Modeling and simulation of multi-domain, dynamical systems

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Senior Sales Representative

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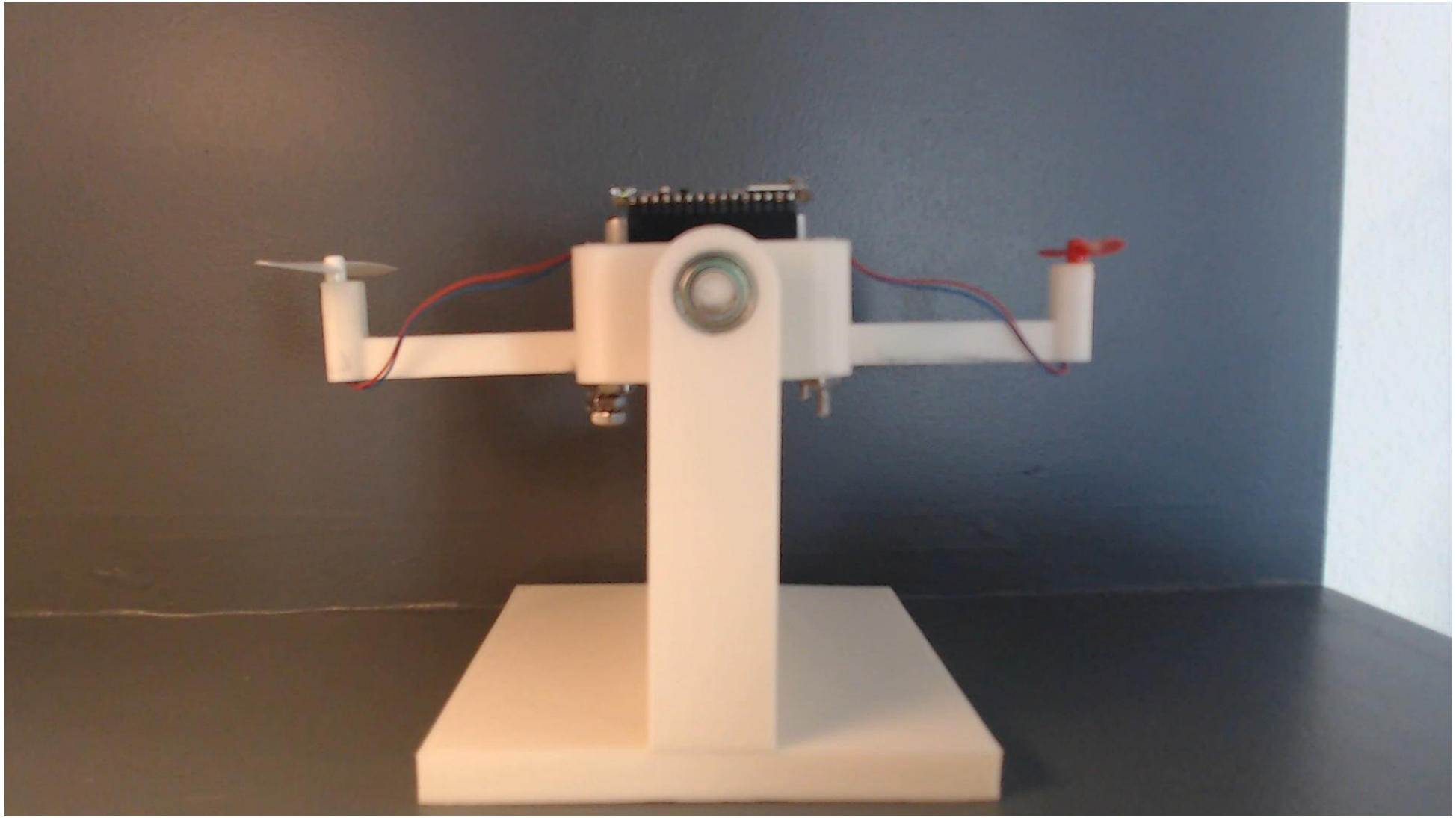
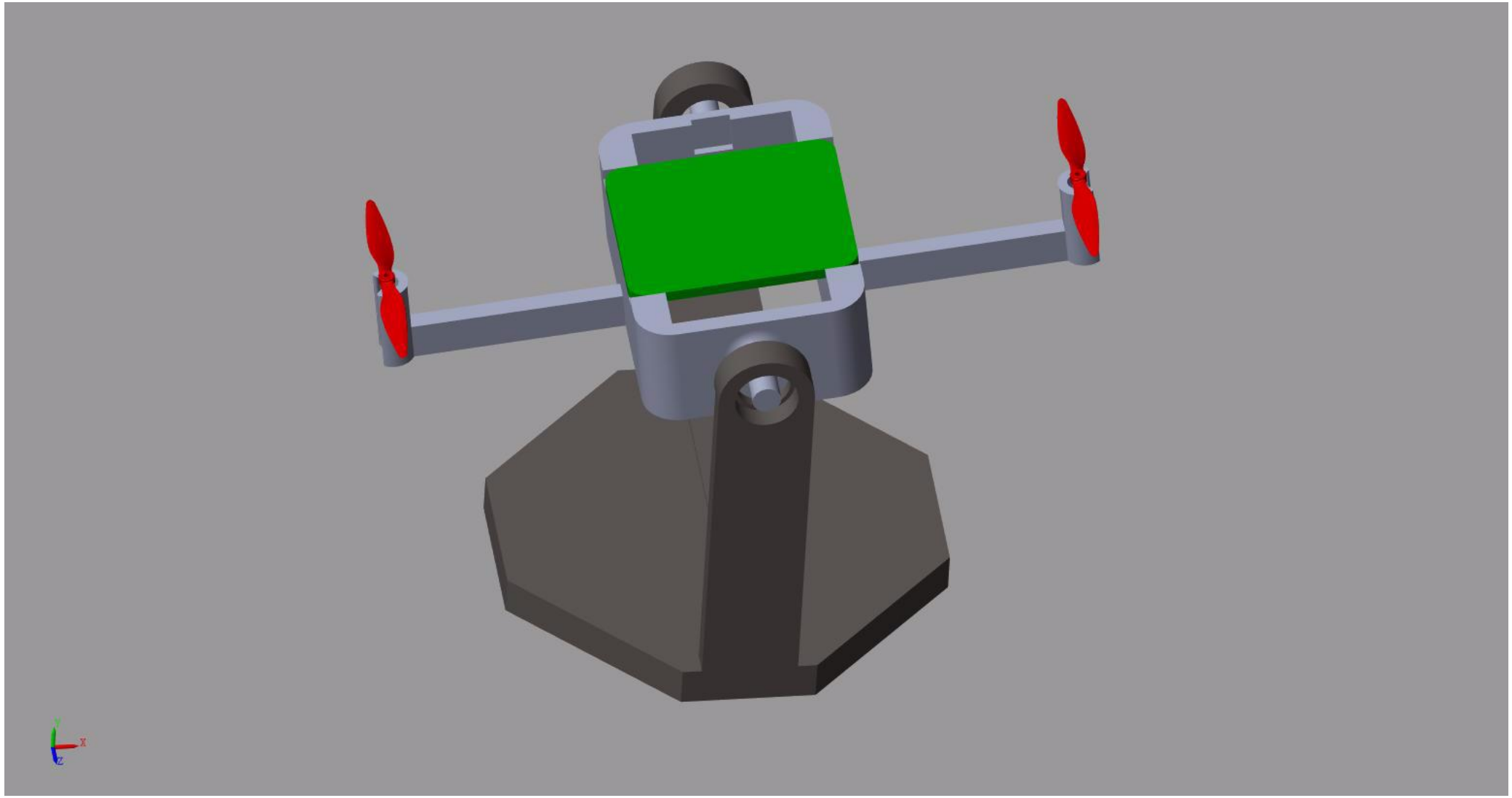
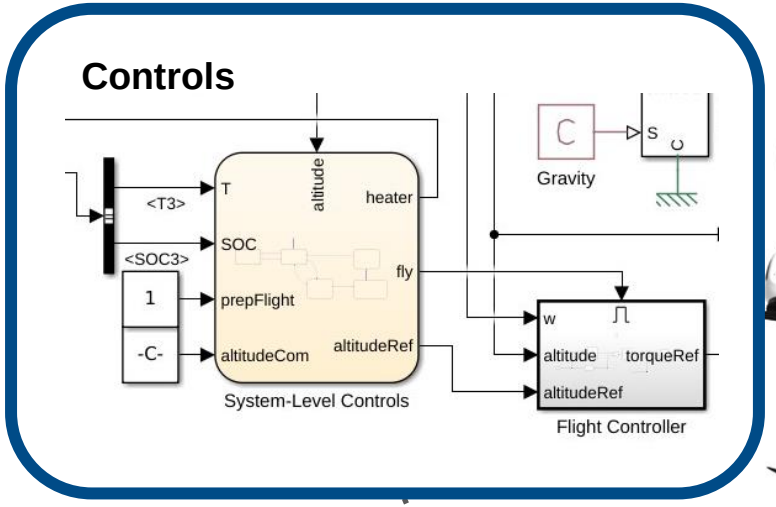
Bicopter in operation

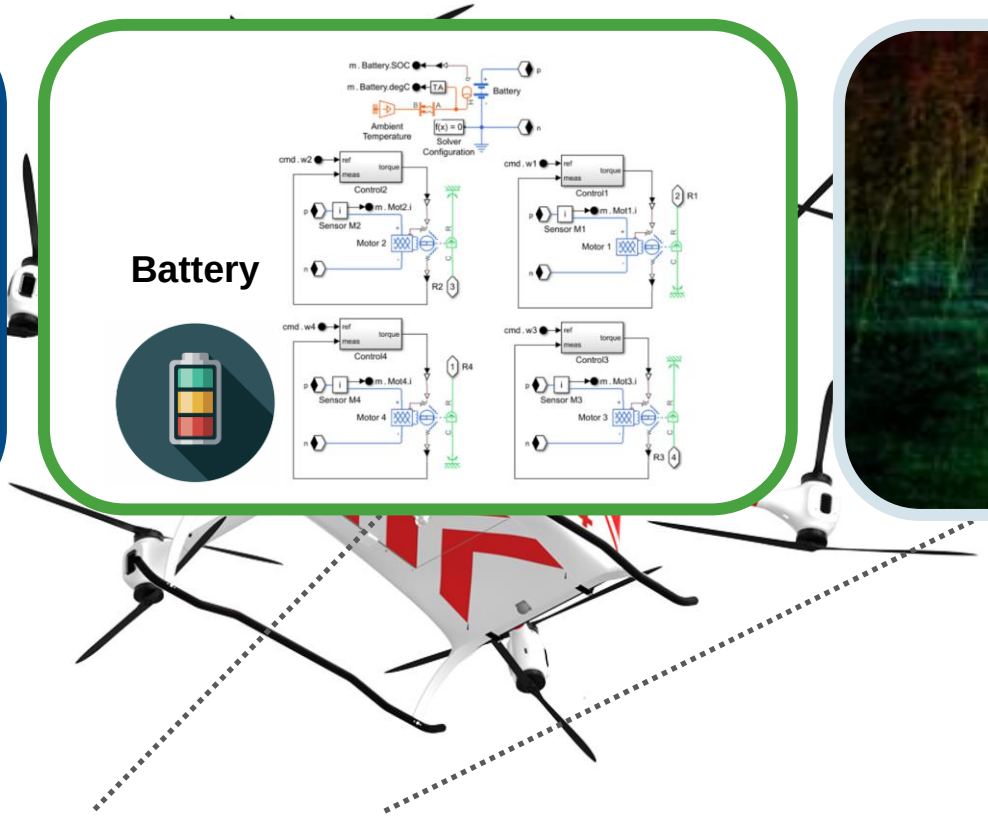


Bicopter simulation (2X speed)



Engineering Systems are Dynamical and Multidomain





Aerospace **Mechanical** **Electrical** **Computer** **Chemical** **Civil** **Environmental**

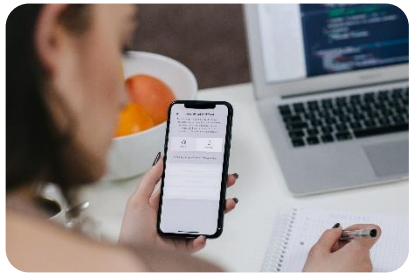
Avilus Autonomous Rescue Drone

Where do we find multi-domain systems?

Aerospace and Defense

Automotive

Industrial Machinery



Electronics

Renewable Energy

Medical Devices

Metals, Materials, Mining

Communications

Railway Systems

Industry seeks engineers with diverse skill sets beyond theory

HITACHI
Inspire the Next

Controls Software Engineer

Requirements:

- Proficient use of modeling & simulation software (MATLAB/Simulink strongly preferred)
- Familiarity with multi-body kinematics and dynamics
- Design of position, velocity, and torque feedback controllers
- Implementation and tuning of high-performance feedback control in software
- Signal processing experience (discrete/digital methods and algorithms)

LILIUM

Modeling & Simulation Engineer

Your Profile:

- M.Sc./PhD in Aeronautical Engineering or similar degree.
- 5+ years of professional experience in flight dynamics modelling or applied aerodynamics.
- Practical experience with the validation of flight dynamics models against flight test data, including:
- System Identification and its application
- Knowledge of applicable standards i.e. EASA FSTD (A)
- In-depth knowledge of the modelling of complex, nonlinear physical systems, aerodynamics and aircraft flight dynamics.
- Highly proficient in developing tools and models using Matlab/Simulink.

McLaren

Engineer – Battery Management System

- Technical knowledge of BMS hardware and software
- Technical knowledge of Energy Storage Systems and lithium ion battery desirable
- Embedded systems knowledge
- HiL (Hardware in the Loop) and Rig systems testing awareness desirable.

https://careers.hitachi.com/jobs/13638572-controls-software-engineer-irc204237
https://lilium.com/jobs/5331863
https://www.motorsportjobs.com/en/job/systems-engineer-electric-drive-controls

Industries standardize using MATLAB and Simulink

Jobs In F1: How To Become A Formula 1 Control Systems Engineer

"RedBull offered a Control Engineers position and explained that ***'coding and programming using MATLAB and Simulink was a daily task'"***

https://motorsportengineer.net/jobs-in-f1-how-to-become-a-formula-1-control-systems-engineer/

Academia also wants the same skills

Cranfield University

1. Dynamic systems – including Laplace transforms and state-space models.
2. Mathematics of basic circuit modelling.
3. Modelling/programming in MATLAB and Simulink.
4. Practical laboratory skills.
5. Technical writing.
6. Good verbal communication.

