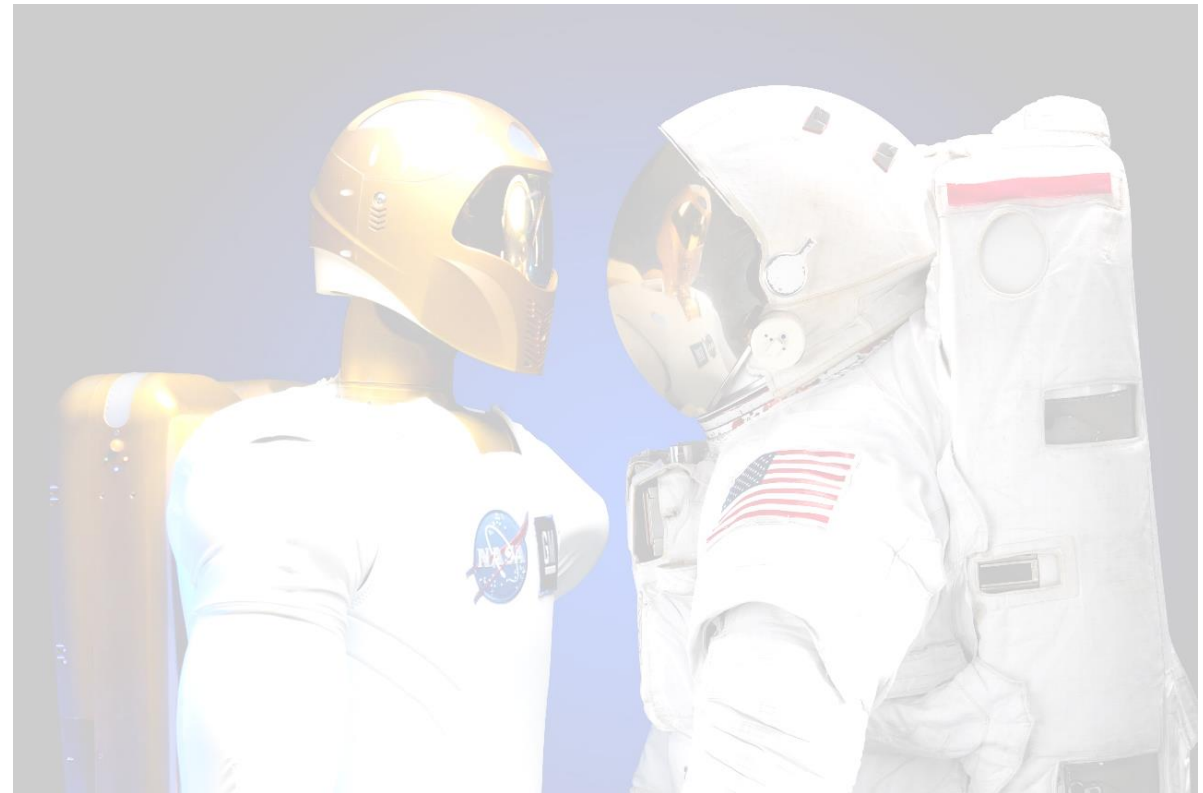
Kevin Roblet

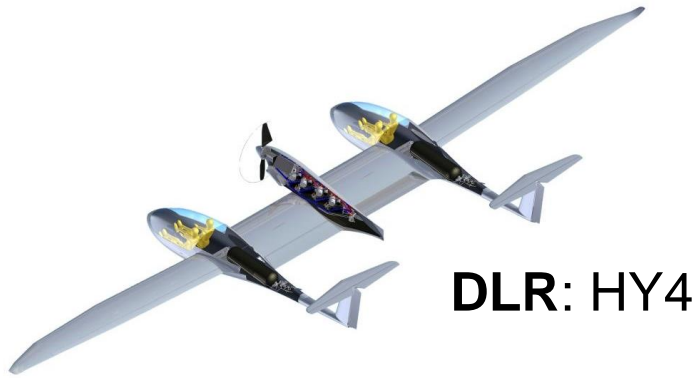


# How can we use system-level modelling to support *innovative product design*?

# INNOVATION

# What about aeronautics?





**DLR: HY4**



**Airbus:  
Vahana E-Fan**

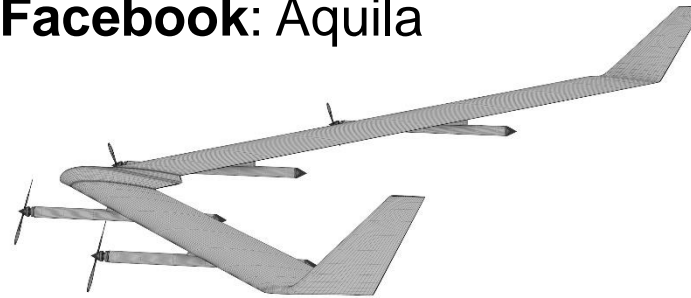


**Boeing: Fuel Cell**

**AMP Electric  
Vehicles:  
Workhorse Surefly**



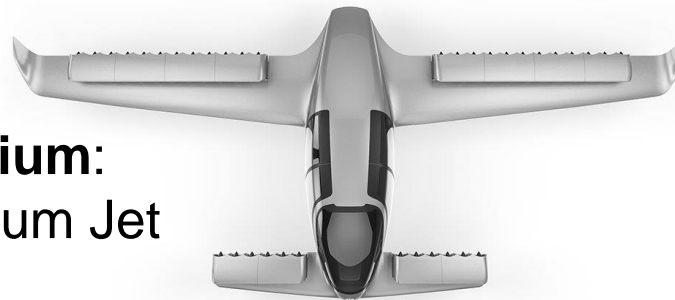
**Facebook: Aquila**



**Siemens: eFusion**

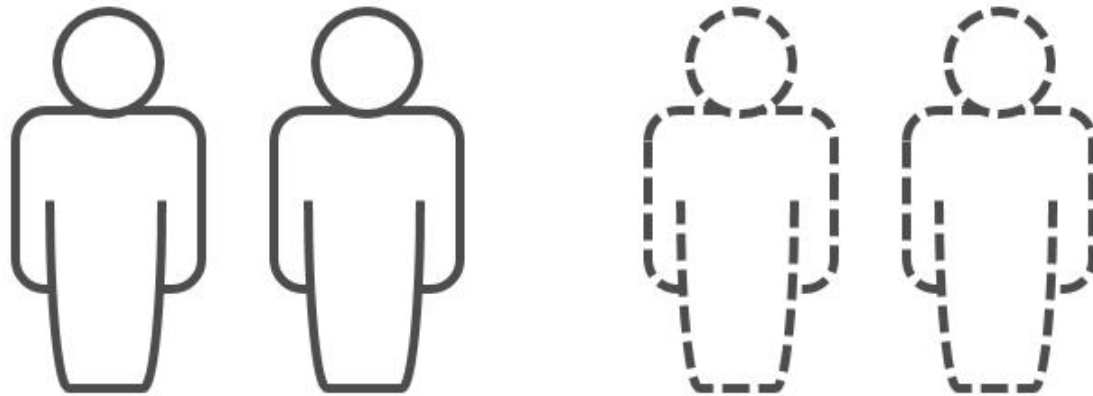


**Lilium:  
Lilium Jet**



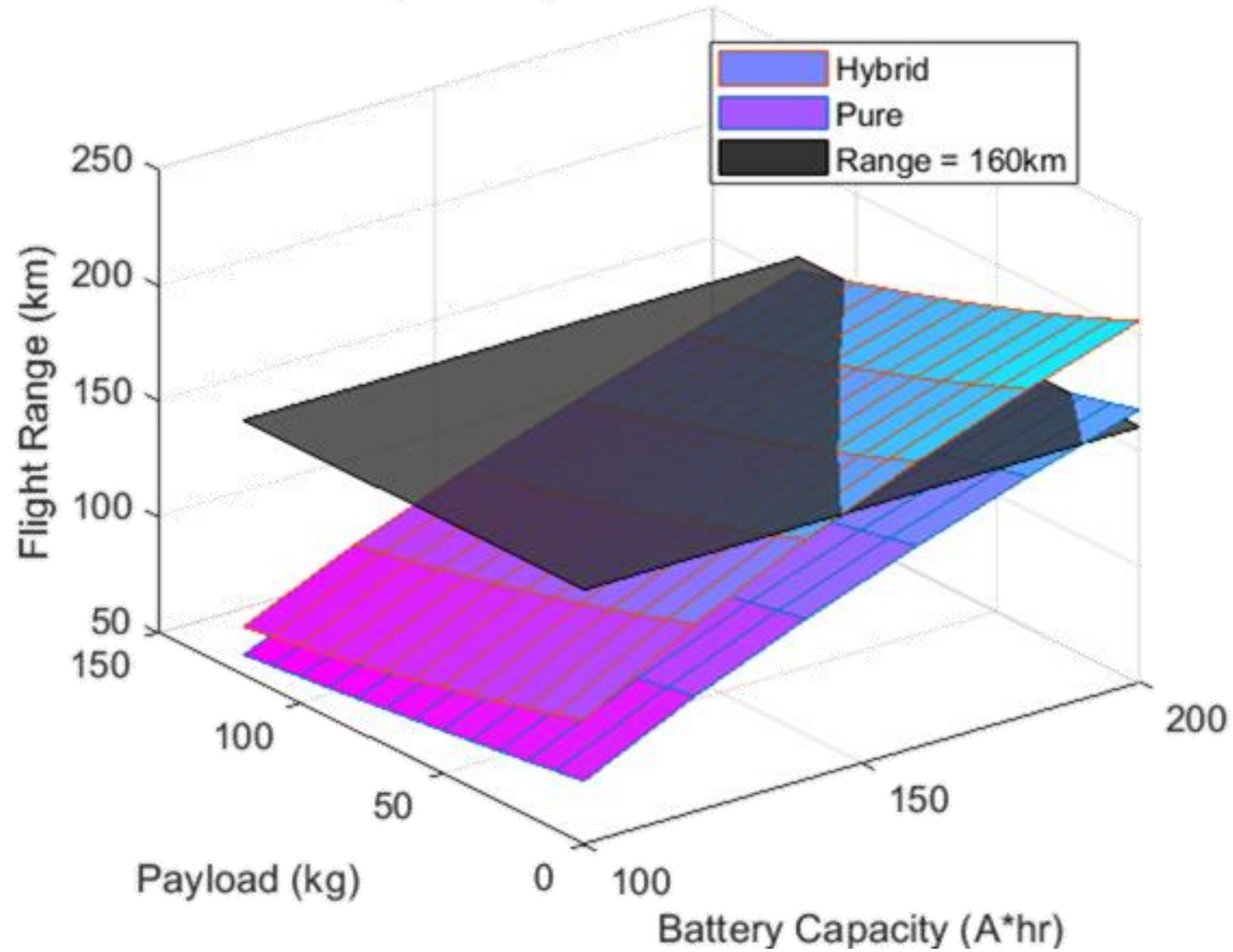
**Pipistrel:  
Panthera**



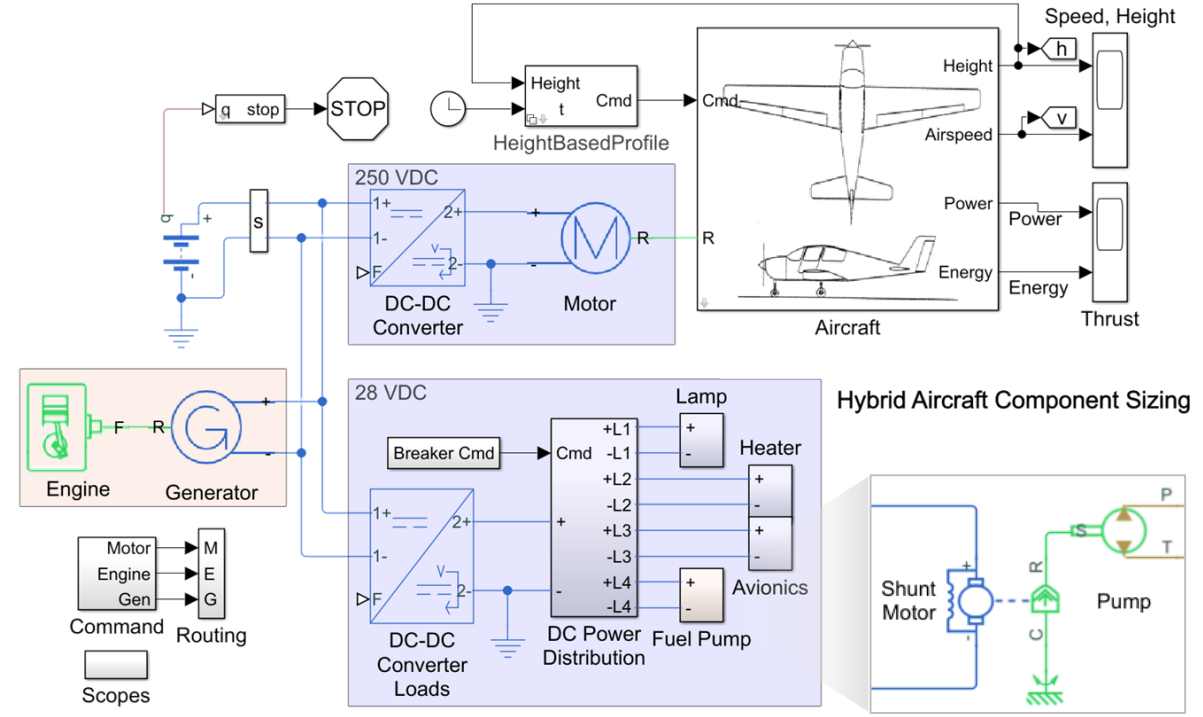
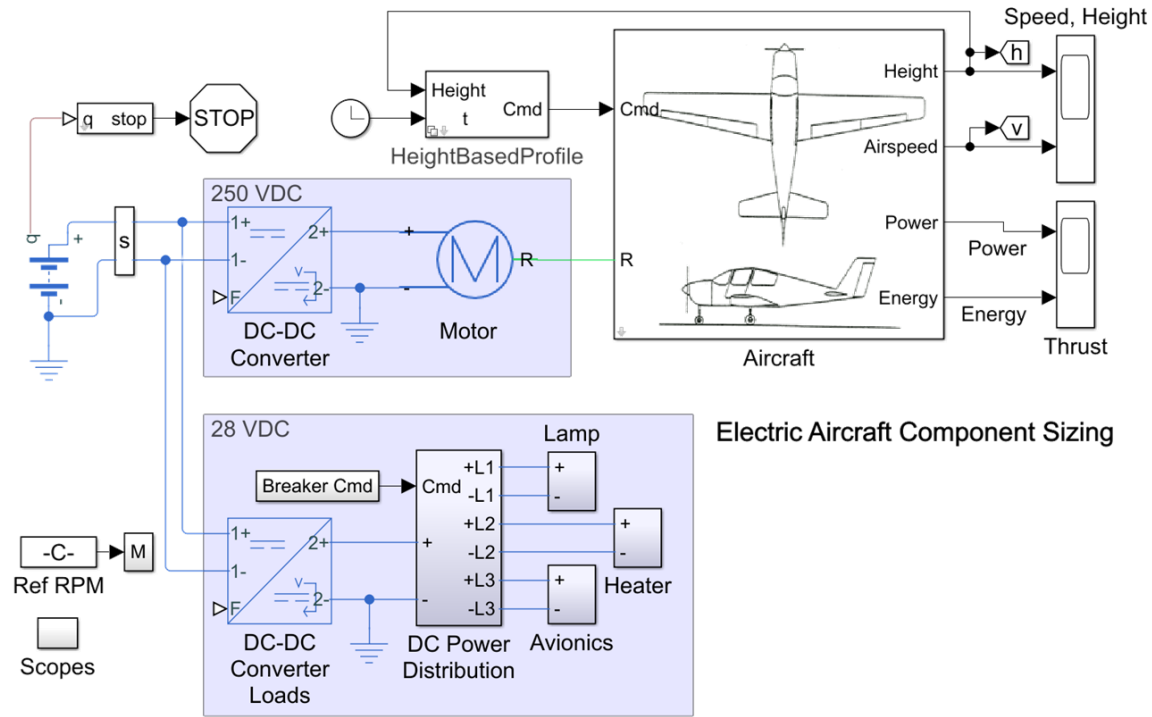




## Flight Range for Electric Aircraft



# System-level models

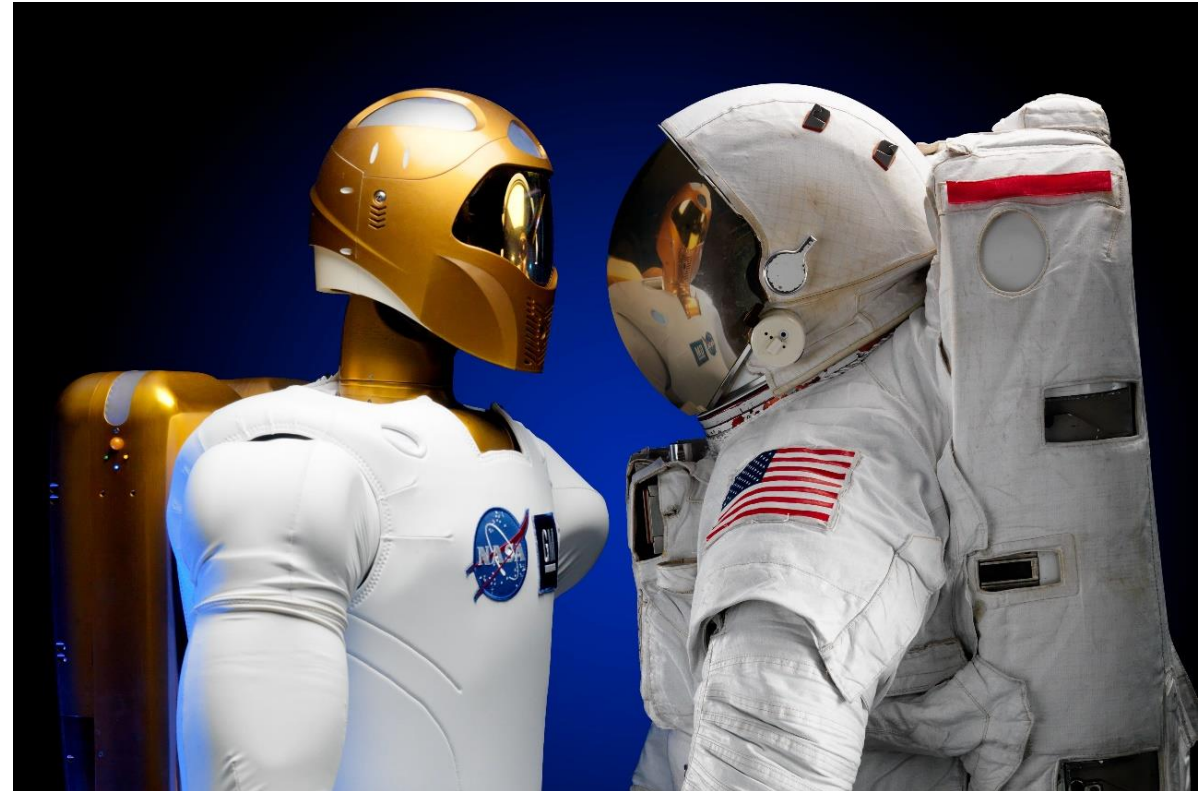


## Electric

## Hybrid



# What about robotics?



# Quadruped running robot

Biologically-inspired design (*biomimetics*)





# Quadruped running robot

Biologically-inspired design (*biomimetics*)







Boston Dynamics

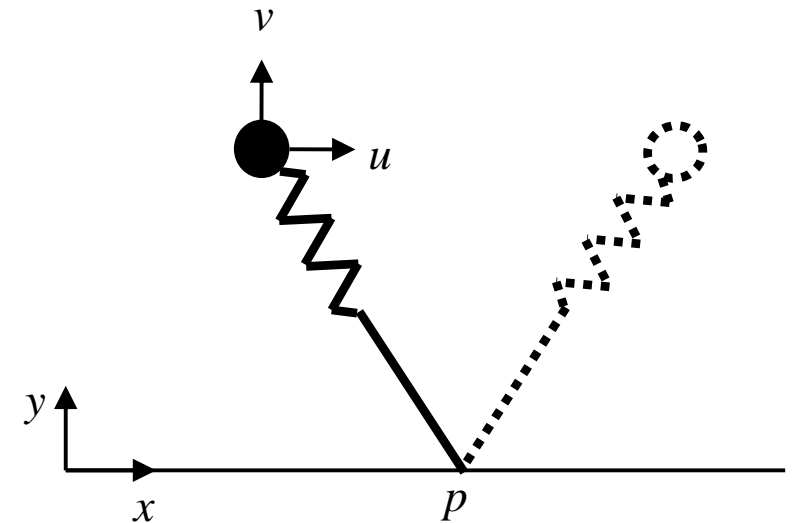


# Quadruped running robot

Biologically-inspired design (*biomimetics*)



Equivalent inverted pendulum model as basis for gait



**1** **Gait Selection**

**2** **Actuator Requirements**

**3** **Actuator Selection**

**4** **Actuator Validation**

**5** **System Evaluation**





# Gait Selection

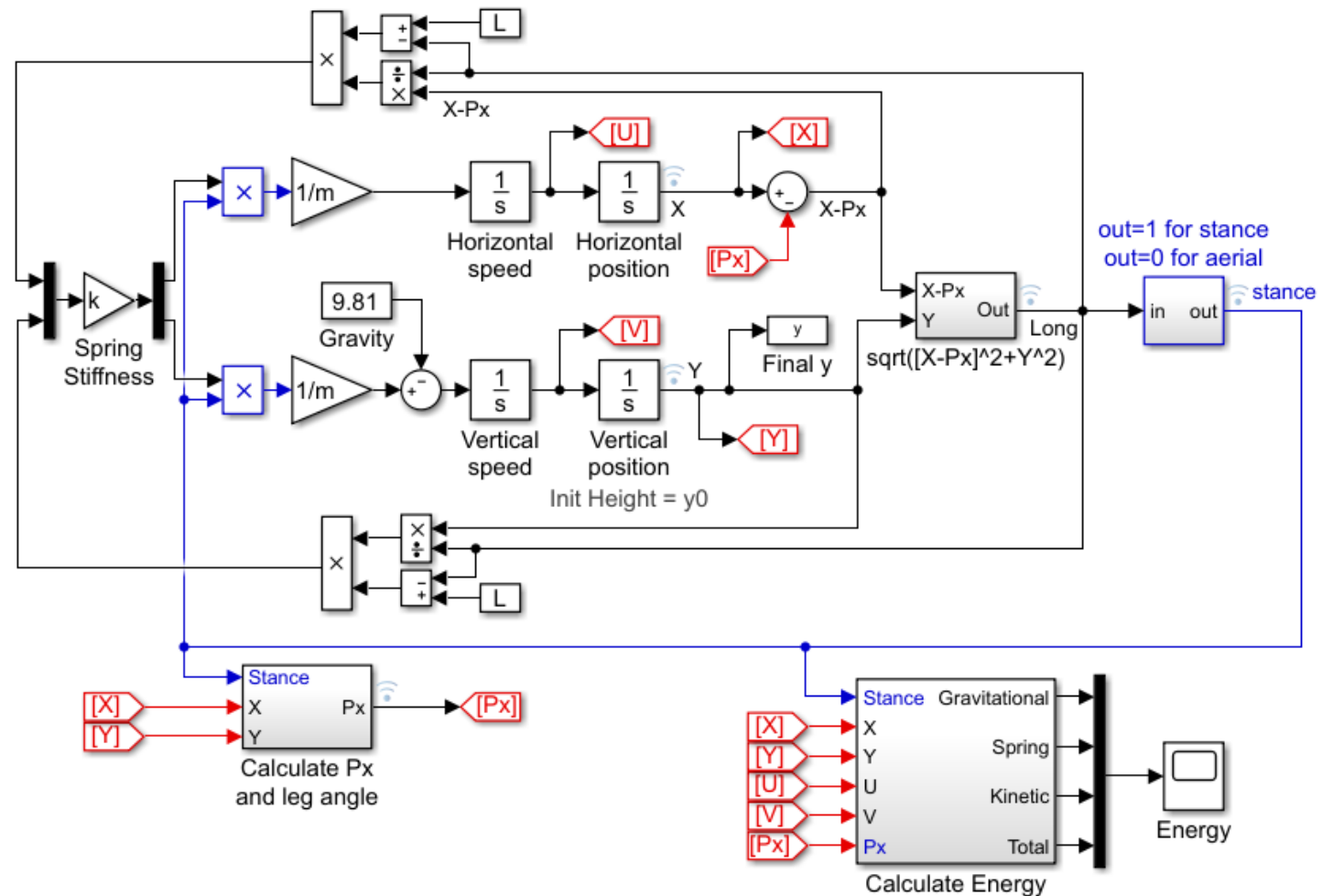
## Design Steps

### Fixed parameters

- Leg length
- Running speed
- Mass

### Design parameters

- Leg (spring) stiffness
- Stance height





## Gait Selection

### Fixed parameters

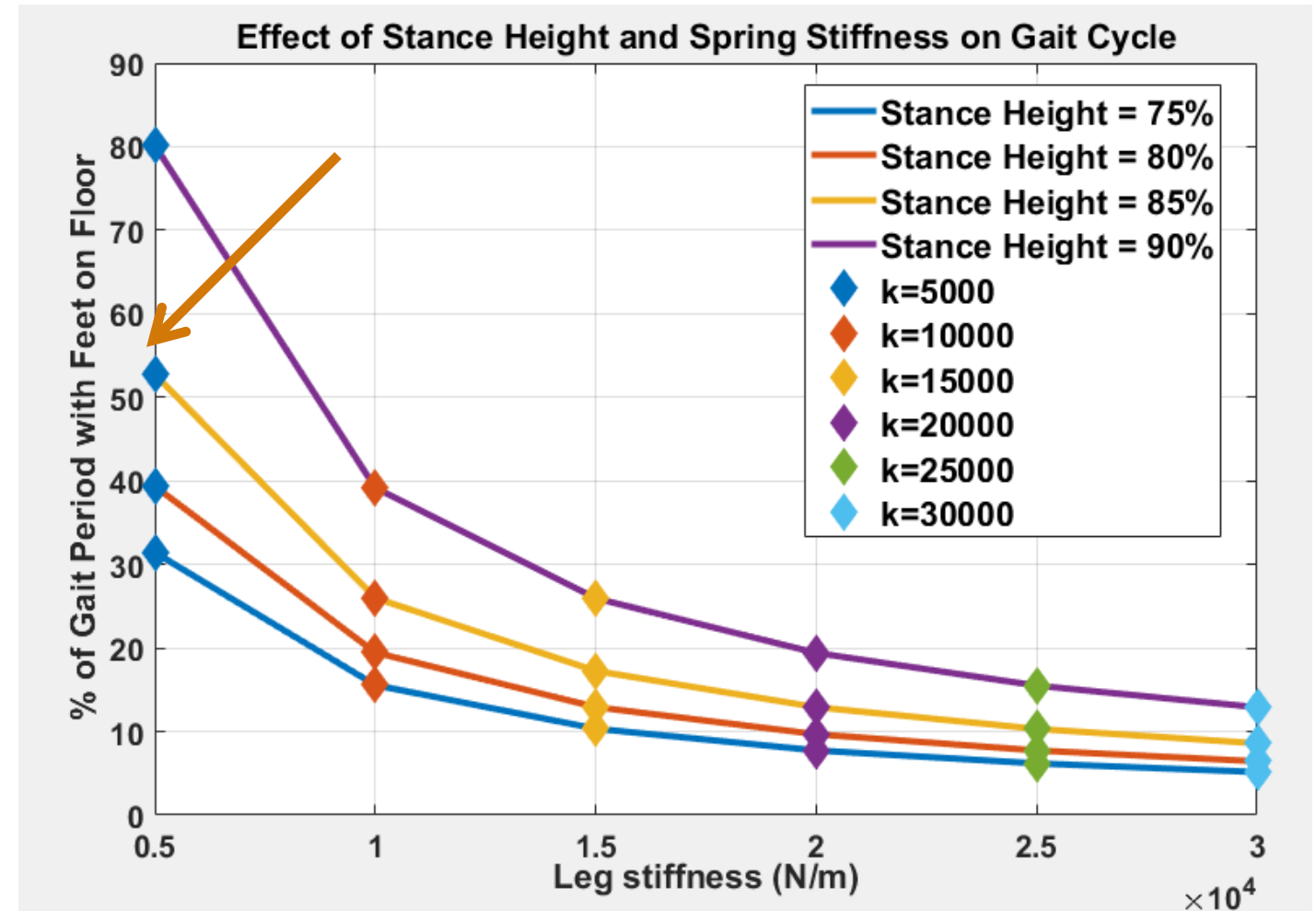
- Leg length
- Running speed
- Mass

### Design parameters

- Leg (spring) stiffness
- Stance height

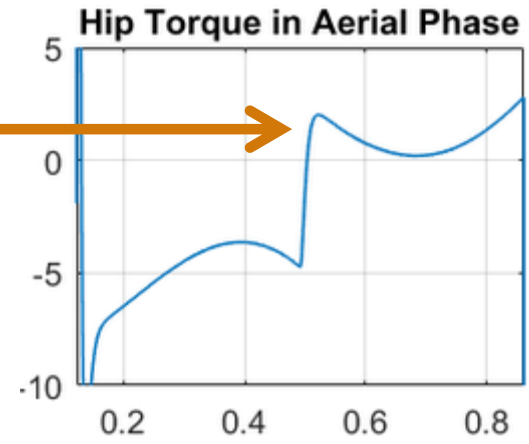
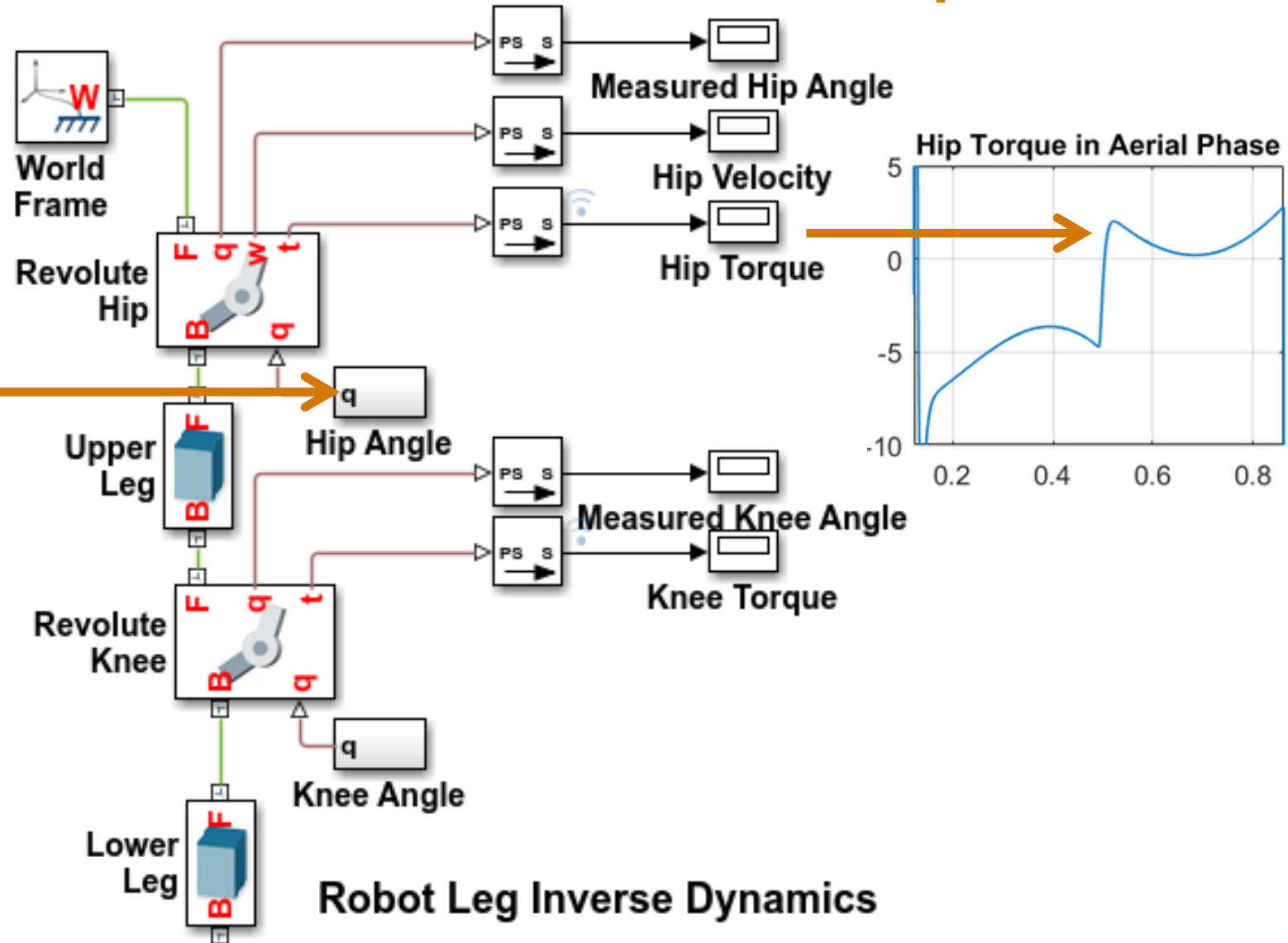
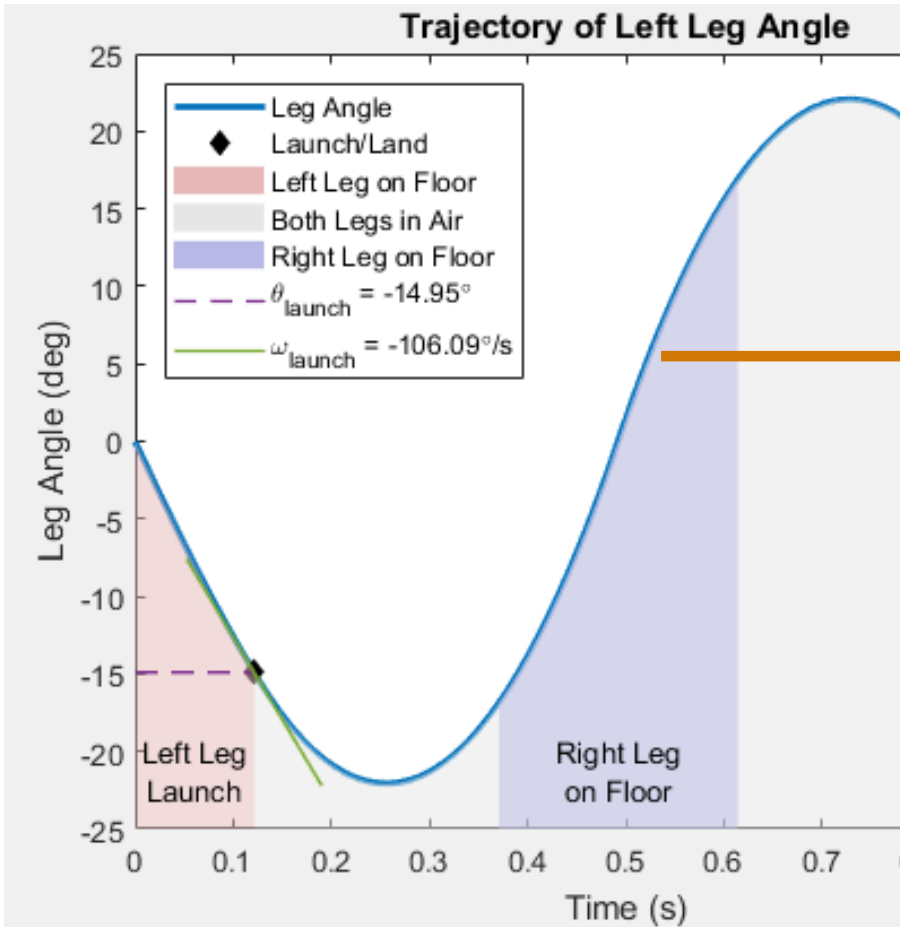
### Simple point-mass model