1495 UNIVERSITY OF ABERDEEN

- **A solid background with evidence in power systems and/or power electronics is essential.**
- **Experience in dynamic simulation tools (e.g., MATLAB/Simulink, PSCAD, etc.) is essential.**
- **Experience in hardware-in-the-loop experiments is preferred.**
- **Knowledge and experience in optimization theory is preferred.**

UNIVERSITY OF BIRMINGHAM

1. First-class degrees with a strong background in Automotive Engineering, Mechanical Engineering, Control Engineering, or Computer Science.

2. Be familiar with industrial development software i.e., Matlab, and Simulink.

3. Related research or industrial experience is desirable.

4. Related research publications.

5. Experience in industrial projects.

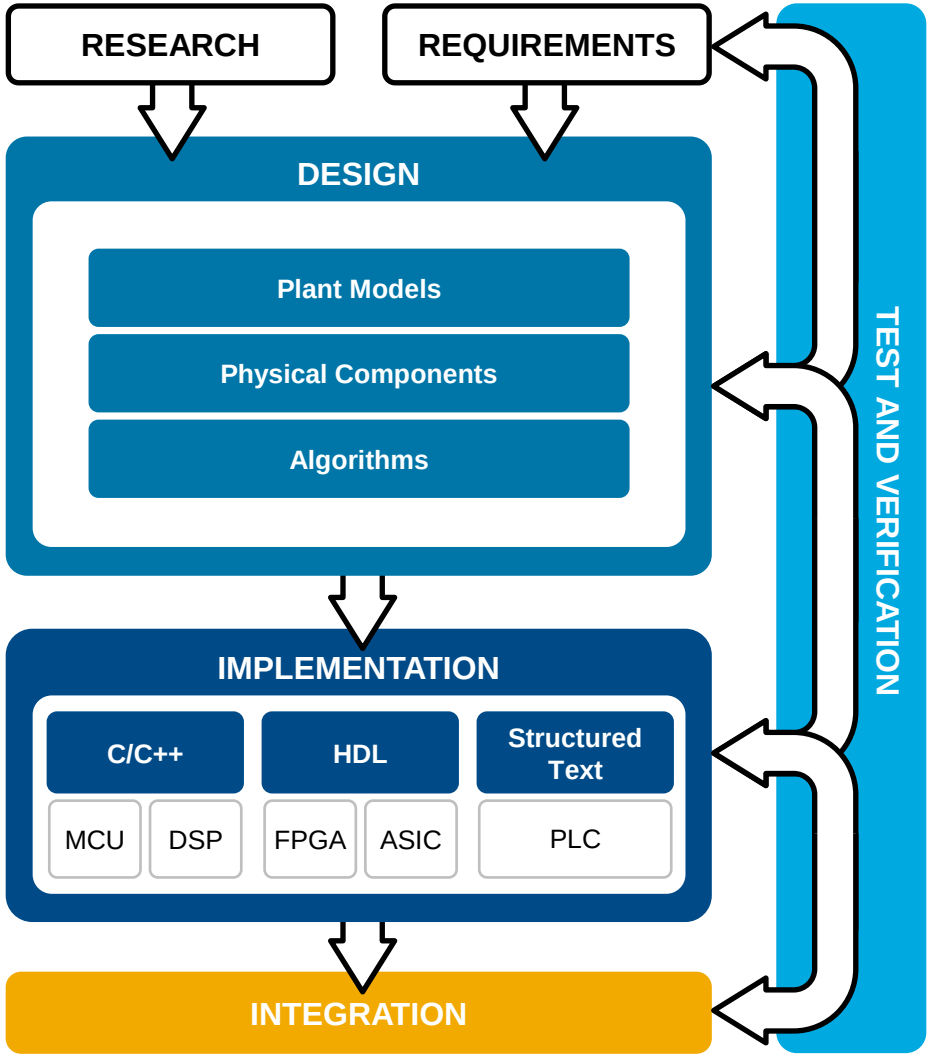
- MATLAB and Simulink
- Knowledge of multidomain systems
- Experience with hands-on projects (HiL / Deployment to Hardware)

Why Model-Based Design

- Modeling
- Implementation

Additional Resources

Model-Based Design Process

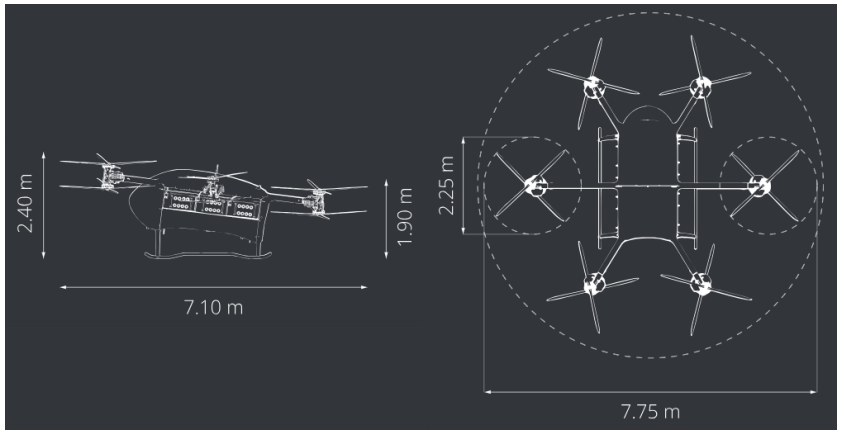


Virtual Design and Testing of an Autonomous Rescue Drone Speeds Up Product Development

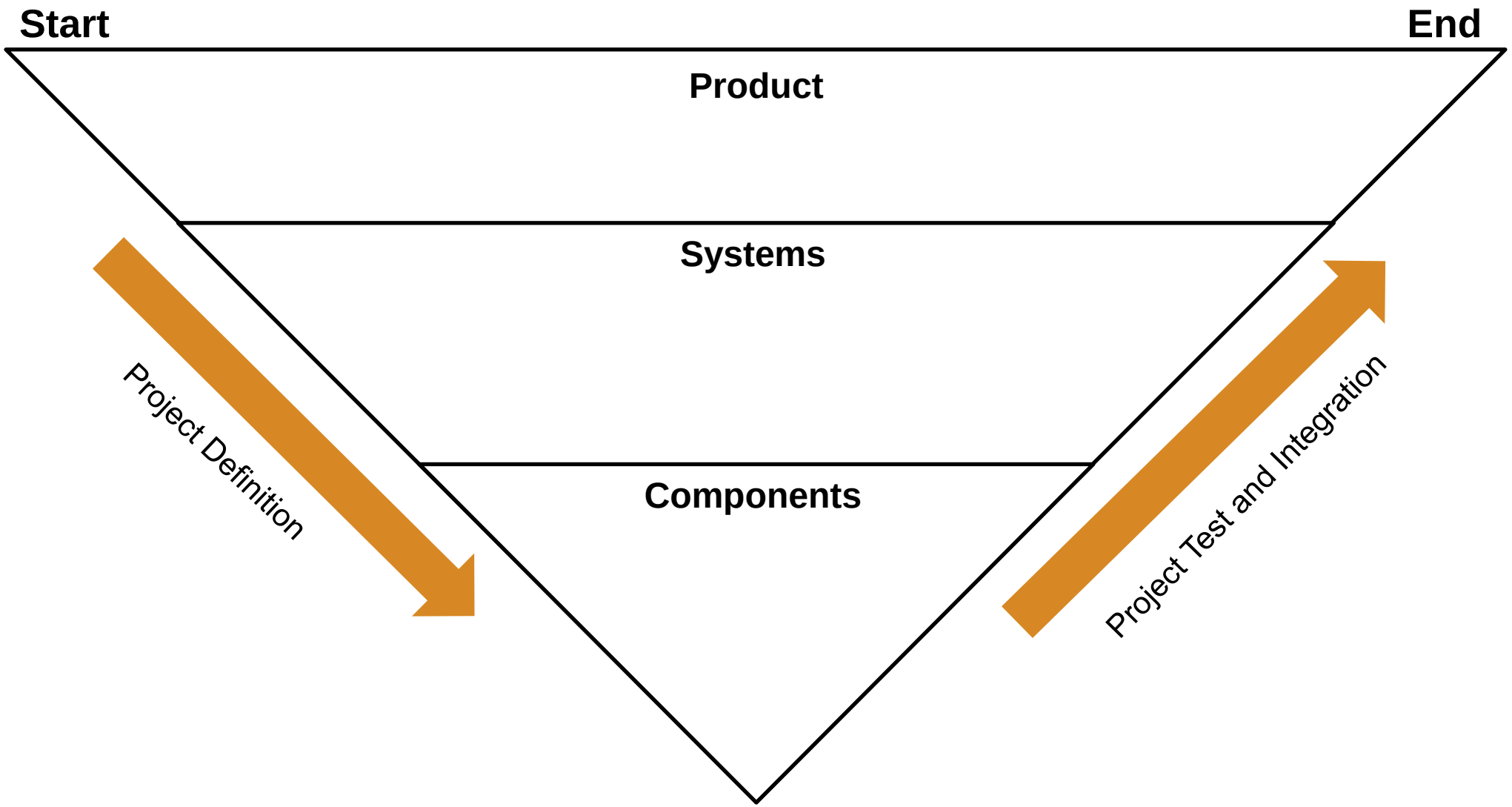
- **Problem:** AVILUS was founded by Ph.D. students at the Technical University in Munich (TUM). The need? A “flying stretcher.”

- **Building From Scratch:** Starting with a blank slate was challenging but ensured that the vehicle could meet the precise needs of rescue teams.

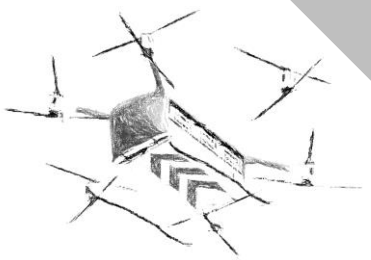
- **Model-Based Design:** MathWorks used for detailed models of powertrain, battery, circuit, and engine. MBD also made it easier to perform hardware-in-the-loop testing.