- MATLAB script for trade-off



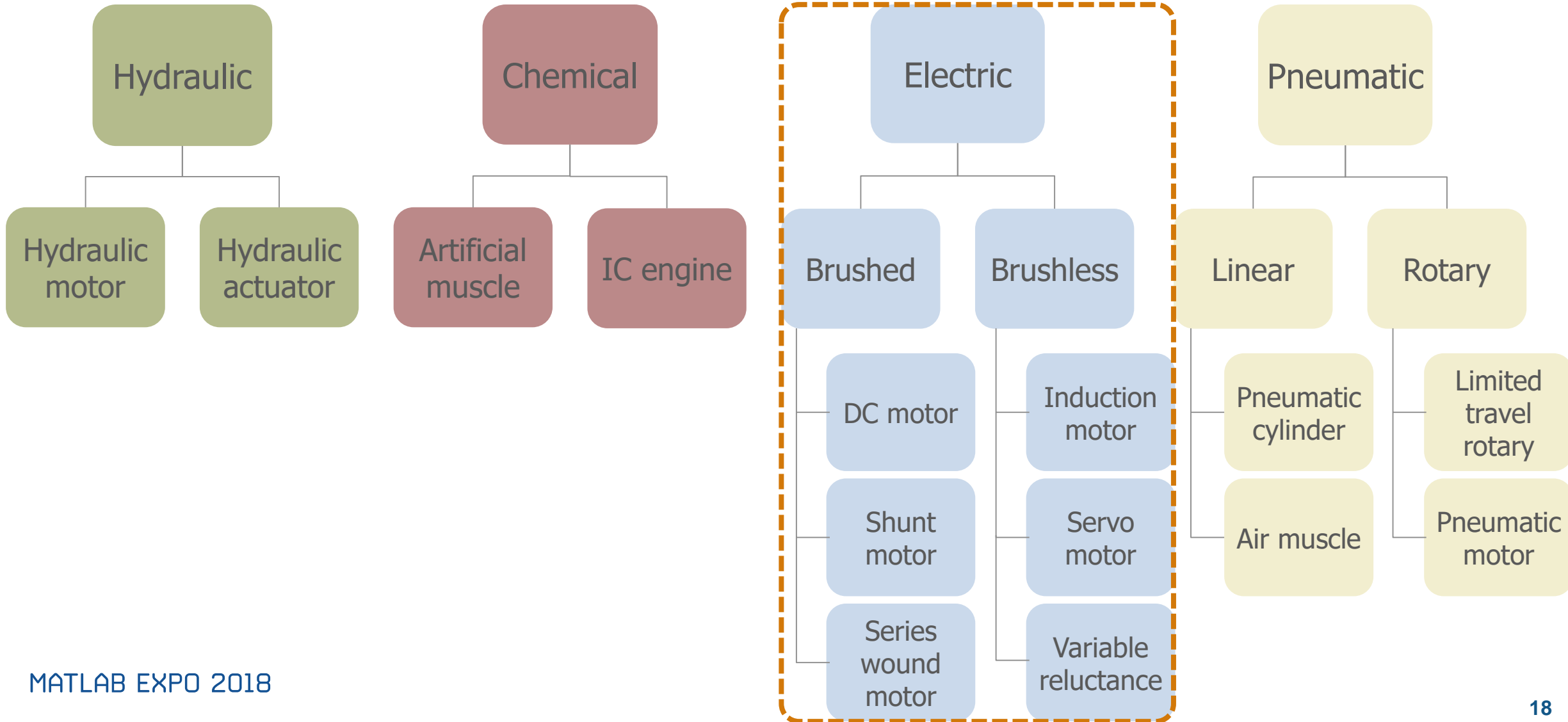


# Actuator Requirements



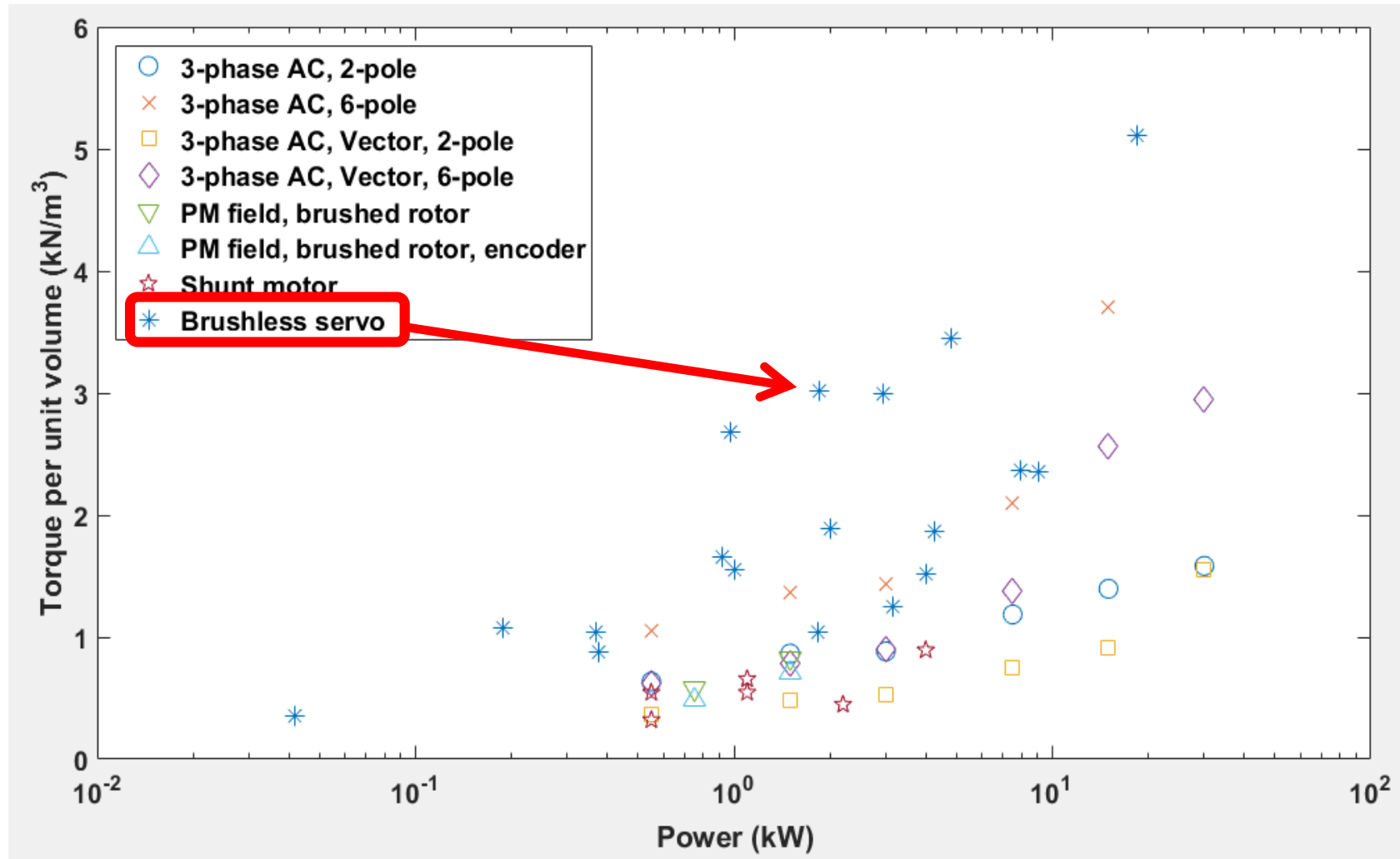


# Actuator Selection



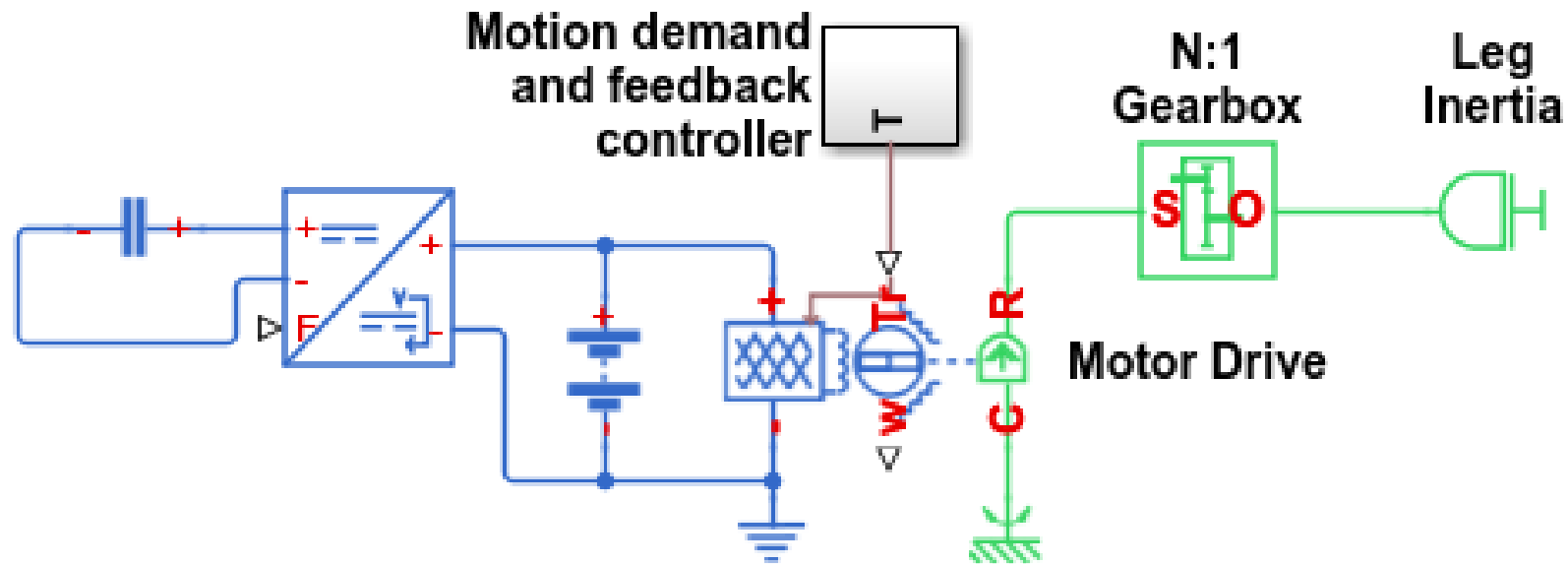


# Actuator Selection





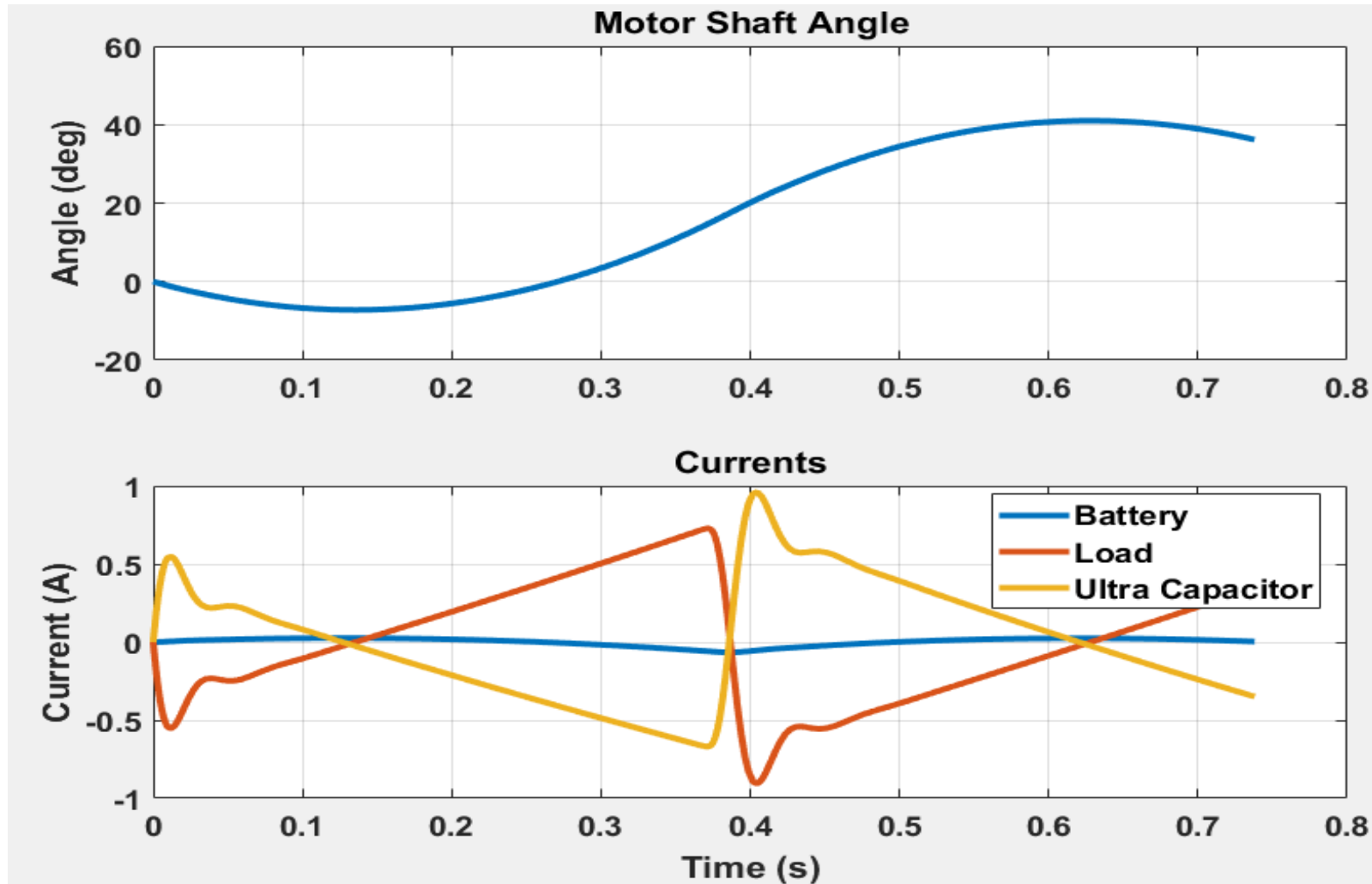
# Actuator Validation





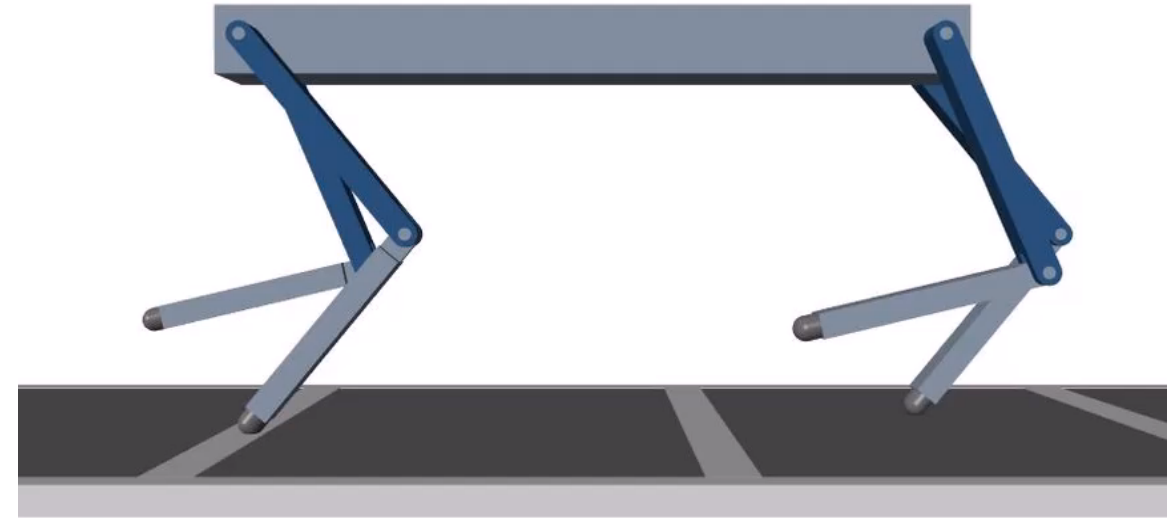
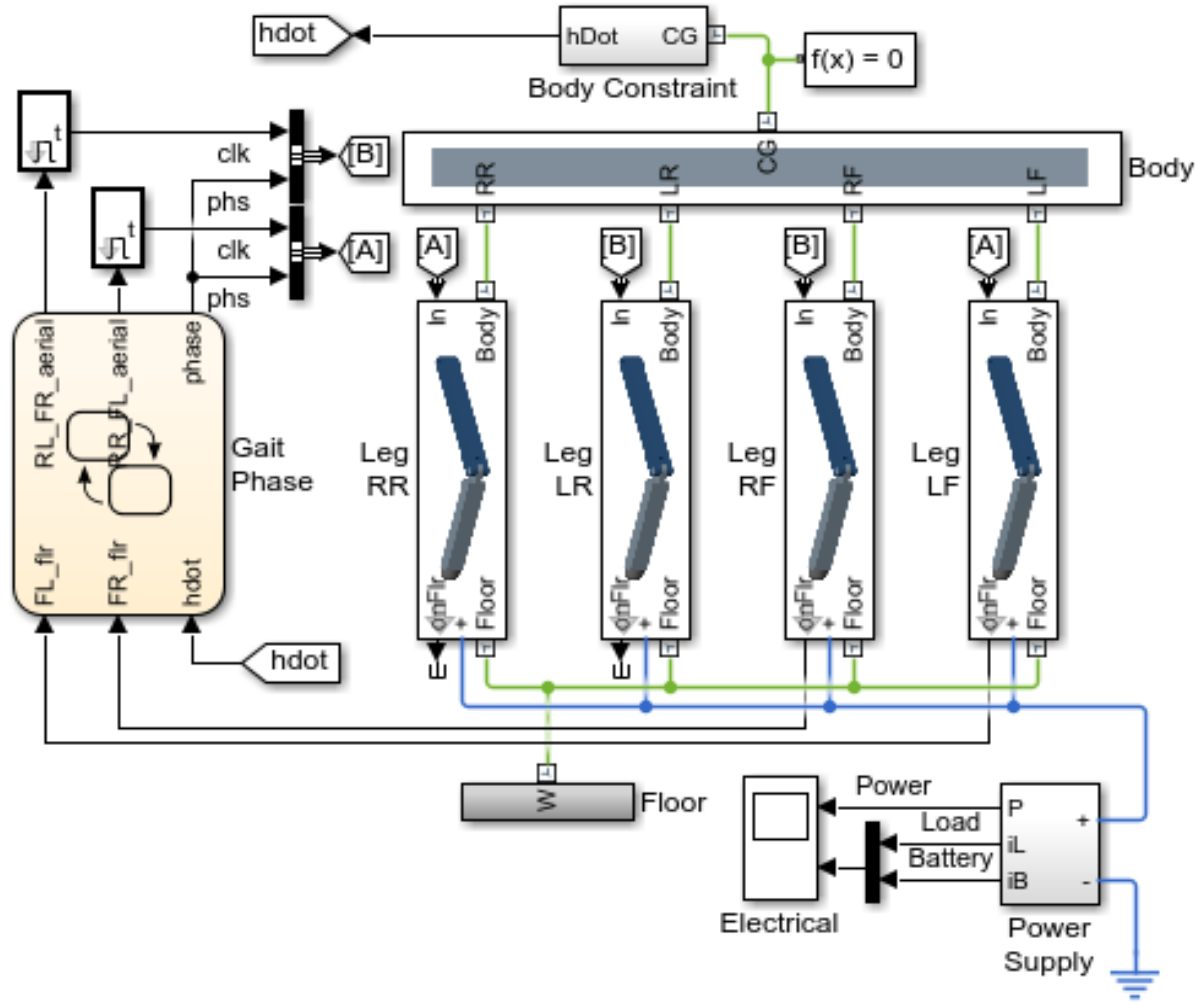


# Actuator Validation





# System Evaluation





## Automation

```

%% Generate nominal gait, leg length and payload mass

% Biomechanical parameters
L = 1.0;    % Leg length (m)
m = 25;    % Mass (Kg)
k = 5315;  % Leg stiffness (N/m)

% Initial conditions for normalized positions and speeds
x0 = 0.0;   % Horizontal position of mass in middle of stance phase ()
y0 = 0.85*L; % Height of mass in middle of stance phase ()
u0 = 2.0;   % Horizontal speed in middle of stance phase (/s)

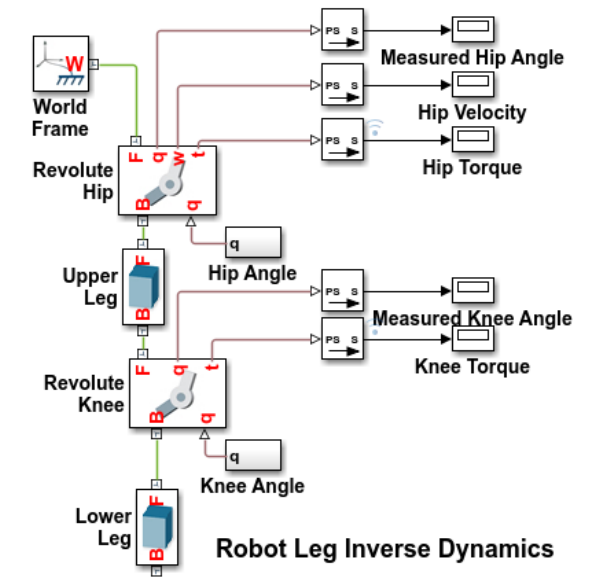
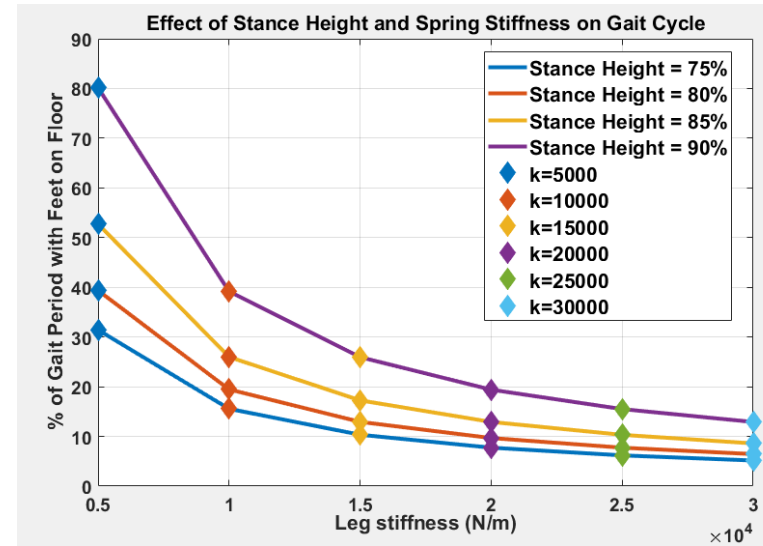
```

- facilitates iterations
- permits greater understanding of design trade-offs

Example:

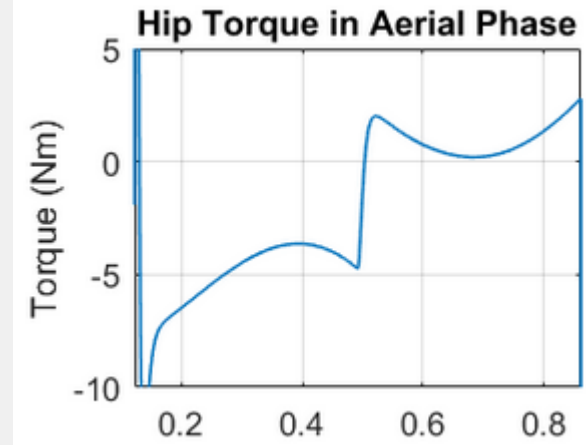
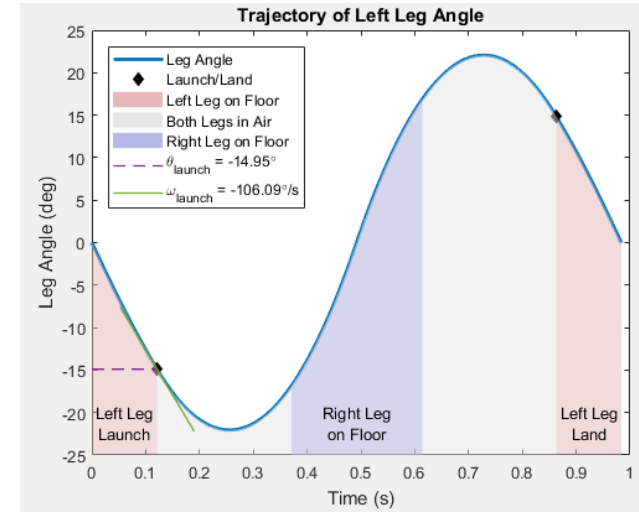
Gear ratio	80	100	120
Efficiency	84%	81%	78%