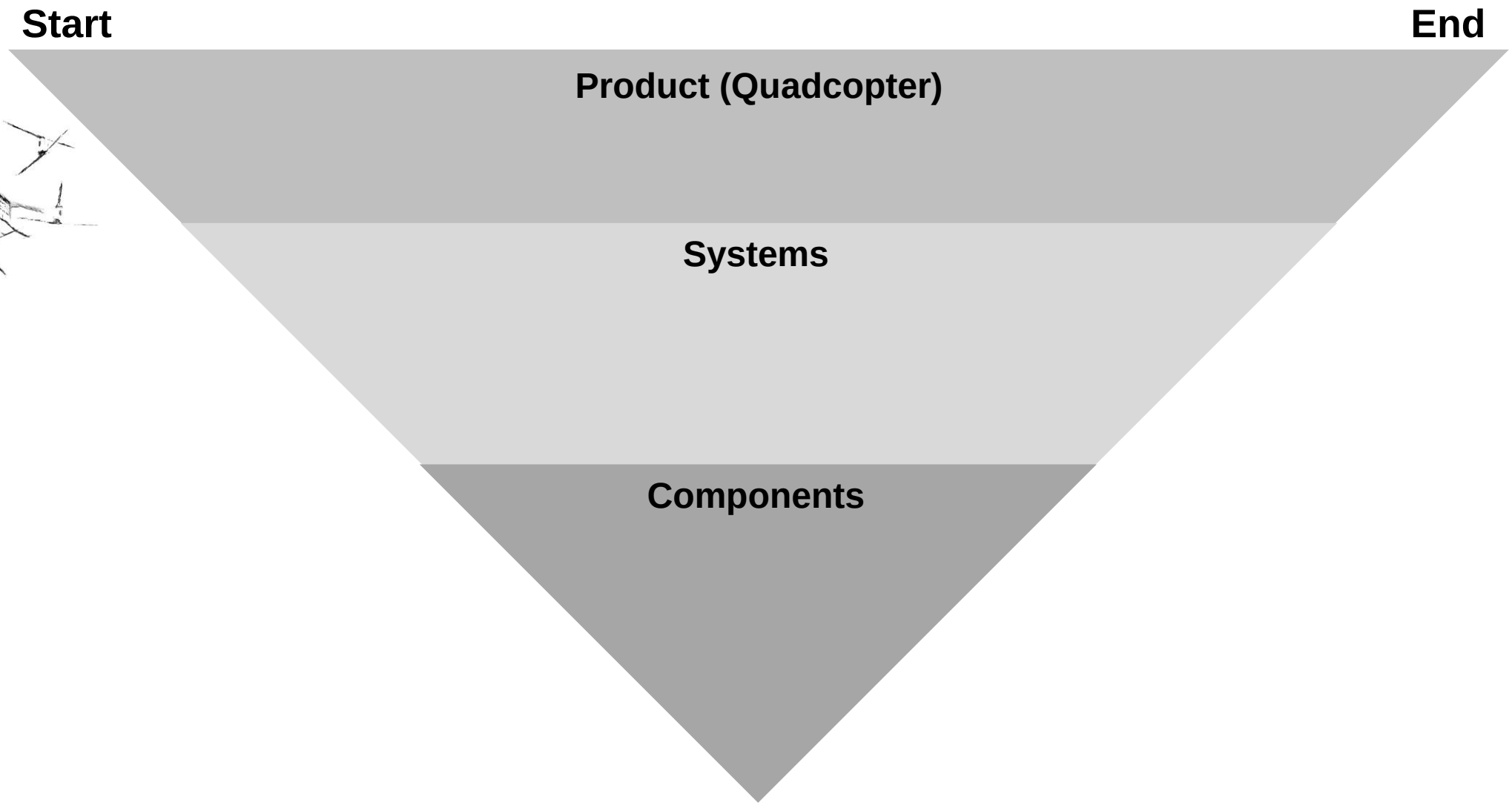


The V Model

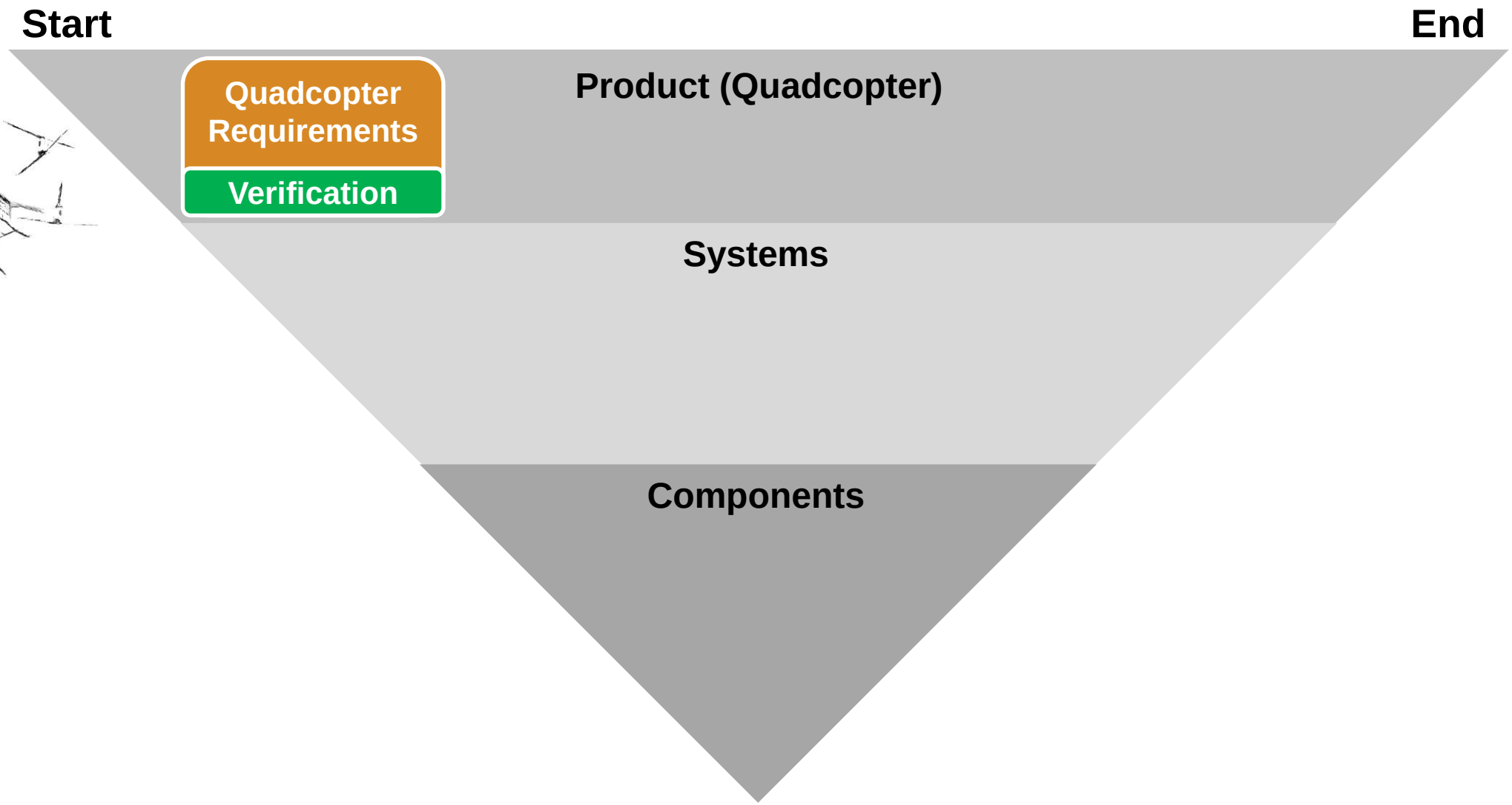

Start
End
Product
Systems
Components
Project Definition
Project Test and Integration