# Multiple models



# Multiple models

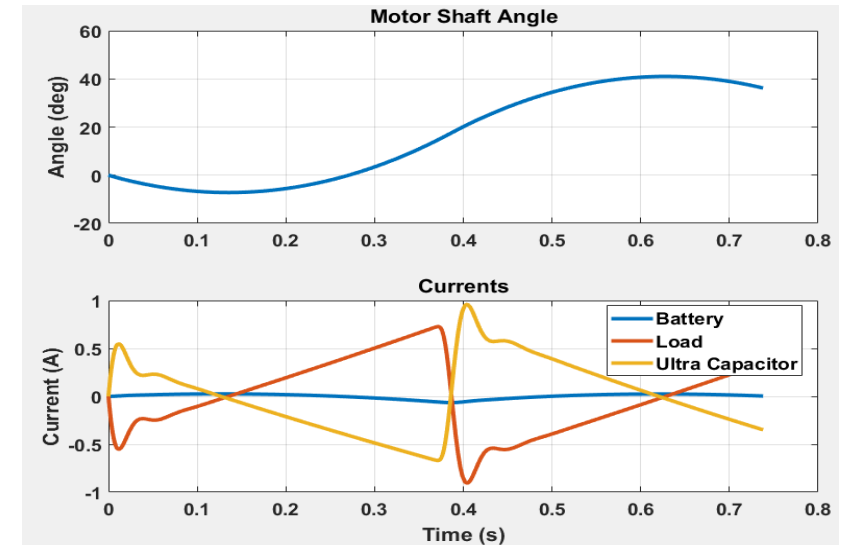
Each model matched to a design task



## Multiple models

Each model matched to a design task

**Design data passed between models**





Multiple models

Each model matched to a design task

Design data passed between models

**Automation to support analysis & optimisation**

```
%% Generate nominal gait, leg length and payload mass

% Biomechanical parameters
L = 1.0;    % Leg length (m)
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% Initial conditions for normalized positions and speeds
x0 = 0.0;  % Horizontal position of mass in middle of stance phase ()
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```

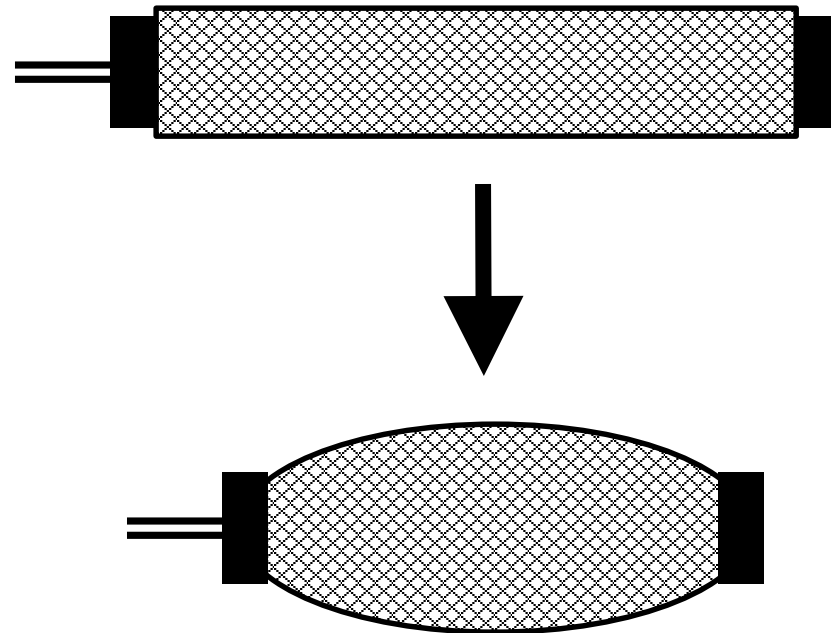
Multiple models

Each model matched to a design task

Design data passed between models

Automation to support analysis & optimisation

# Custom Simscape components



## Example: McKibben air muscle

**1**

Write out defining equations

**2**

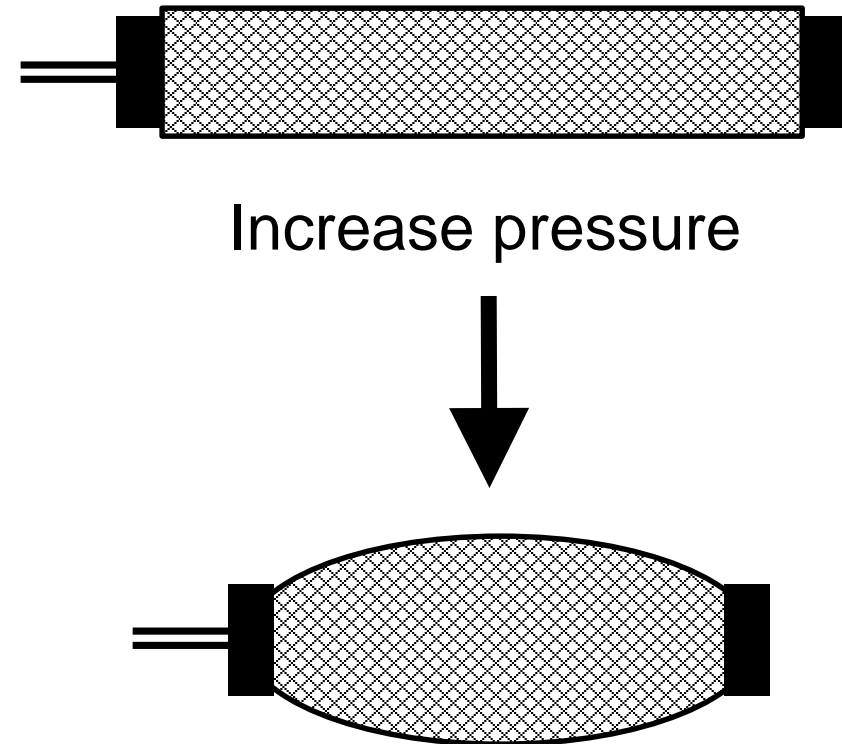
Find starting point in Simscape foundation library

**3**

Incrementally add functionality, testing as you go

**4**

Build library and test model



# 1 Write out equations

## Assumptions

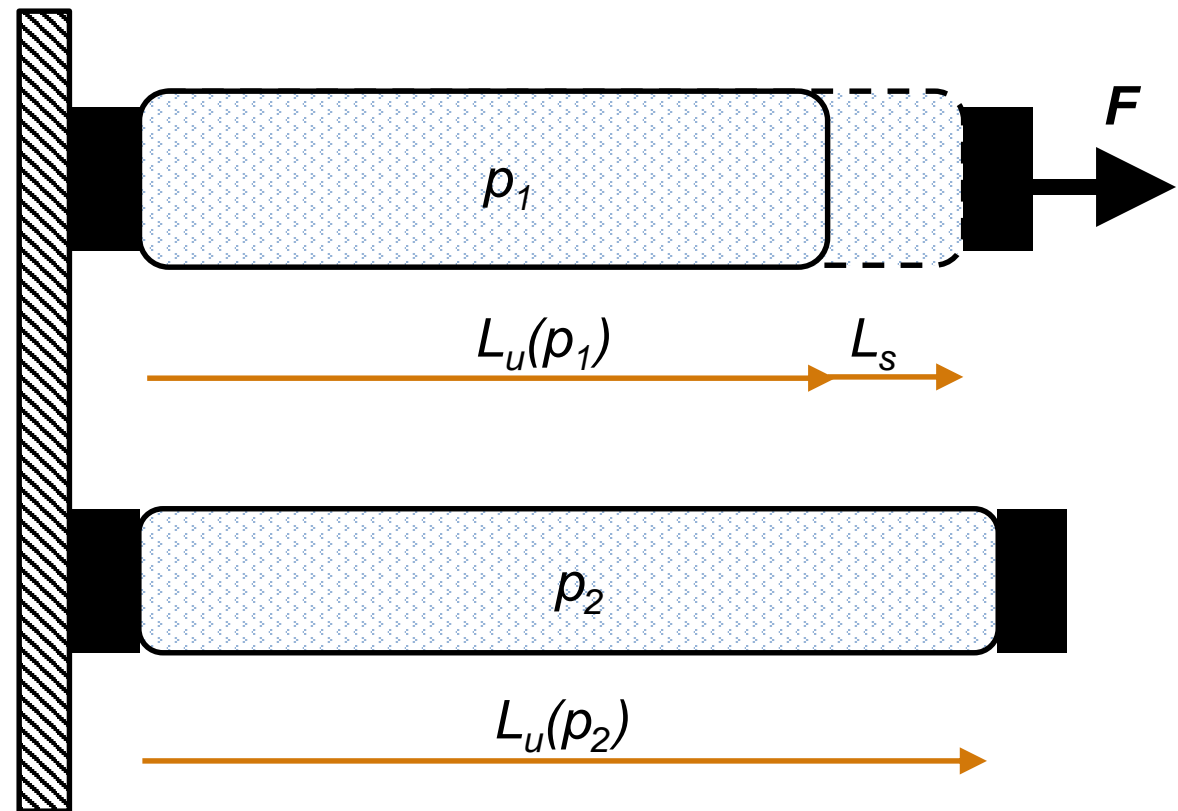
- Volume is approximately constant
- Stretch force is proportional to  $L_s$

## Equations

- $L = L_u(p) + L_s$
- $F = k \times L_s$
- $pV = nRT$

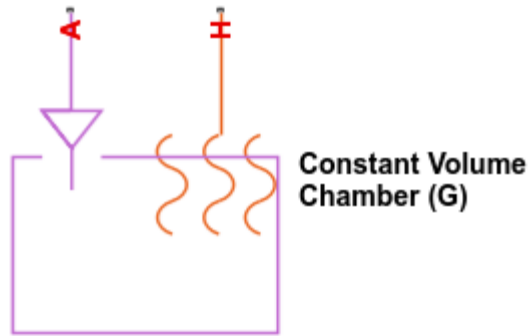
$L_u$  = Un-stretched length

$L_s$  = Additional stretch due to force,  $F$



## 2

## Find starting point from foundation library



But:

- Need mechanical ports
- Need equations

Block Parameters: Constant Volume Chamber

Constant Volume Chamber (G)

This block models mass and energy storage in a gas network. It contains a constant volume of gas. The pressure and temperature are based on the compressibility and thermal capacity of this gas.

Port A is the gas conserving port associated with the chamber. Port H is the thermal conserving port associated with the temperature of the gas inside the chamber.

[Source code](#)

Settings

Parameter variables

Chamber volume: 0

Cross-sectional area at port A: 0

```

1 component constant_volume_chamber < foundation.gas.one_port_v
2 % Constant Volume Chamber (G)
3 % This block models mass and energy storage in a gas network.
4 % contains a constant volume of gas. The pressure and temperat
5 % based on the compressibility and thermal capacity of this g
6 %
7 % Port A is the gas conserving port associated with the chambe
8 % H is the thermal conserving port associated with the temper
9 % gas inside the chamber.
10
11 % Copyright 2016 The MathWorks, Inc.
12
13 nodes
14     H = foundation.thermal.thermal; % H:top
15 end
16
17 parameters
18     volume = {0.001, 'm^3'}; % Chamber volume
19     area_A = {0.01, 'm^2'}; % Cross-sectional area at port A
20 end
21

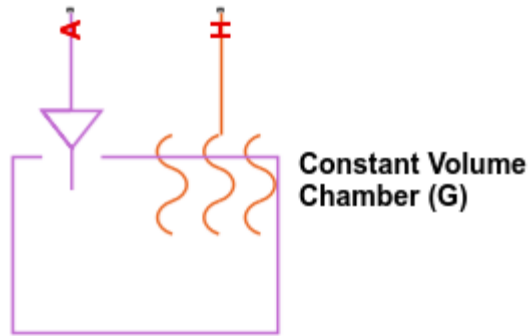
```

Simscape model file



## 3

## Incrementally add functionality



Add:

- Two mechanical ports

```

1  component air_muscle < foundation.gas.one_port_vertical
2  % Air Muscle (G)
3  % This block models a McKibben air muscle.
4
5  % Copyright 2016-2017 The MathWorks, Inc.
6
7  nodes
8  |   H = foundation.thermal.thermal; % H:top
9  |   R = foundation.mechanical.translational.translational; % R:bottom
10 |   C = foundation.mechanical.translational.translational; % C:top
11 end

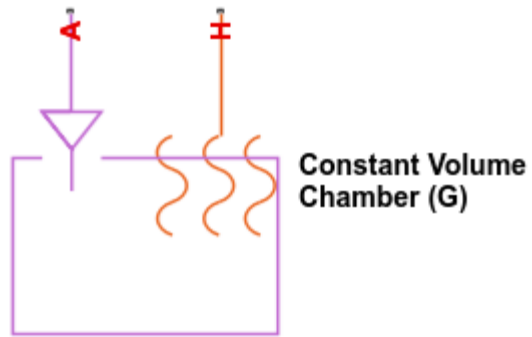
```

- Two additional new equations

$$L = L_u(p) + L_s \longrightarrow 152 \quad \mathbf{L} \quad == \quad \mathbf{Ls} + \mathbf{Lu};$$

$$F = k \times L_s \longrightarrow 153 \quad \mathbf{force} == \mathbf{K} * \mathbf{Ls};$$

### 3 Incrementally add functionality



Add definitions for:

- Variables
- Parameters

```

33 variables
34     % Mechanical variables
35     force = {0, 'N'}; % Force
36     Ls = {0, 'm'};    % Stretch
37 end