The V Model - Quadcopter

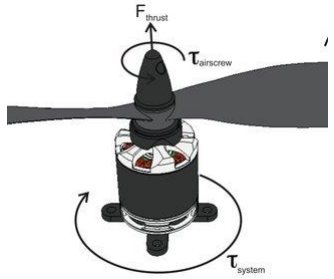


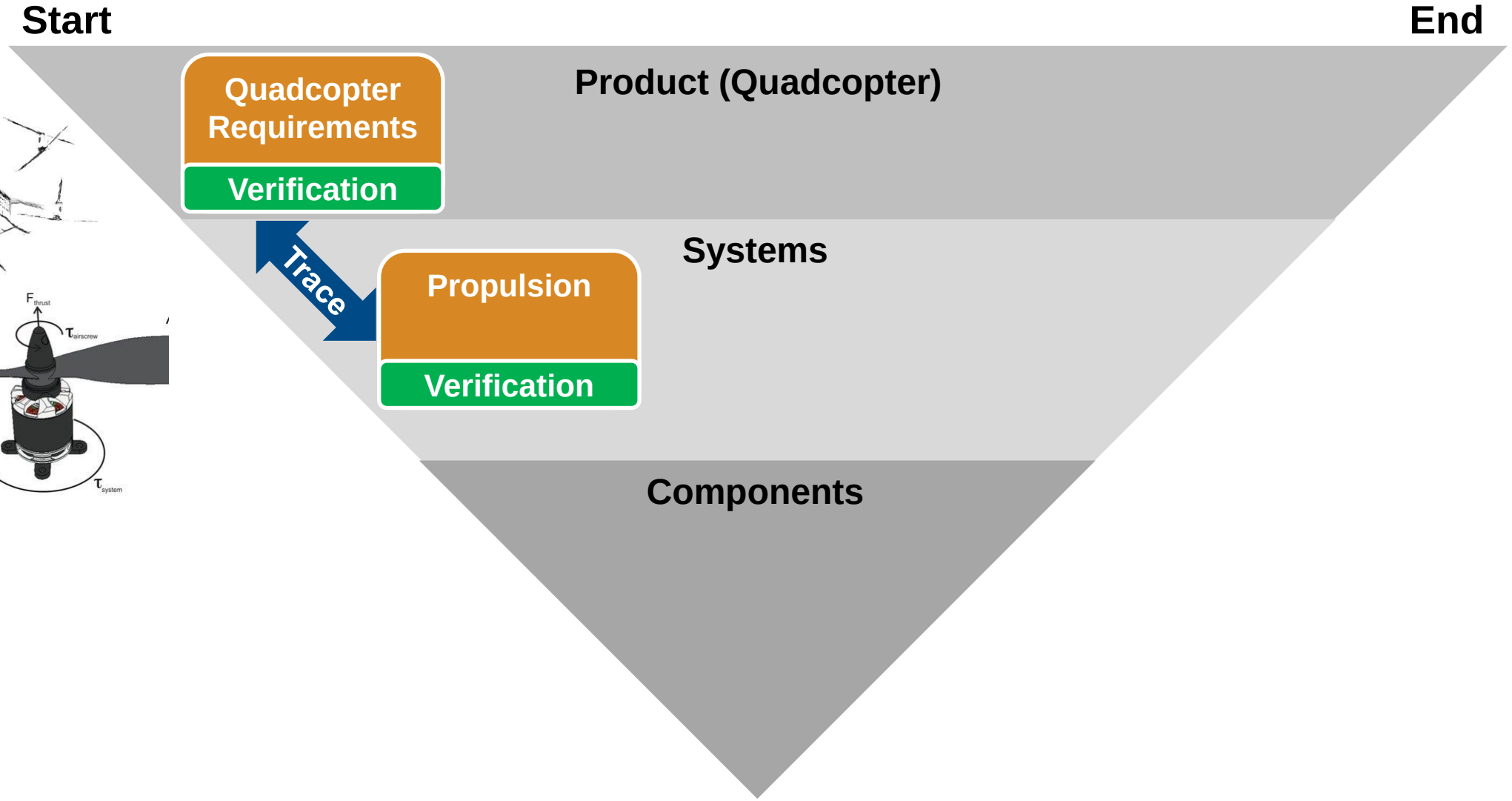


The V Model - Quadcopter

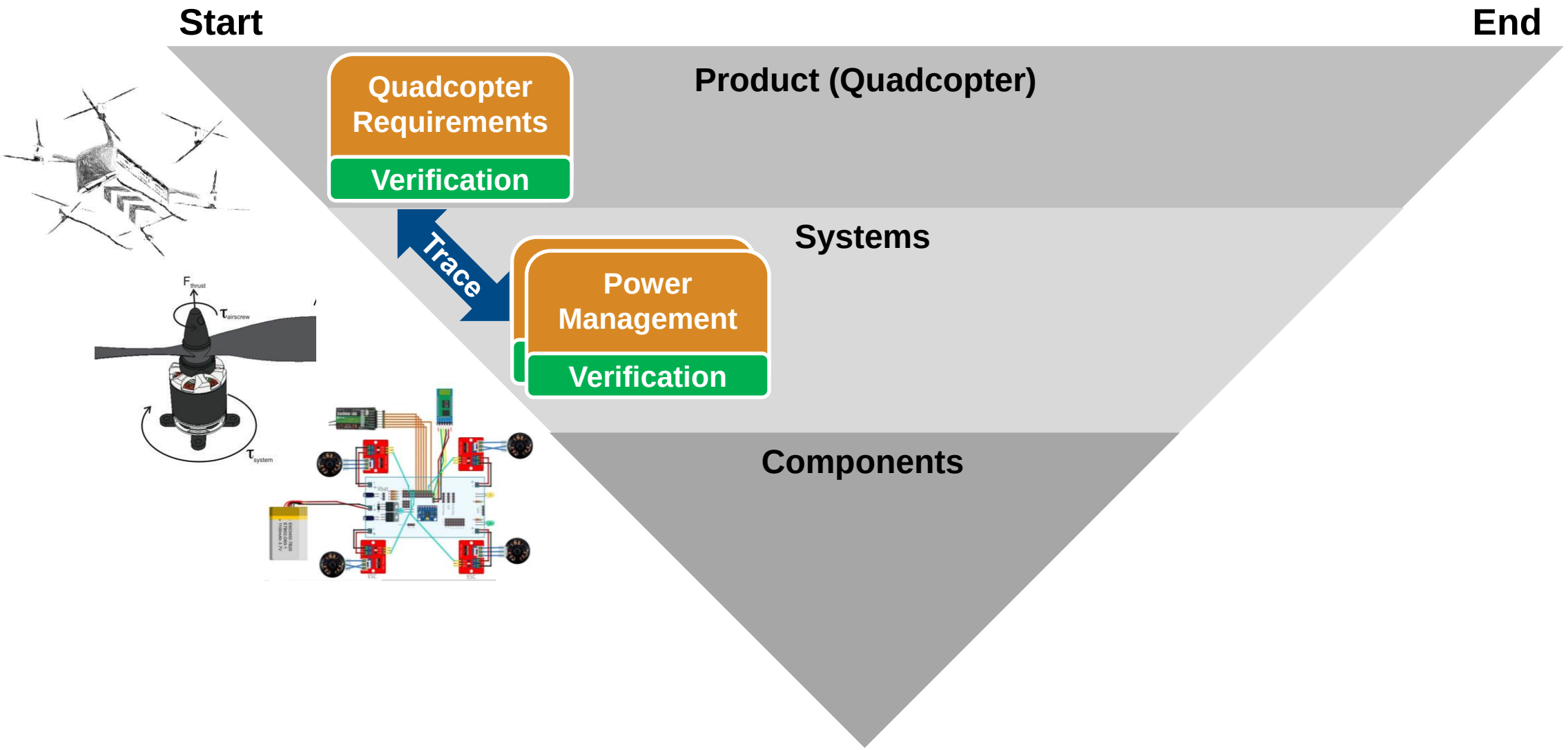


The V Model - Quadcopter

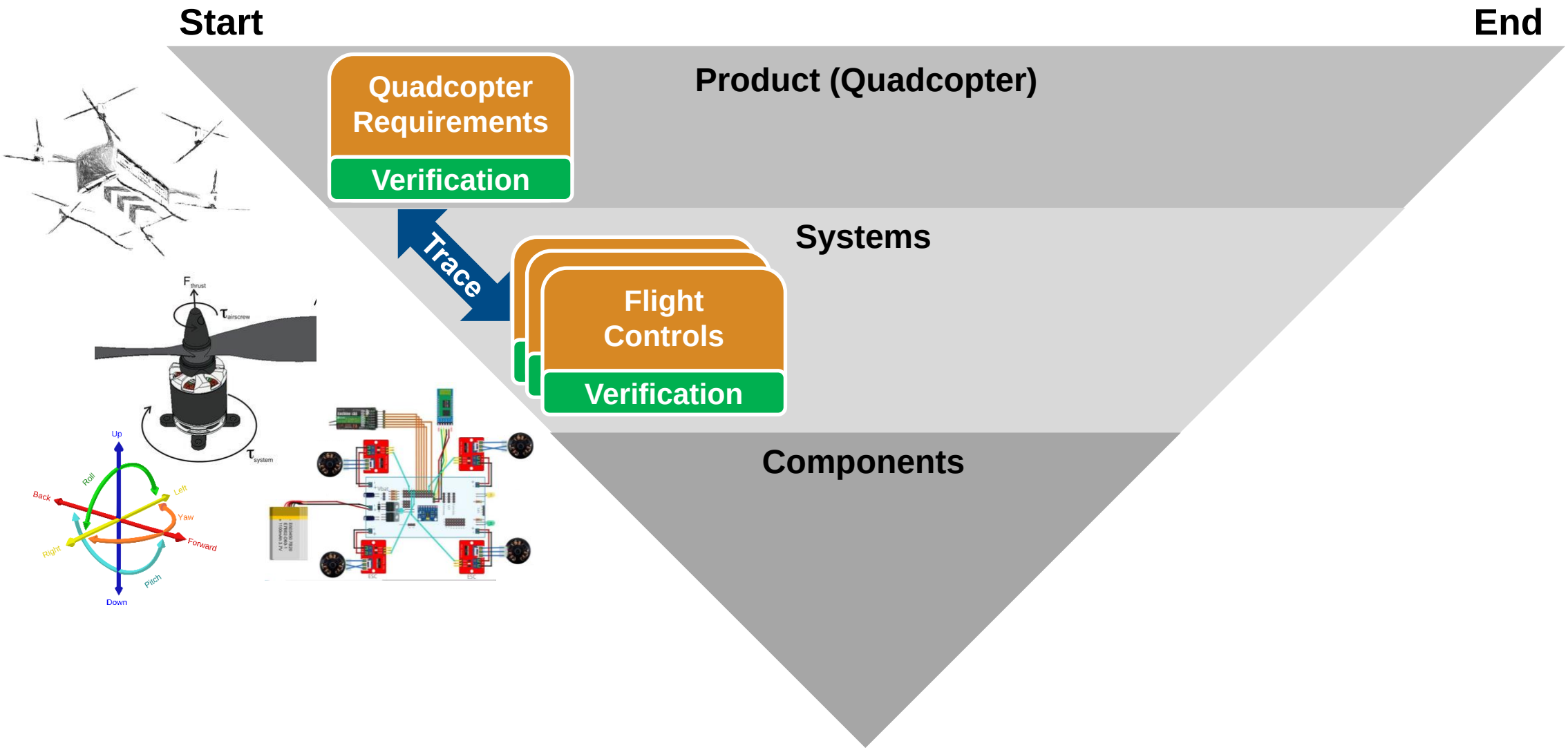




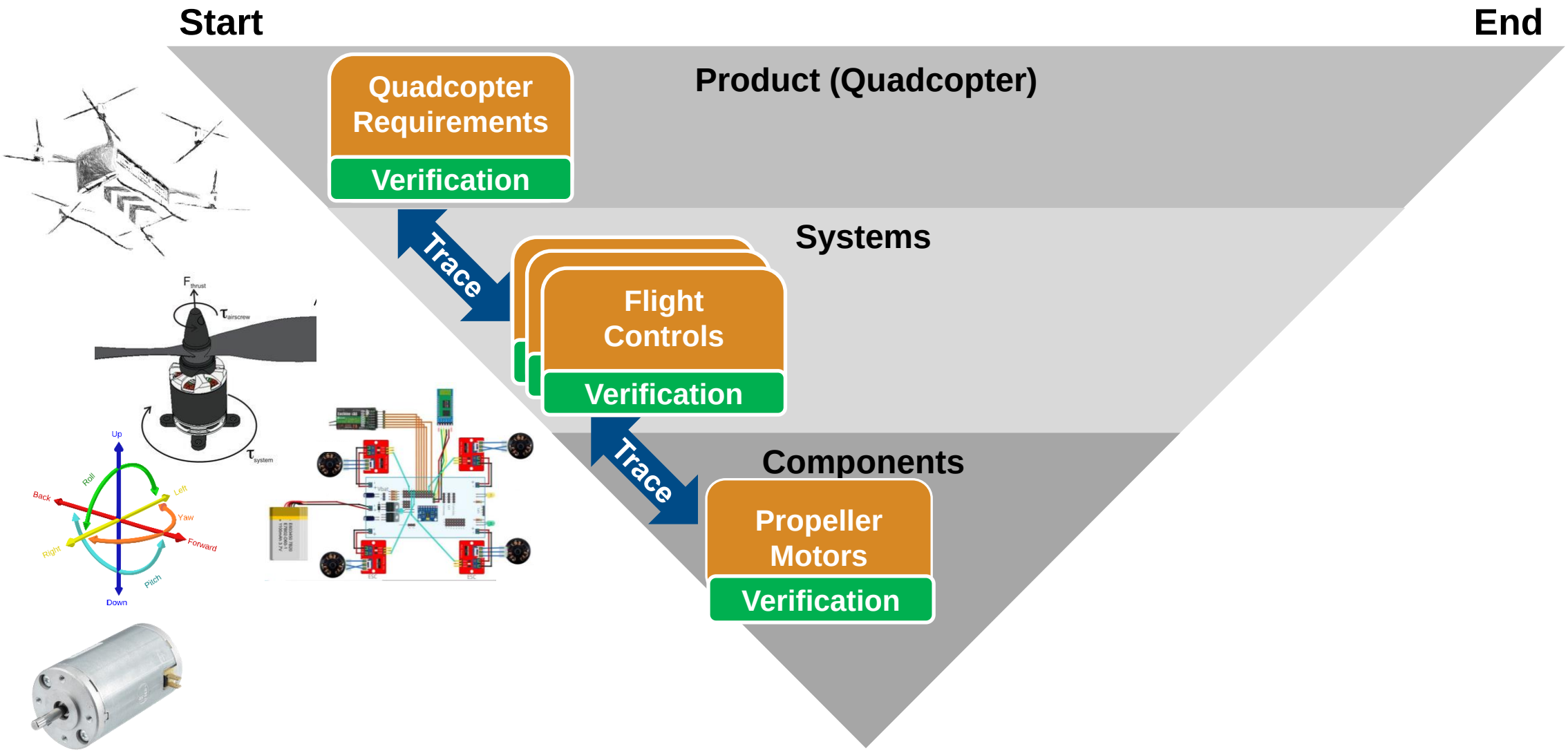
The V Model - Quadcopter



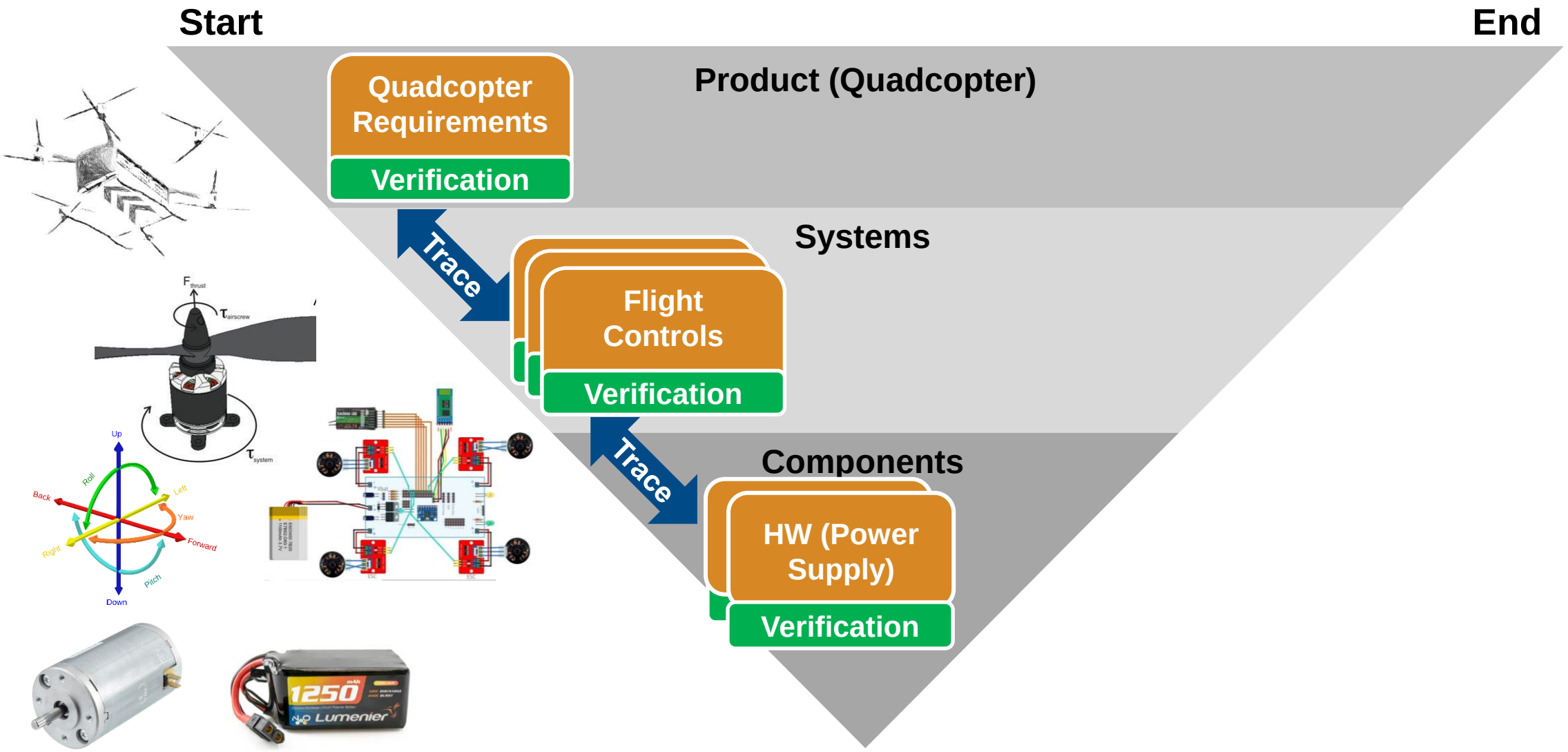
The V Model - Quadcopter



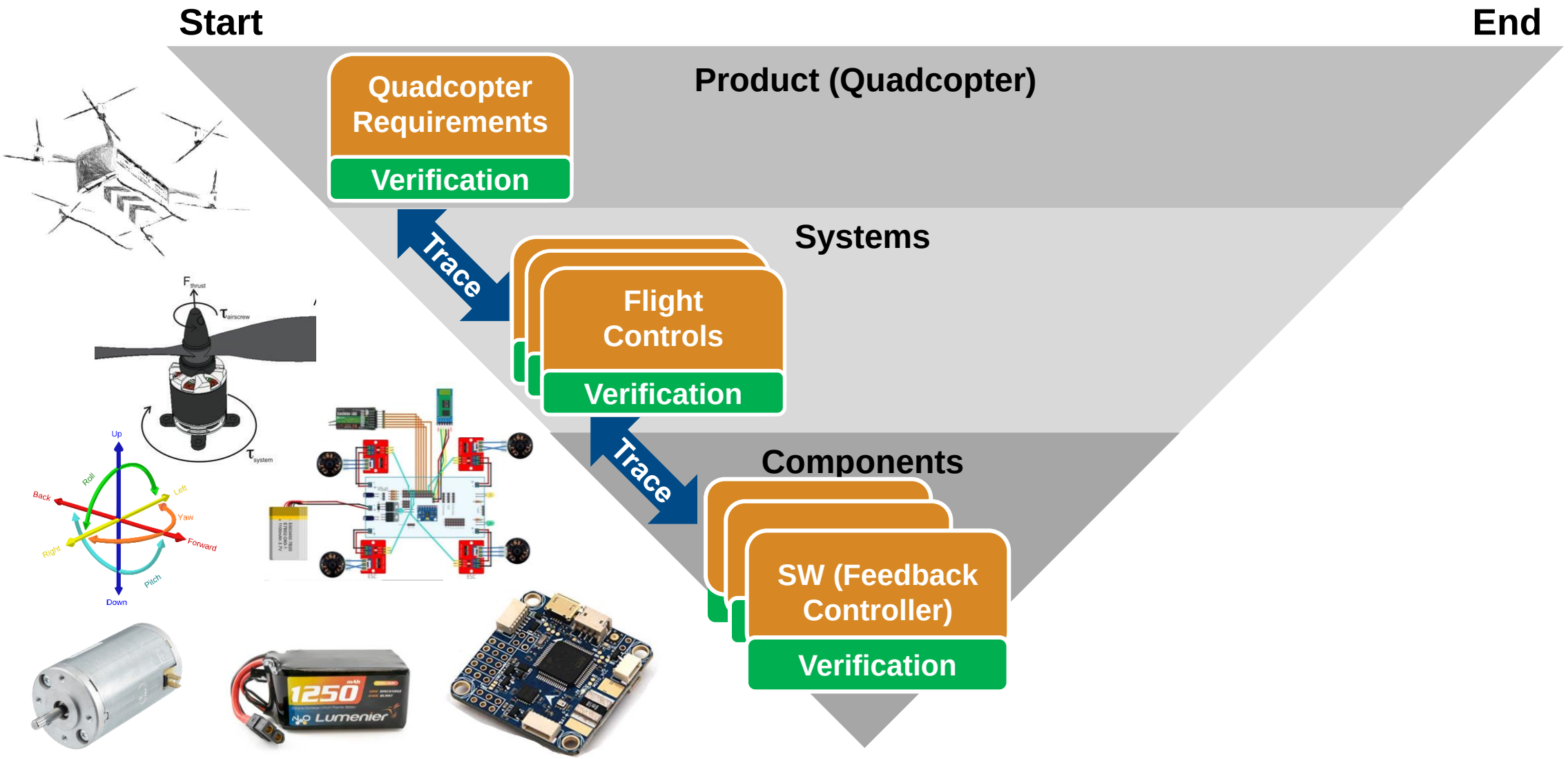
The V Model - Quadcopter



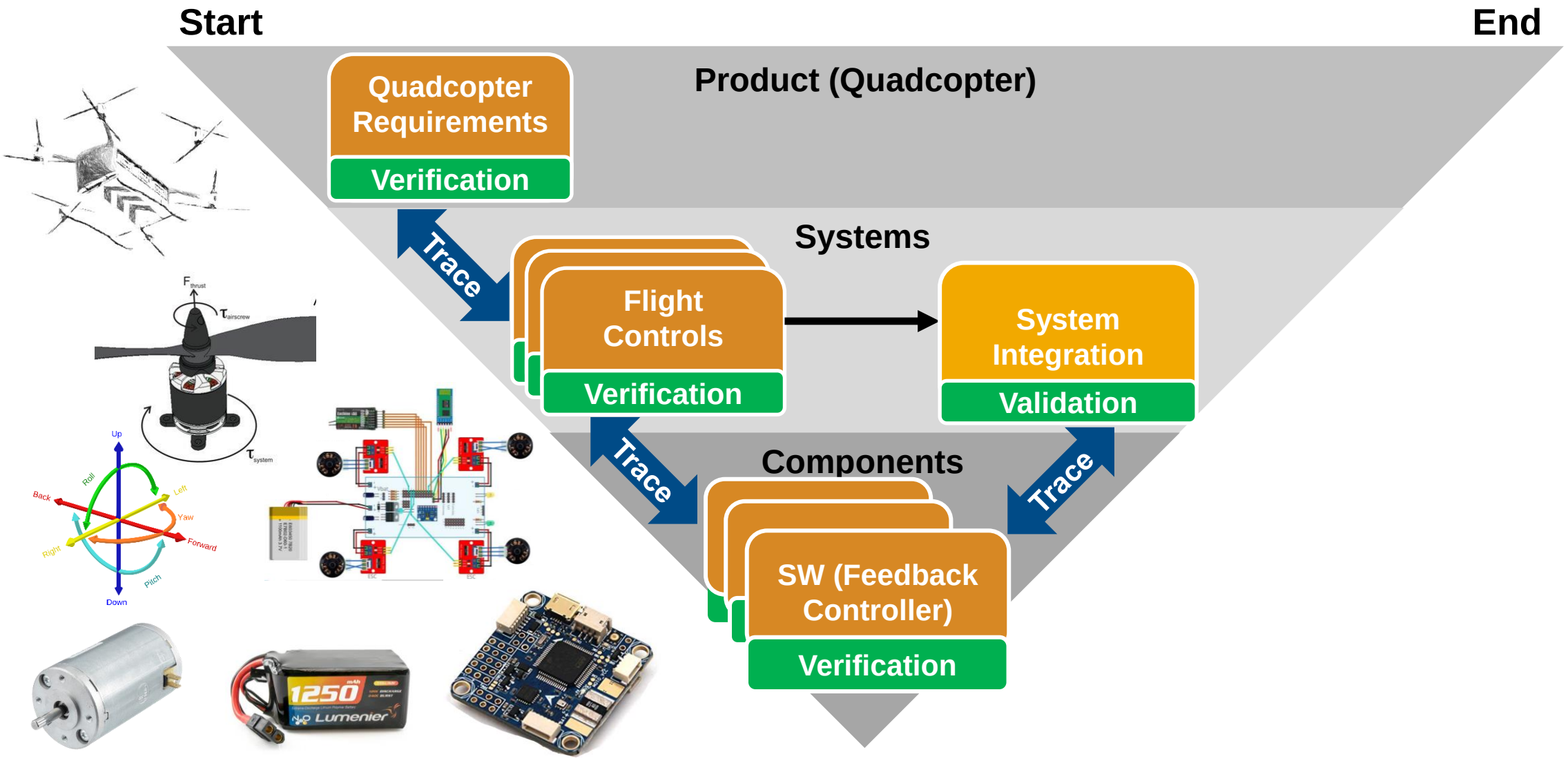
The V Model - Quadcopter



The V Model - Quadcopter



The V Model - Quadcopter



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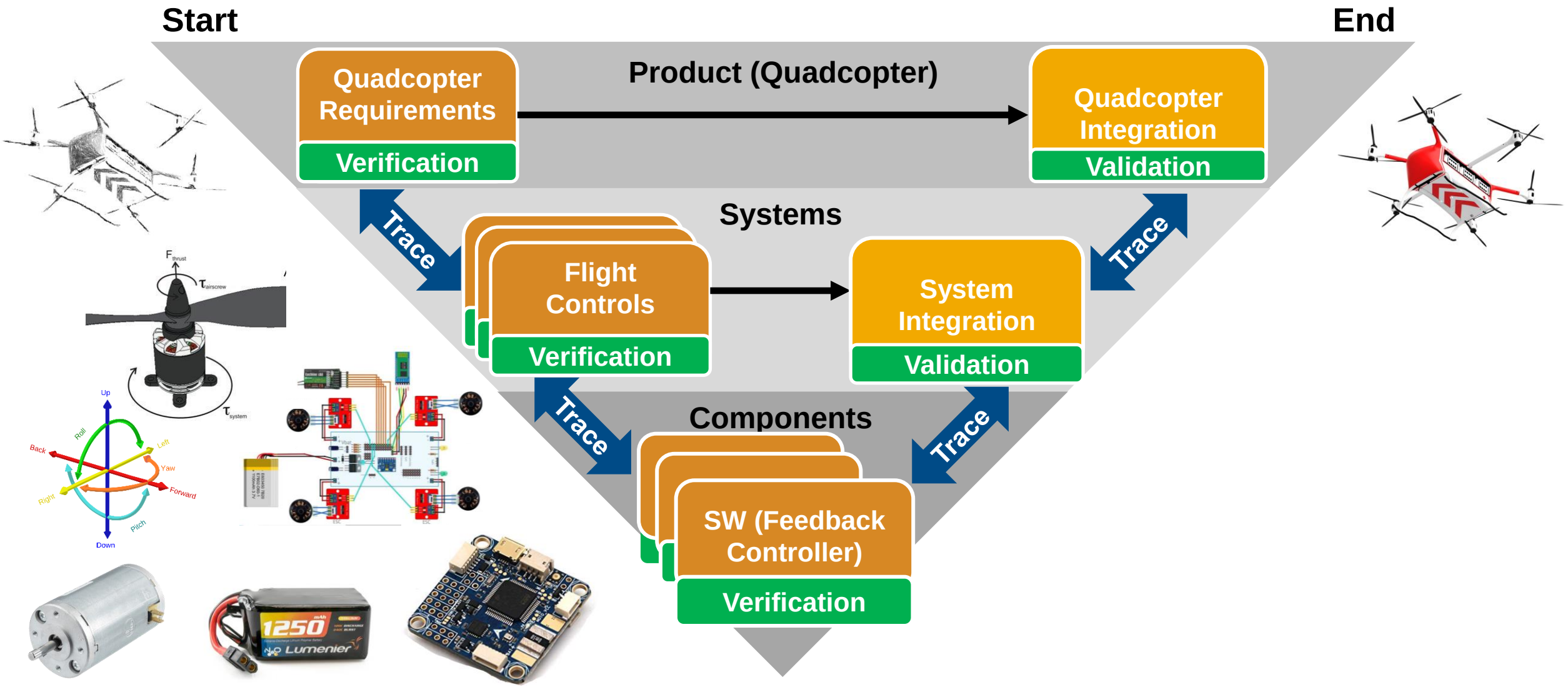
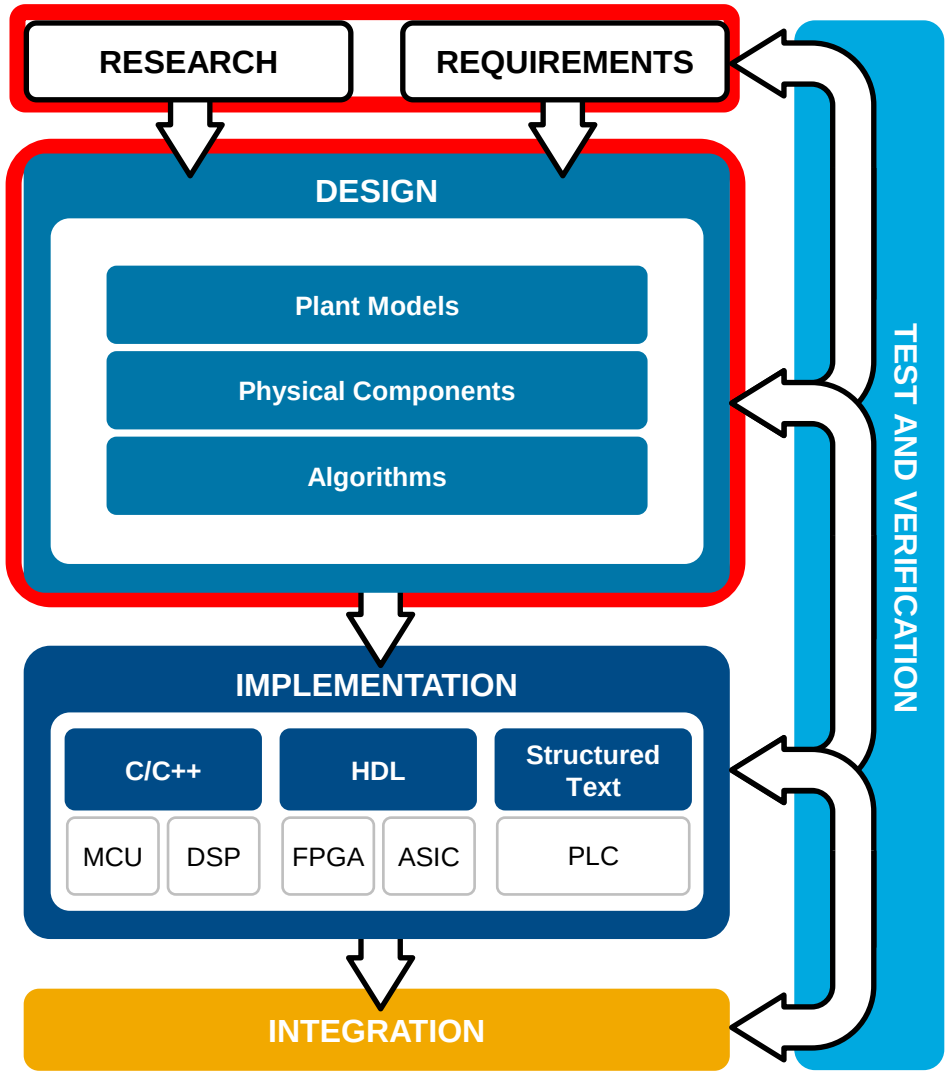


Model-Based Design Process

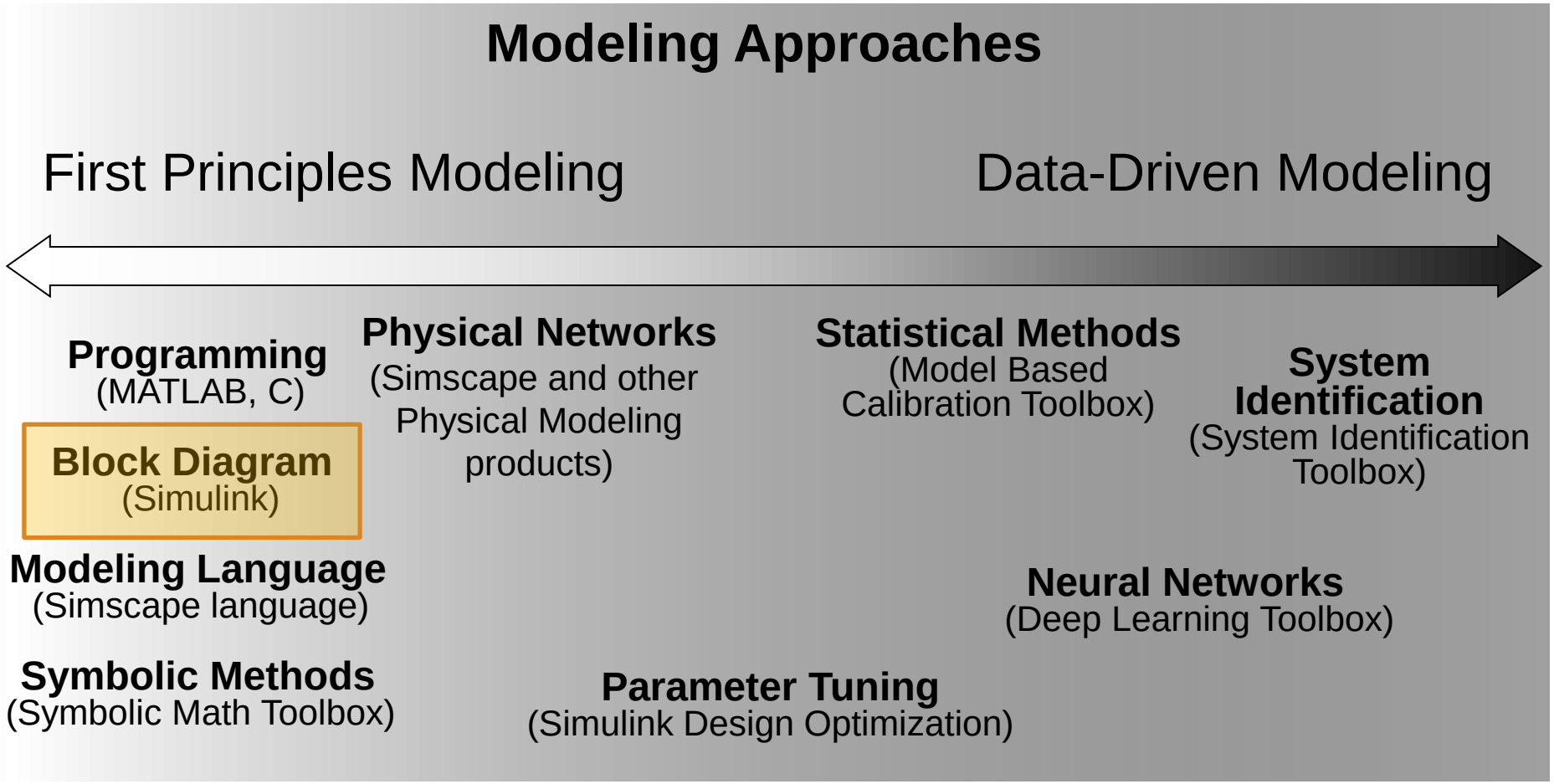


What are models anyway?