21 parameters
22     K = {140, 'N/cm'}; % Stiffness
23     pVec = {[0 1 2 3 4 5 6] , 'bar'}; %
24     LuVec = {[30 27.3 25.1 23.5 22.3
25 end
  
```

## 4 Building library and test model

Block Parameters: McKibben Air Muscle

Air Muscle (G)

This block models a McKibben air muscle

[Source code](#)

Settings

Parameters Variables

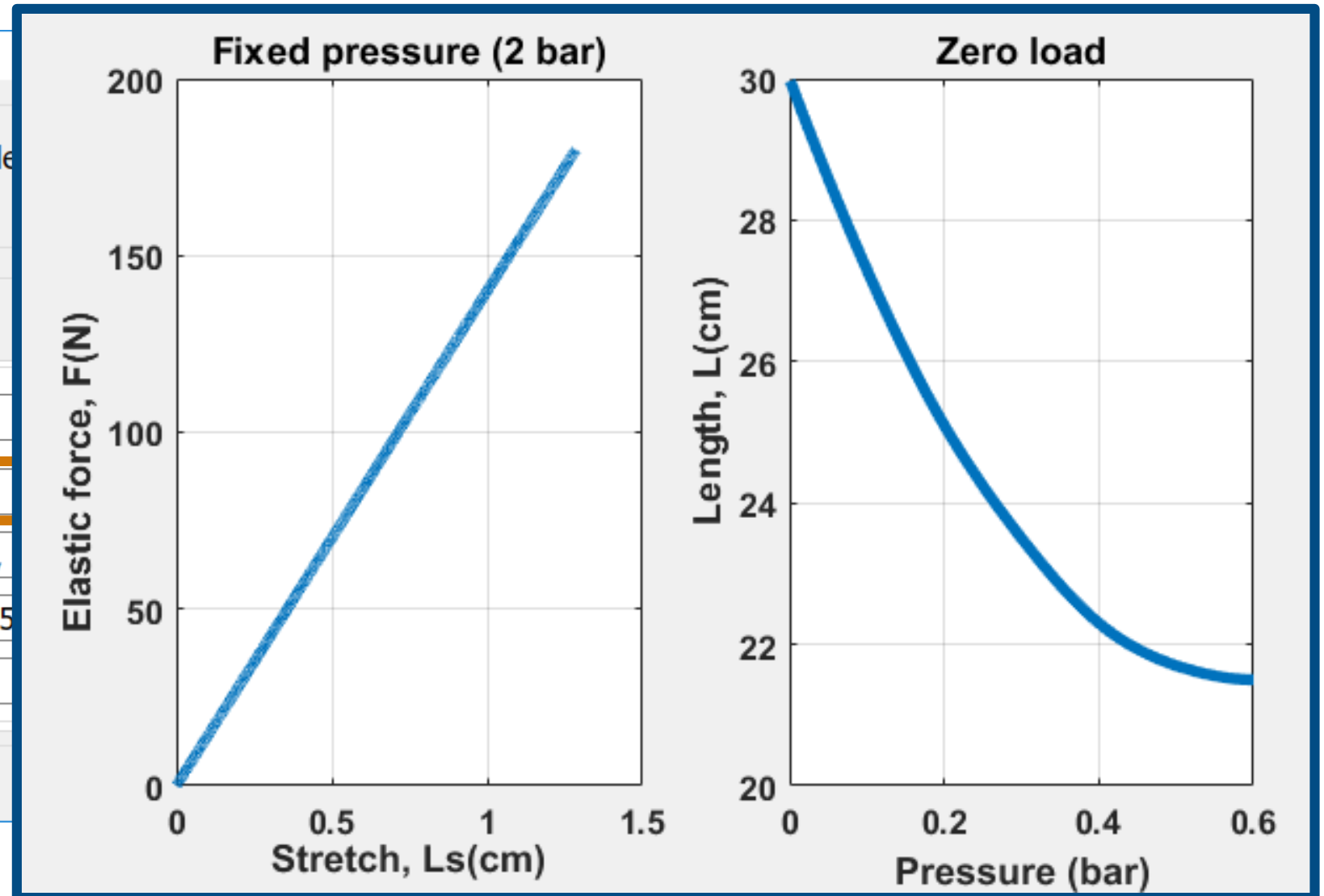
Cross-sectional area at port A: 0.01

**Stiffness: 140**

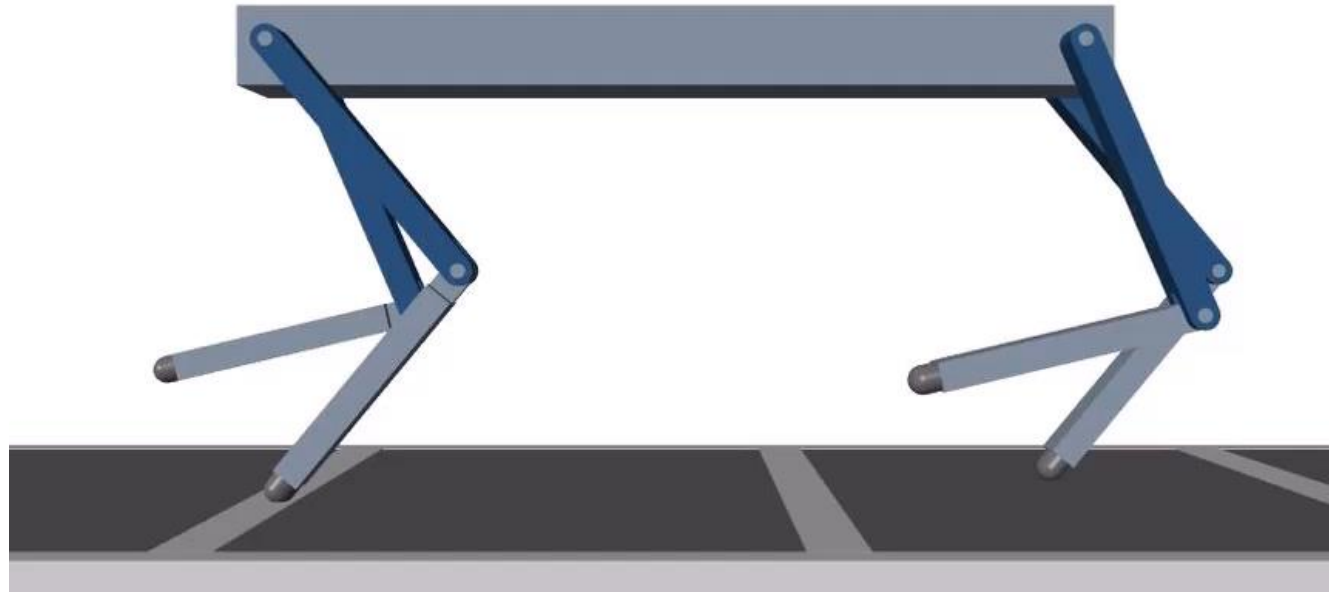
Pressures: [0.0, 1.0, 2.0, ...]

Unstretched lengths: [7.3, 25.1, 23.5, ...]

Volume: 85



# Why use Simscape?



# Building the right model







## PHYSICS

*The science where you use long formulas to explain why a ball rolls*



## PERFECTION

*Have no fear of perfection, you will never reach it*



## DATA

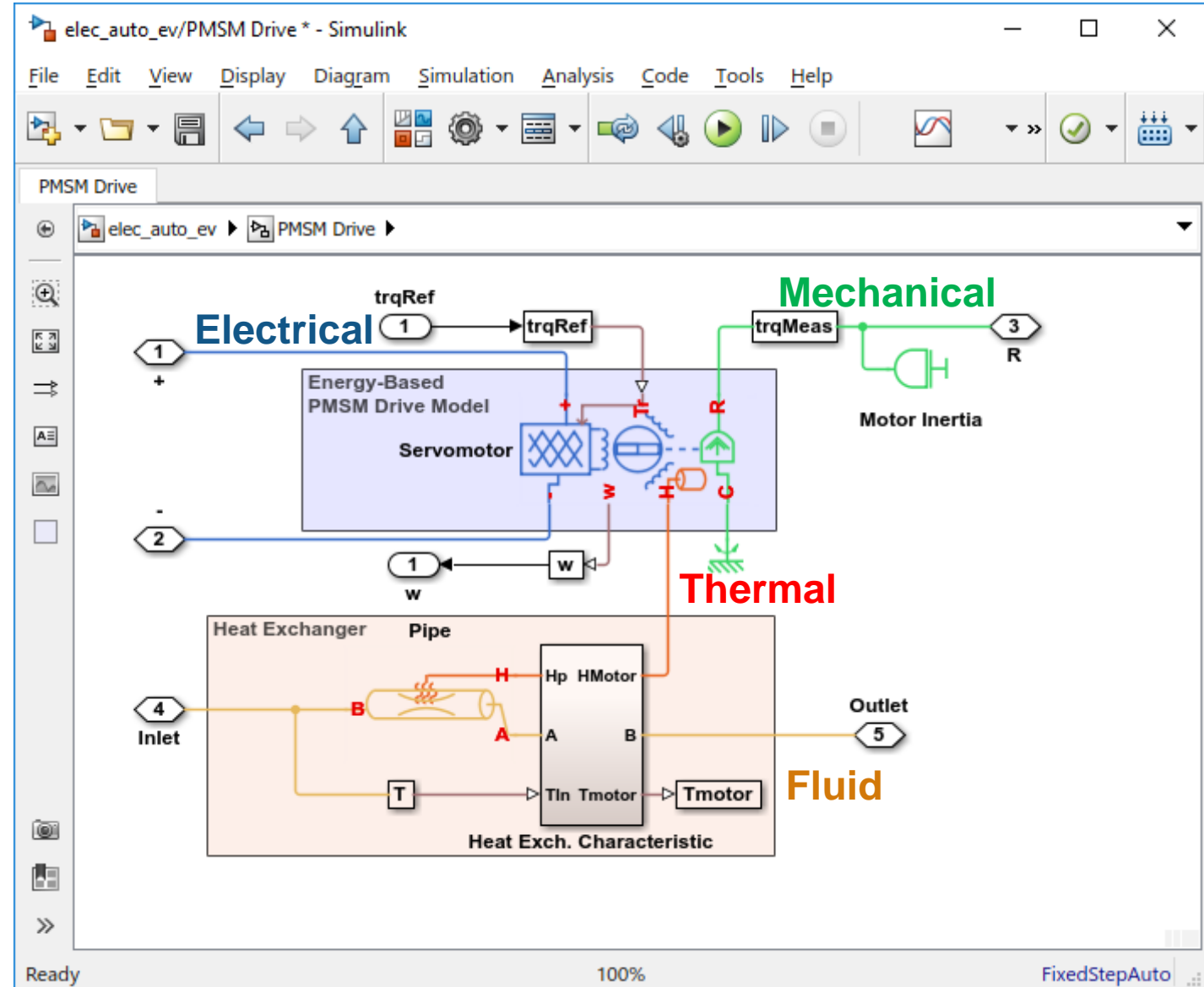
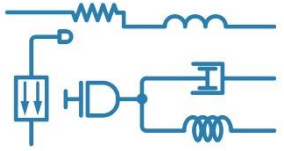
*People can make up statistics to prove anything ! ... 14% of people know that*



## TIME

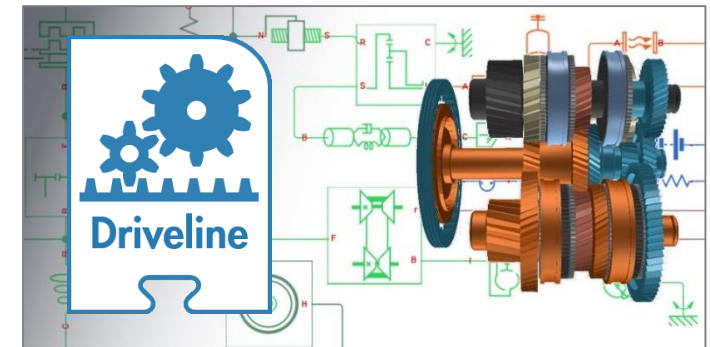
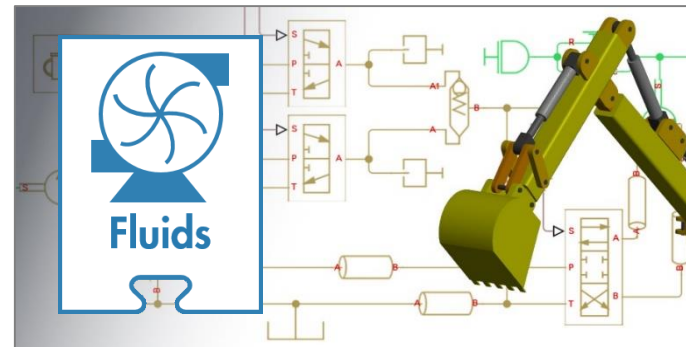
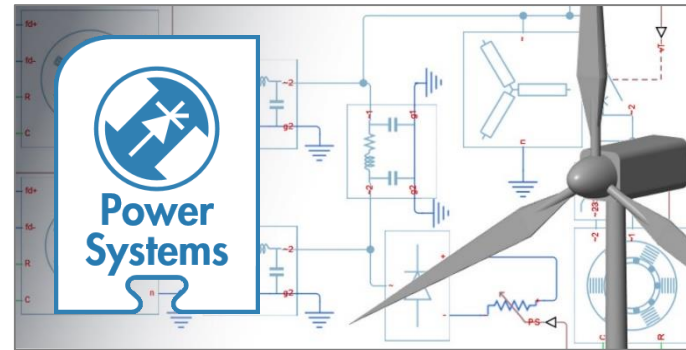
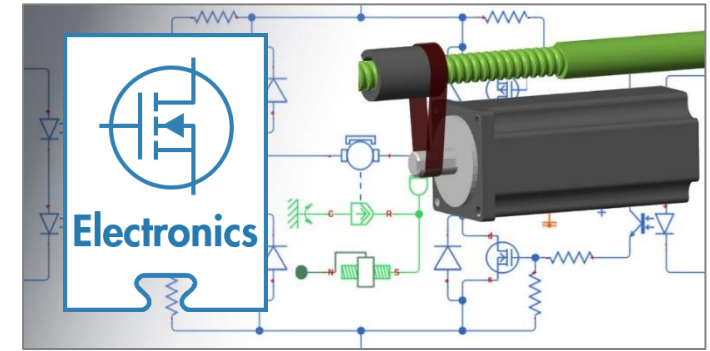
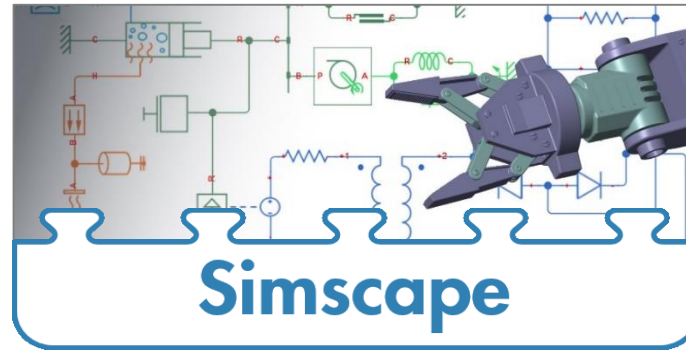
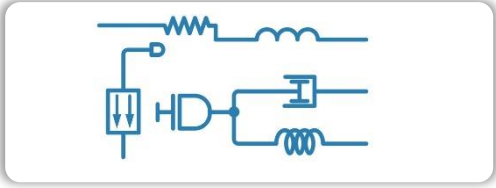
*Some people have too much of it*

# Multidomain



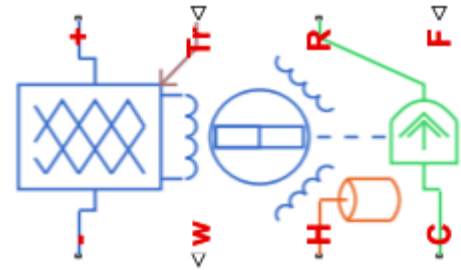
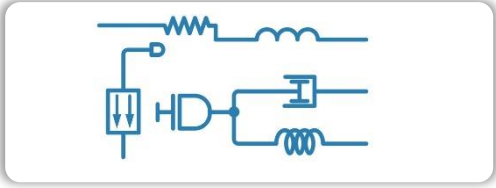


# Multidomain

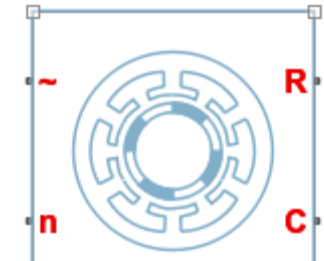




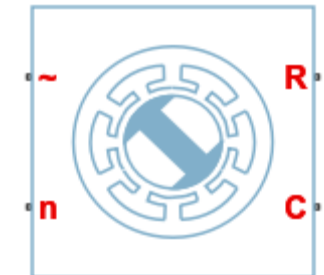
# Multidomain



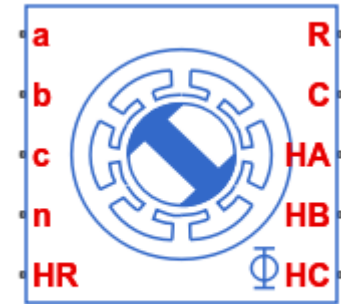
Servomotor



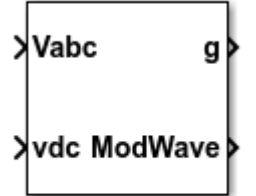
Brushless DC Motor



Permanent Magnet Synchronous Motor



FEM-Parameterized PMSM



PWM Generator (3-phase, 2-level)



PWM Generator (3-phase, 3-level)



Encoder

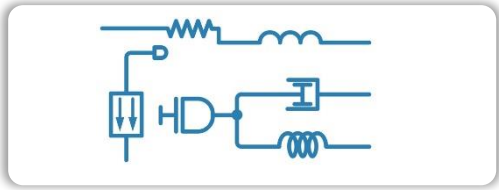