"All models are wrong, but some are useful"

George Box
British statistician

Different Approaches for Modeling Dynamic Systems



Simulink works like engineers think

- **Graphical** block diagram environment
- Design **dynamical systems**
- **Simulate** before moving to hardware
- **Deploy** without writing code

MODELING

Simulation

Analysis

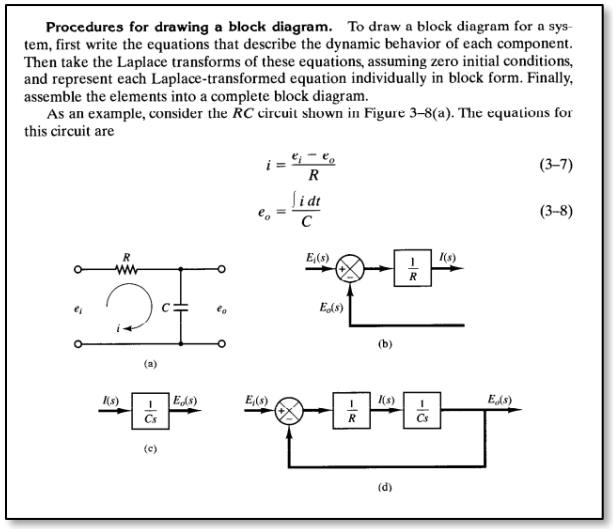
+

AUTOMATION

Coding

Verification

Textbook



Procedures for drawing a block diagram. To draw a block diagram for a system, first write the equations that describe the dynamic behavior of each component. Then take the Laplace transforms of these equations, assuming zero initial conditions, and represent each Laplace-transformed equation individually in block form. Finally, assemble the elements into a complete block diagram.