Resolver




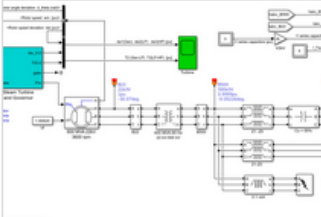
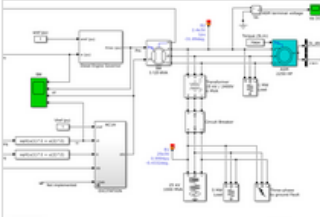
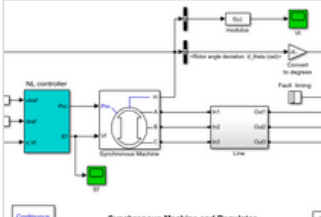
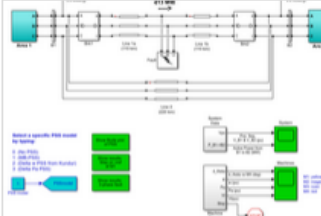
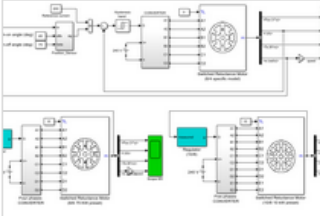
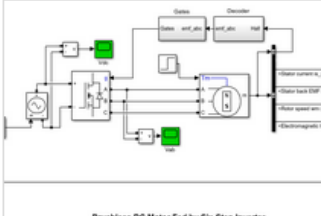


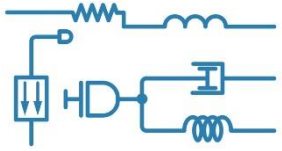
Modeling detail

# Multidomain



# Useful starting points

 <p><b>Permanent Magnet Synchronous Machine</b></p> <p>The Permanent Magnet Synchronous Machine in a closed-loop speed and current control on a 1.1 kW, 3000 rpm industrial motor.</p> <p><a href="#">Open Model</a></p>	 <p><b>Five-Phase Permanent Magnet Synchronous Machine</b></p> <p>The use of the Five-Phase PMSM and the Three-Phase PMSM in a closed-loop speed and current control on two 4.4 kW industrial</p> <p><a href="#">Open Model</a></p>	 <p><b>Starting a DC Motor</b></p> <p>The starting of a 5 HP 240V DC motor with a three-step resistance starter.</p> <p><a href="#">Open Model</a></p>
 <p><b>Steam Turbine and Governor System - Sub-synchronous...</b></p> <p>Sub-synchronous resonance (SSR) in Steam Turbine and Governor on a series-compensated network.</p> <p><a href="#">Open Model</a></p>	 <p><b>Emergency Diesel-Generator and Asynchronous Motor</b></p> <p>The Machine Load Flow tool of Powergui block to initialize an induction motor/diesel-generator system.</p> <p><a href="#">Open Model</a></p>	 <p><b>Synchronous Machine and Regulator</b></p> <p>The nonlinear control of a hydraulic turbine and a synchronous generator.</p> <p><a href="#">Open Model</a></p>
 <p><b>Performance of Three PSS for Interarea Oscillations</b></p>	 <p><b>Switched Reluctance Motor</b></p>	 <p><b>Brushless DC Motor Fed by Six-Step Inverter</b></p>



## Build custom components!