As an example, consider the *RC* circuit shown in Figure 3–8(a). The equations for this circuit are

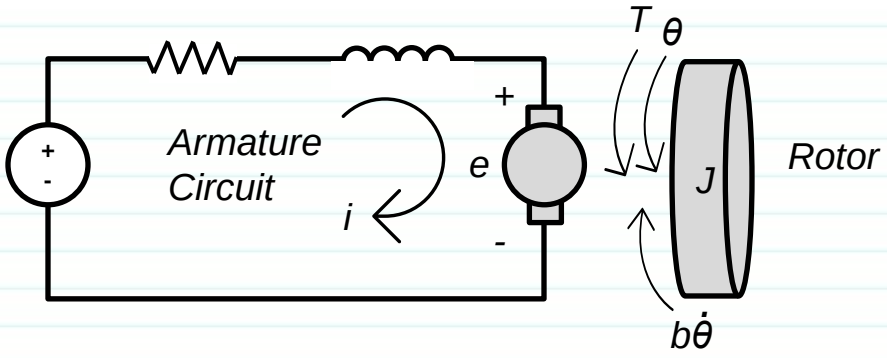
$$i = \frac{e_i - e_o}{R} \quad (3\text{–}7)$$

$$e_o = \frac{\int i\,dt}{C} \quad (3\text{–}8)$$

Modern Control Engineering, Ogata

Application

Let's model a DC Motor in Simulink



$$V = K\dot{\theta} + iR + L\frac{di}{dt}$$

$$\frac{di}{dt} = \frac{1}{L}(V - K\dot{\theta} - iR)$$

$$i = \int \frac{1}{L}(V - K\dot{\theta} - iR)dt$$

Electrical

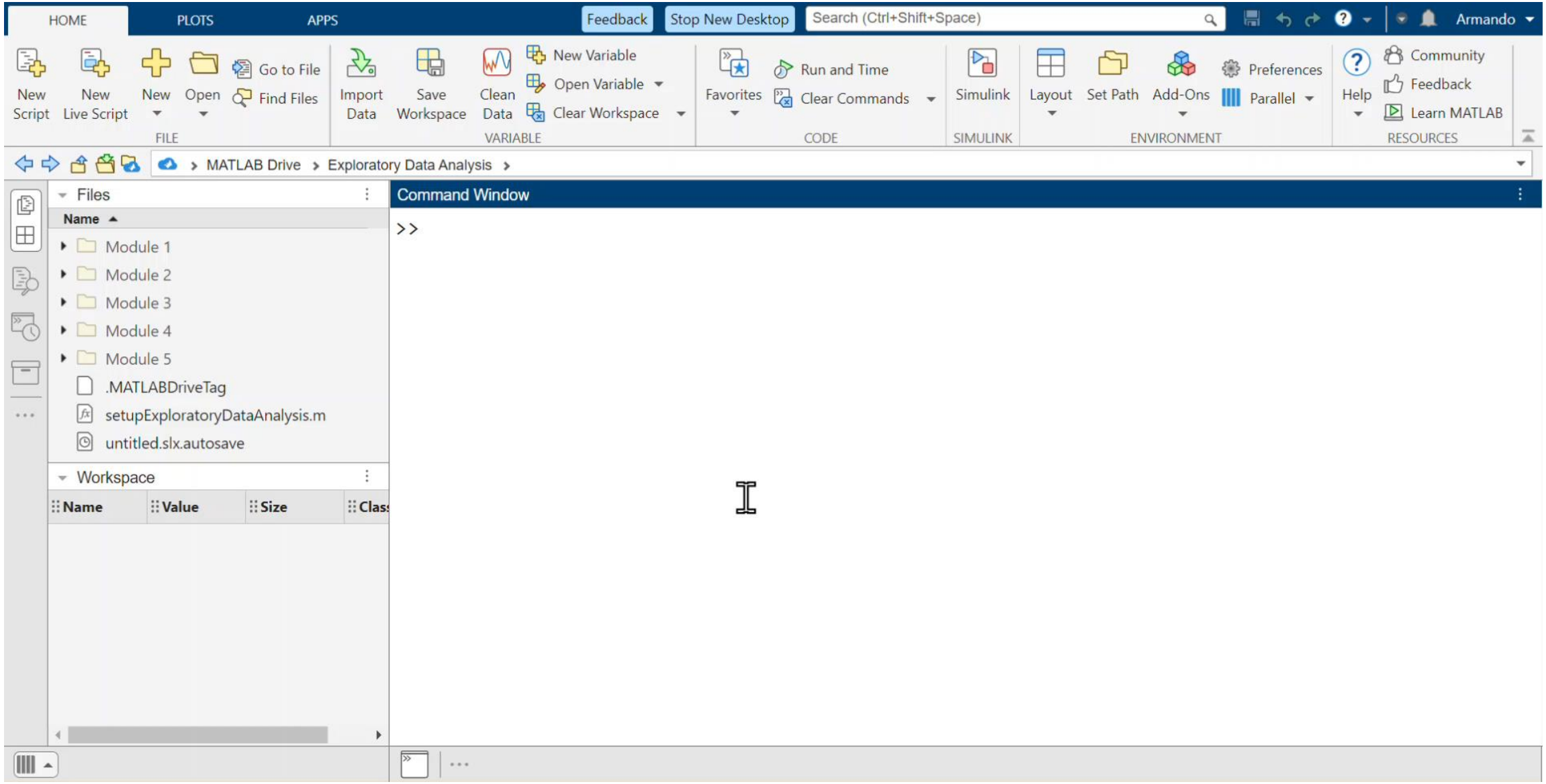
$$j\frac{d\dot{\theta}}{dt} = Ki + b\dot{\theta} + T_{load}$$

$$\frac{d\dot{\theta}}{dt} = \frac{1}{j}(Ki + b\dot{\theta} + T_{load})$$

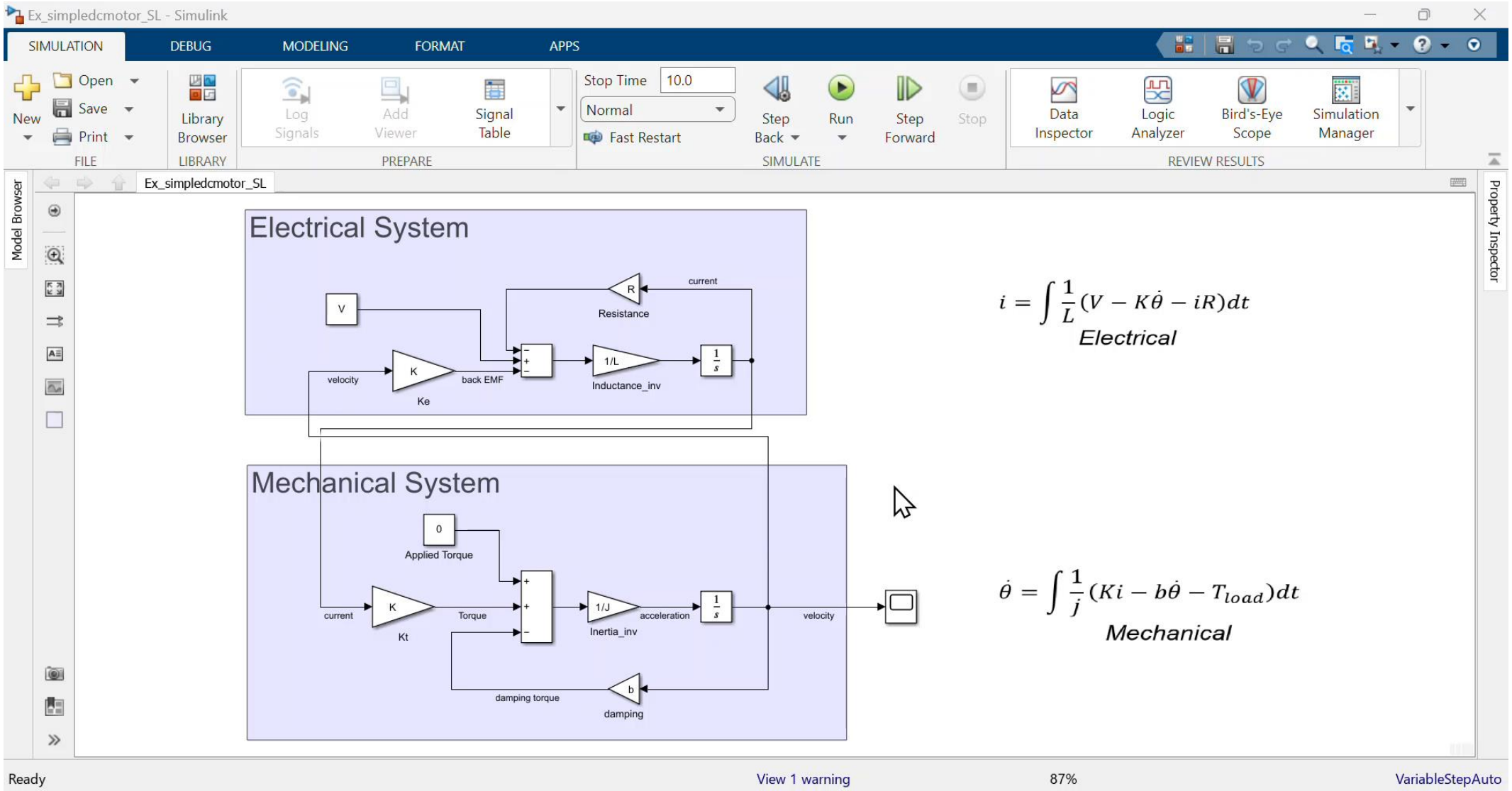
$$\dot{\theta} = \int \frac{1}{j}(Ki - b\dot{\theta} - T_{load})dt$$

Mechanical

How do I model in Simulink?



Causal Modeling with Simulink



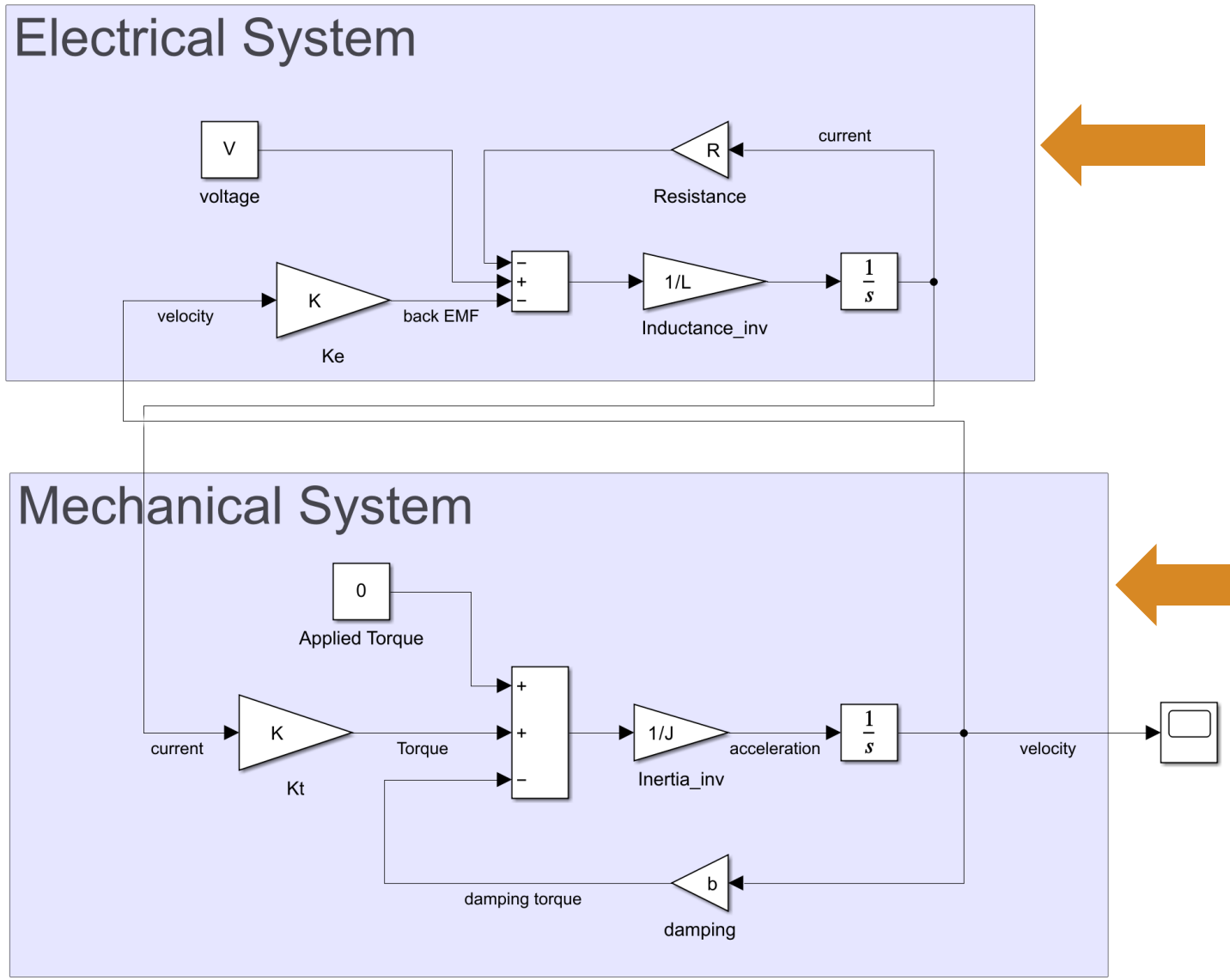
$$i = \int \frac{1}{L}(V - K\dot{\theta} - iR)dt$$

Electrical

$$\dot{\theta} = \int \frac{1}{j}(Ki - b\dot{\theta} - T_{load})dt$$

Mechanical

Causal Modeling with Simulink



$$i = \int \frac{1}{L}(V - K\dot{\theta} - iR)dt$$

Electrical

$$\dot{\theta} = \int \frac{1}{j}(Ki - b\dot{\theta} - T_{load})dt$$

Mechanical

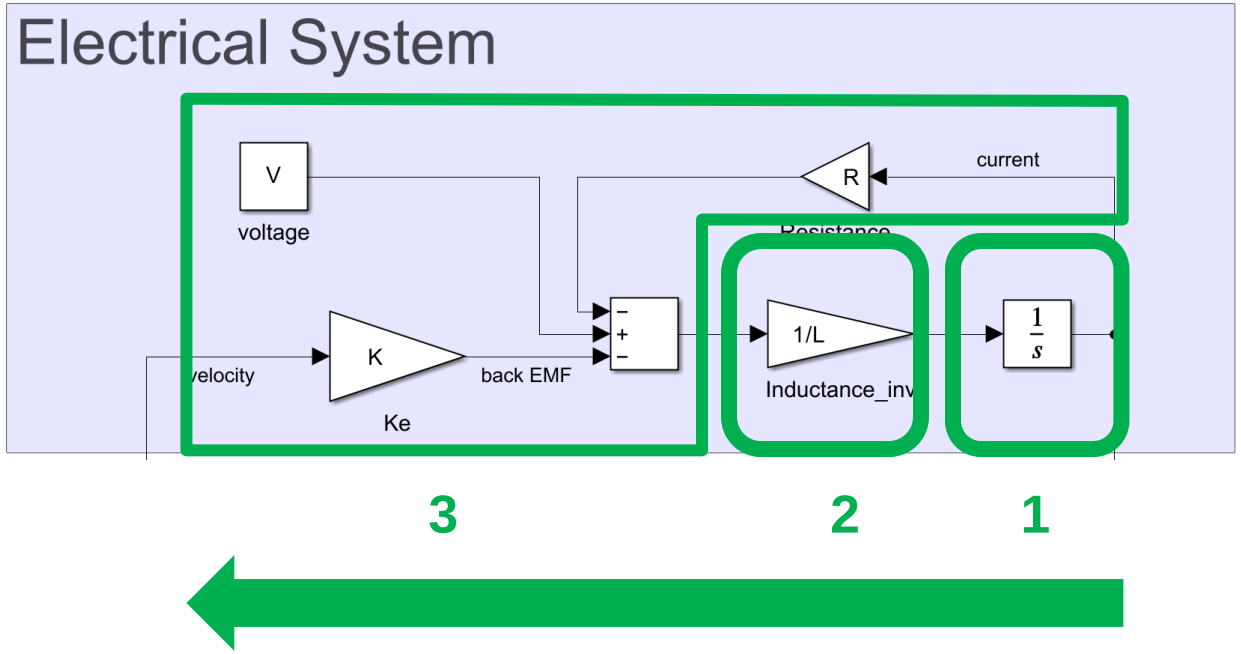
One Approach to Build Your Models

Read your equation from left to right…

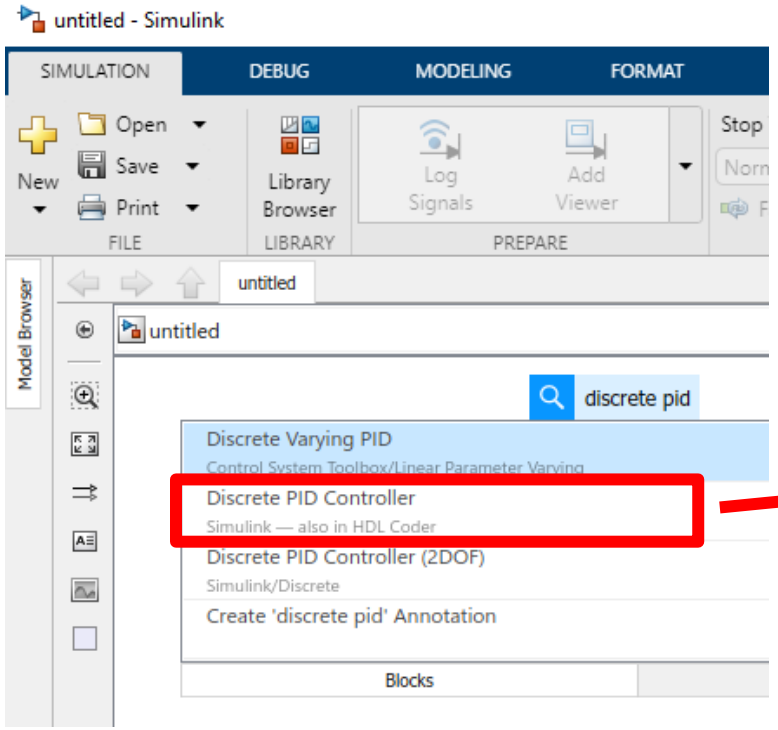
$$i = \int \frac{1}{L}(V - K\dot{\theta} - iR)dt$$

1 2 3

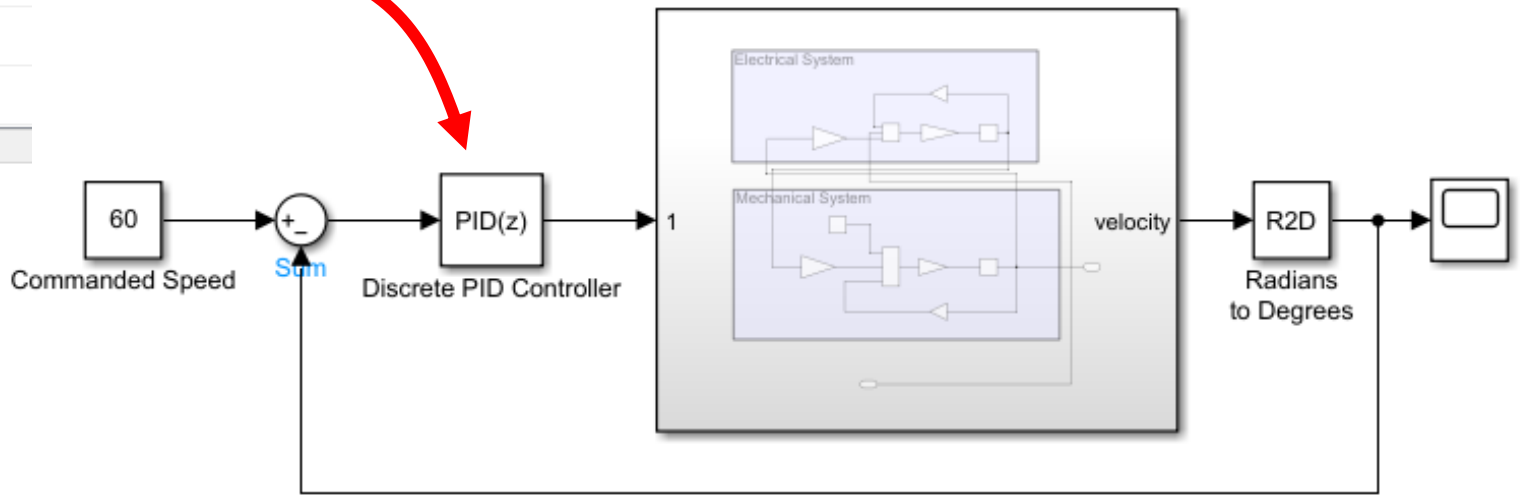
…and build your model from right to left



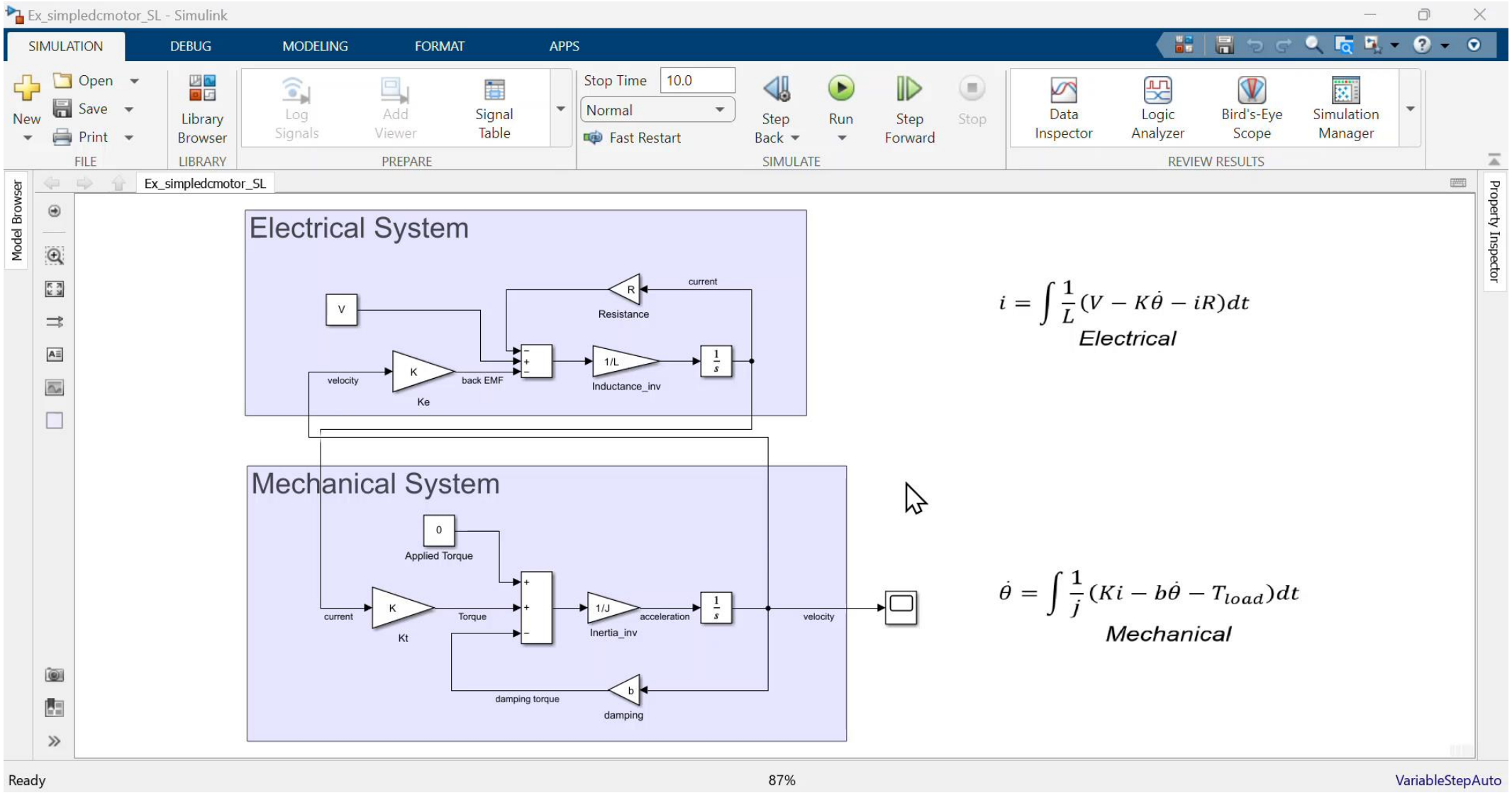
Controller Design



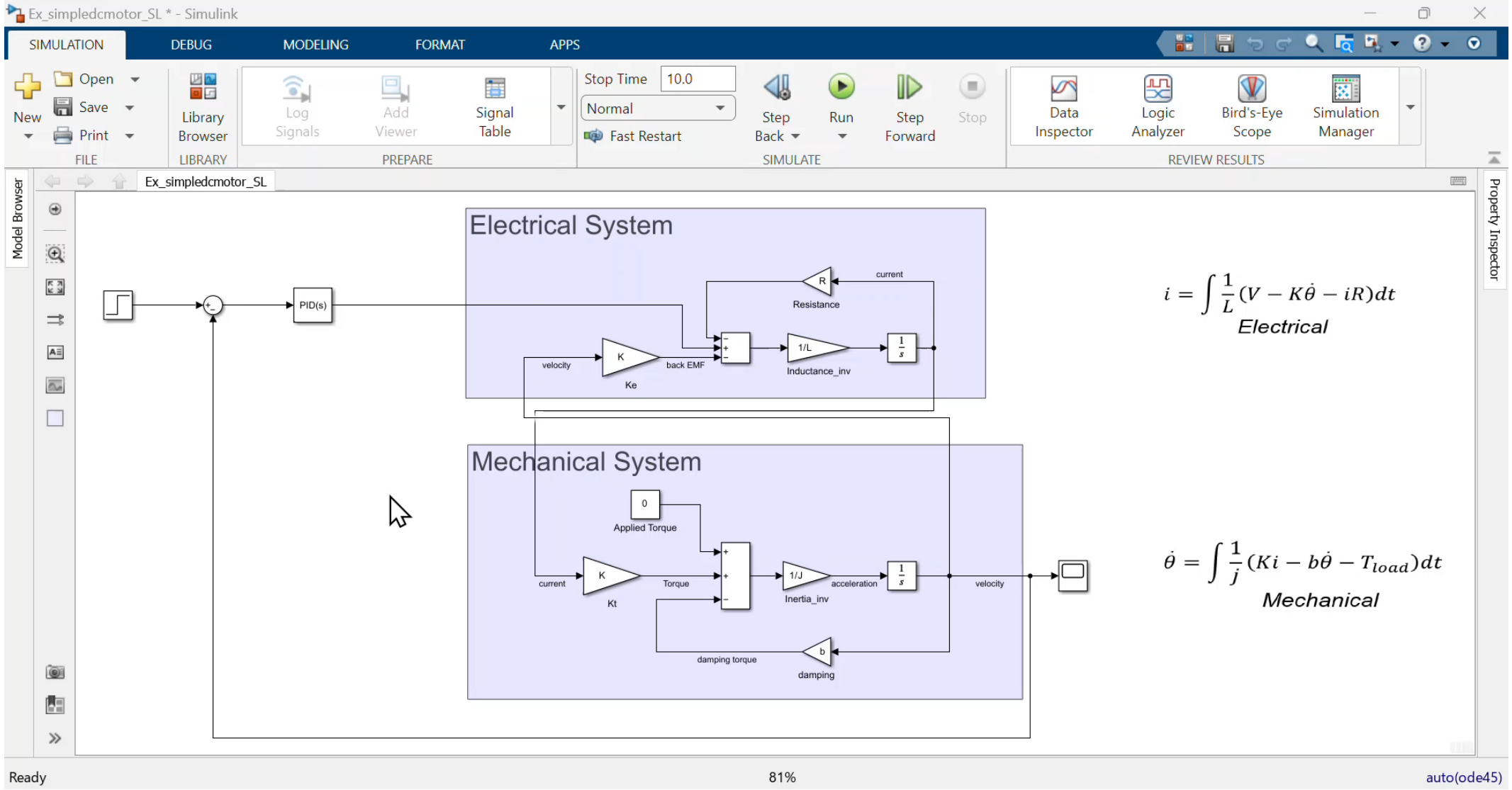
Double-click on the canvas to directly search for blocks