```

equations
  if v > Vf
    i == (v - Vf*
  else
    i == v*Goff;

```

## Simscape Language

```
parameters
```

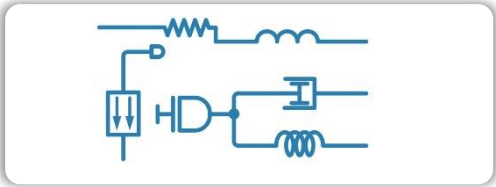
```
  K = {140, 'N/cm'}; % Stiffness
```

```
  pVec = {[0 1 2 3 4 5 6] , 'bar'}; % Pressures
```

```
  LuVec = {[30 27.3 25.1 23.5 22.3 21.7 21.5] , 'cm'};
```

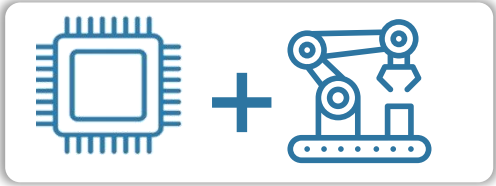
```
end
```



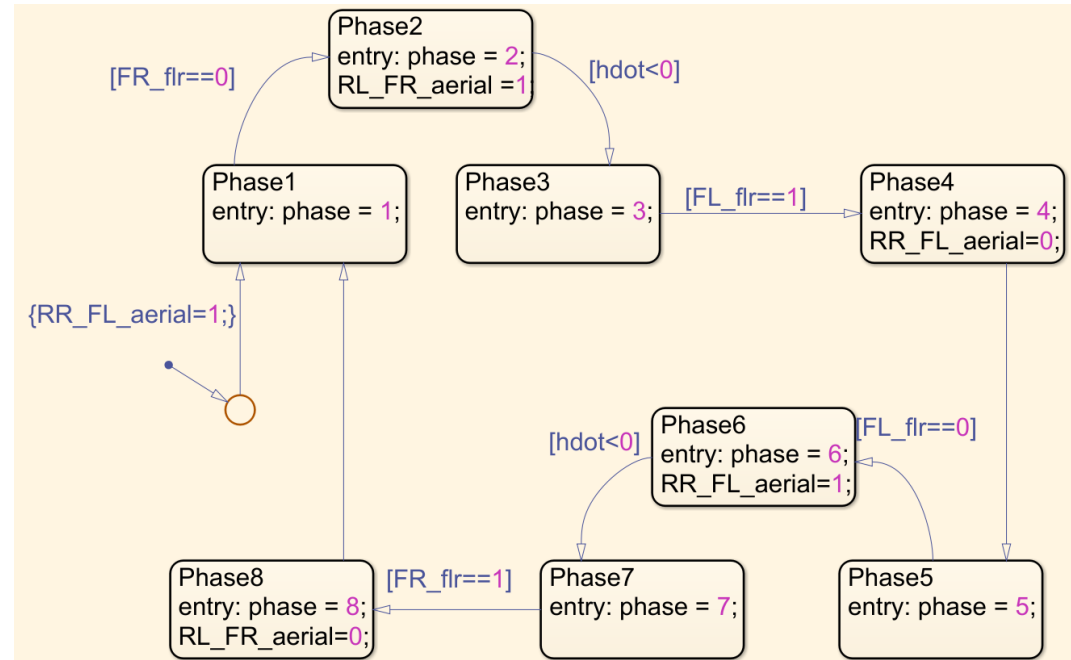
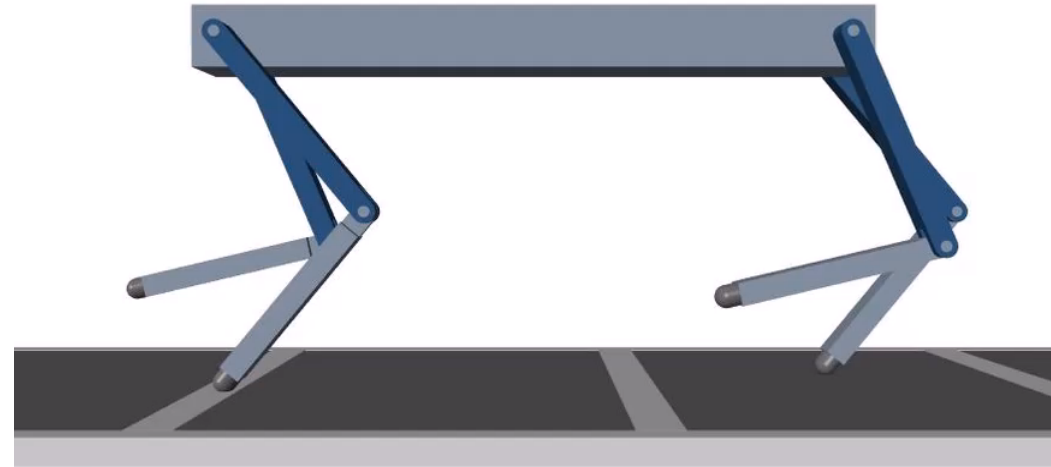


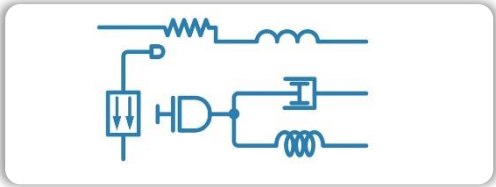
```

equations
  if v > Vf
    i == (v - Vf*
  else
    i == v*Goff;
  
```



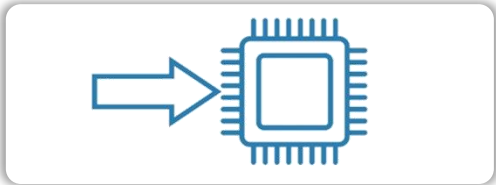
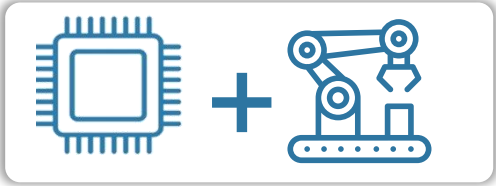
# Control





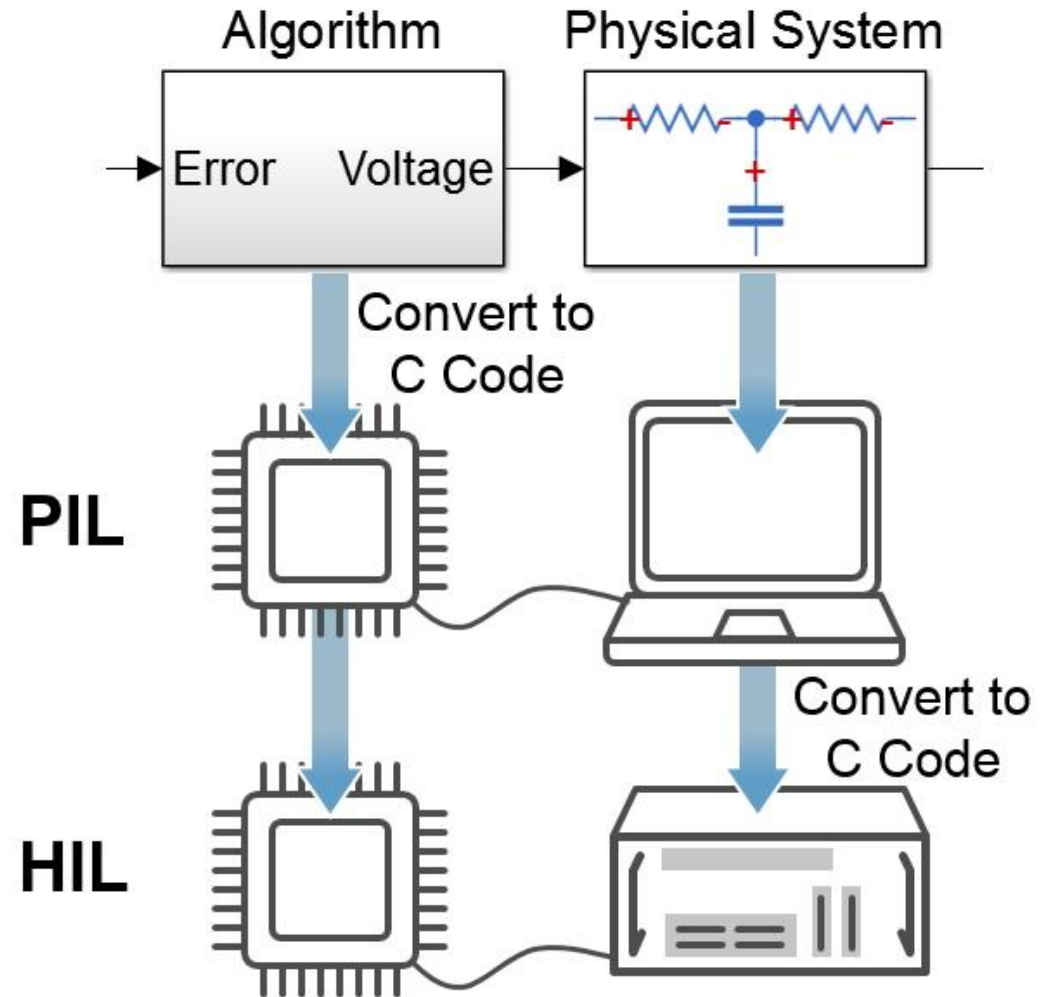
```

equations
if v > Vf
    i == (v - Vf*
else
    i == v*Goff;
    
```

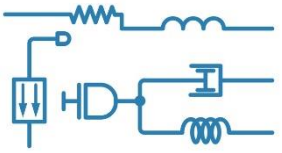


**Code  
Generation**

## Testing without hardware prototypes!



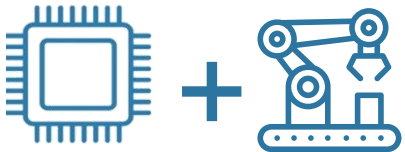
# CONCLUSION



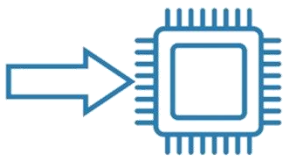
**Multidomain**

```
equations
if v > Vf
    i == (v - Vf*
else
    i == v*Goff;
```

**Simscape  
Language**



**Control**



**Code  
Generation**