Controller Design



Automatically Tune the PID Block



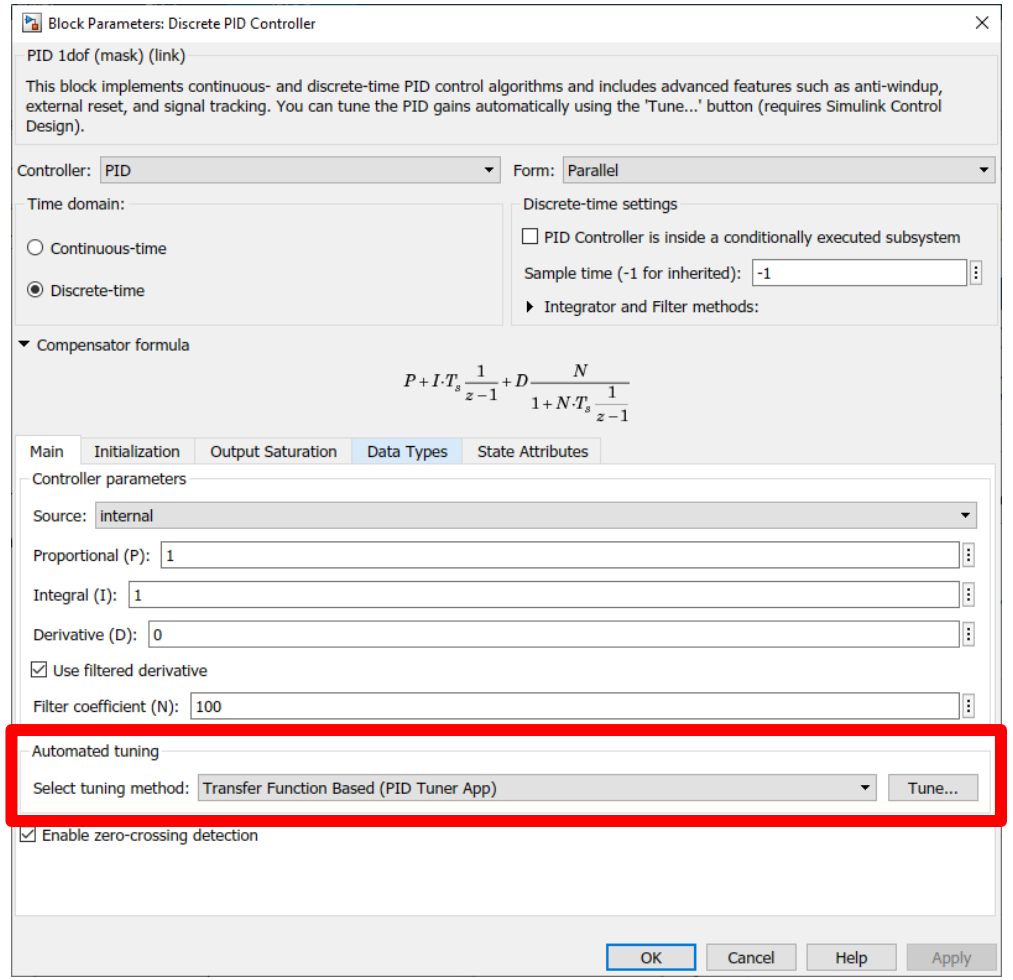
$$i = \int \frac{1}{L}(V - K\dot{\theta} - iR)dt$$

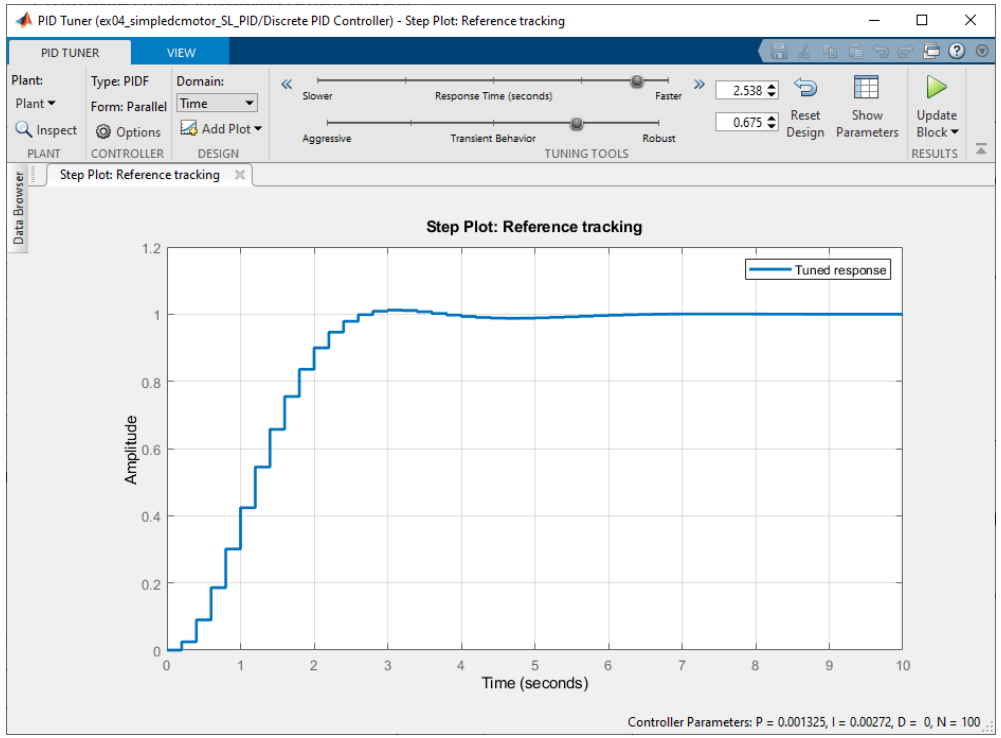
Electrical

$$\dot{\theta} = \int \frac{1}{j}(Ki - b\dot{\theta} - T_{load})dt$$

Mechanical

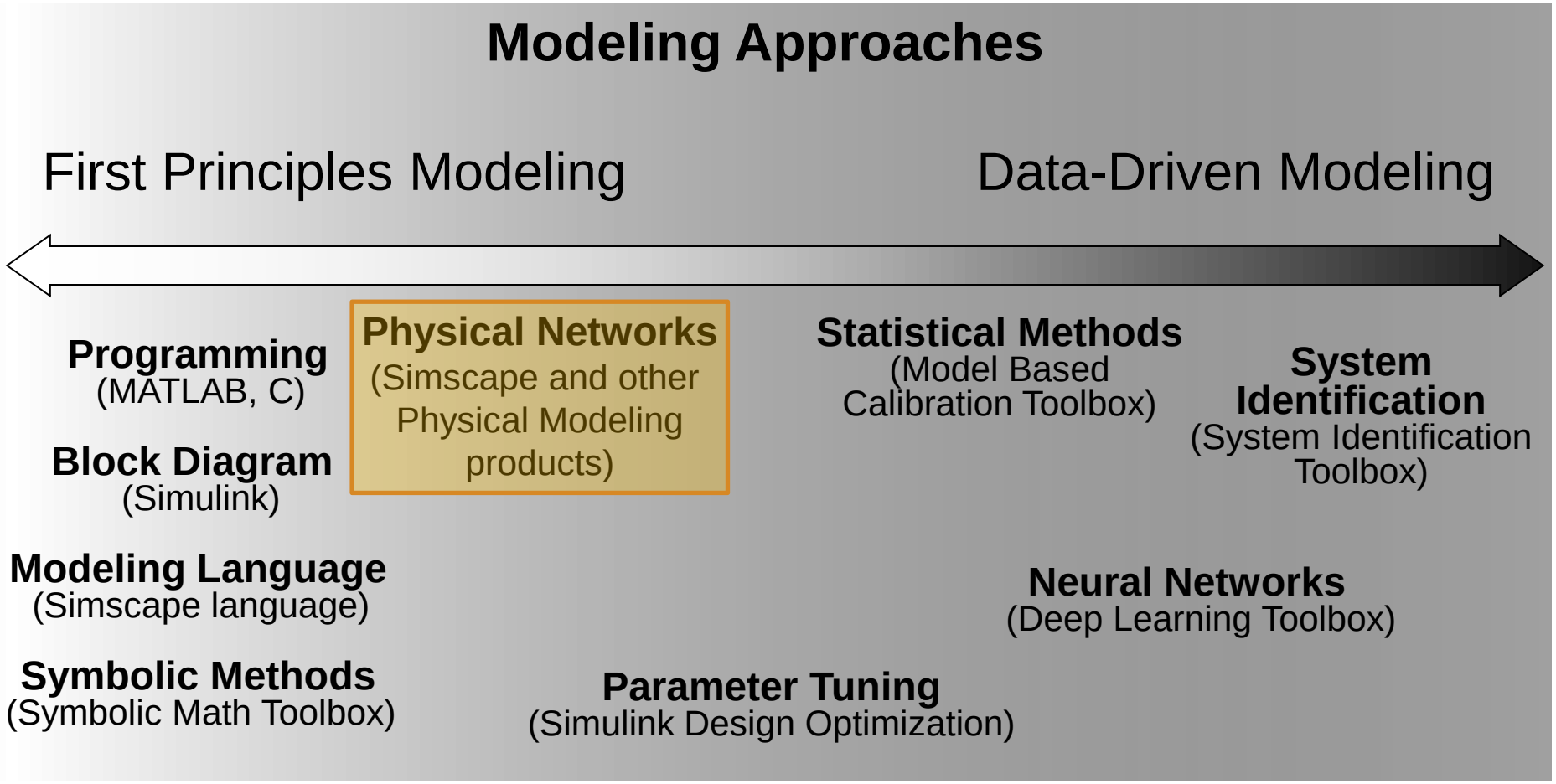
Automatically Tune the PID Block





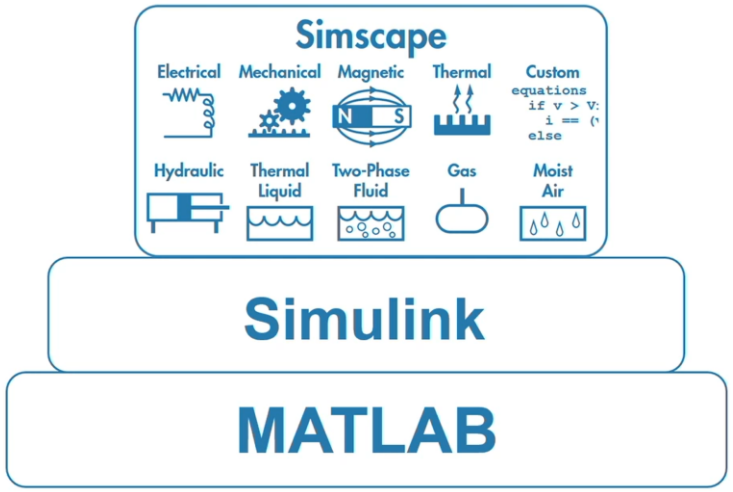
- Tune your response time and transient behavior using slider controls
- Copy the tuned parameters back to your block with one click

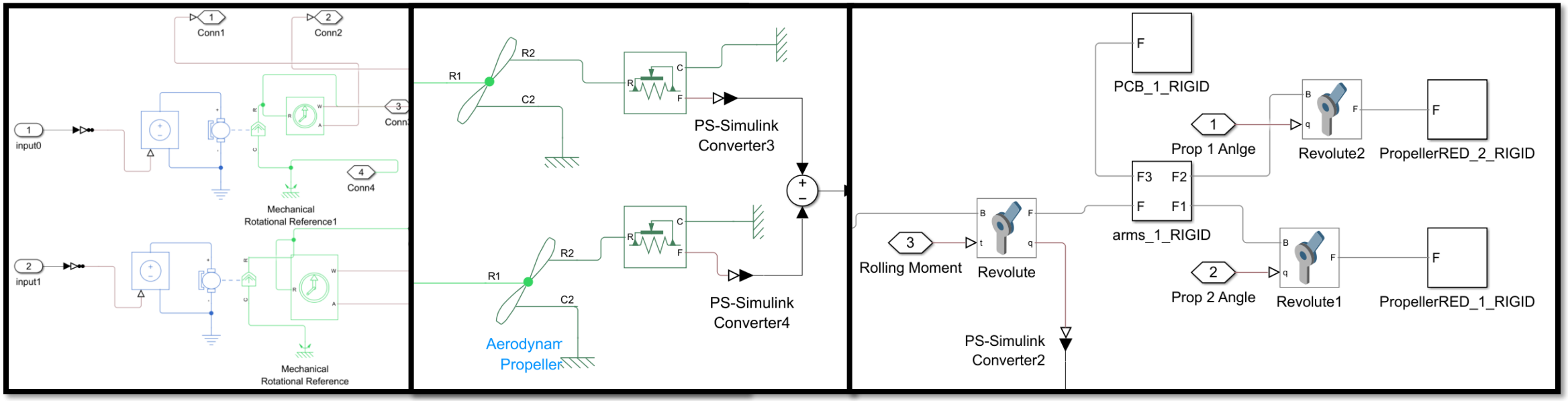
Different Approaches for Modeling Dynamic Systems



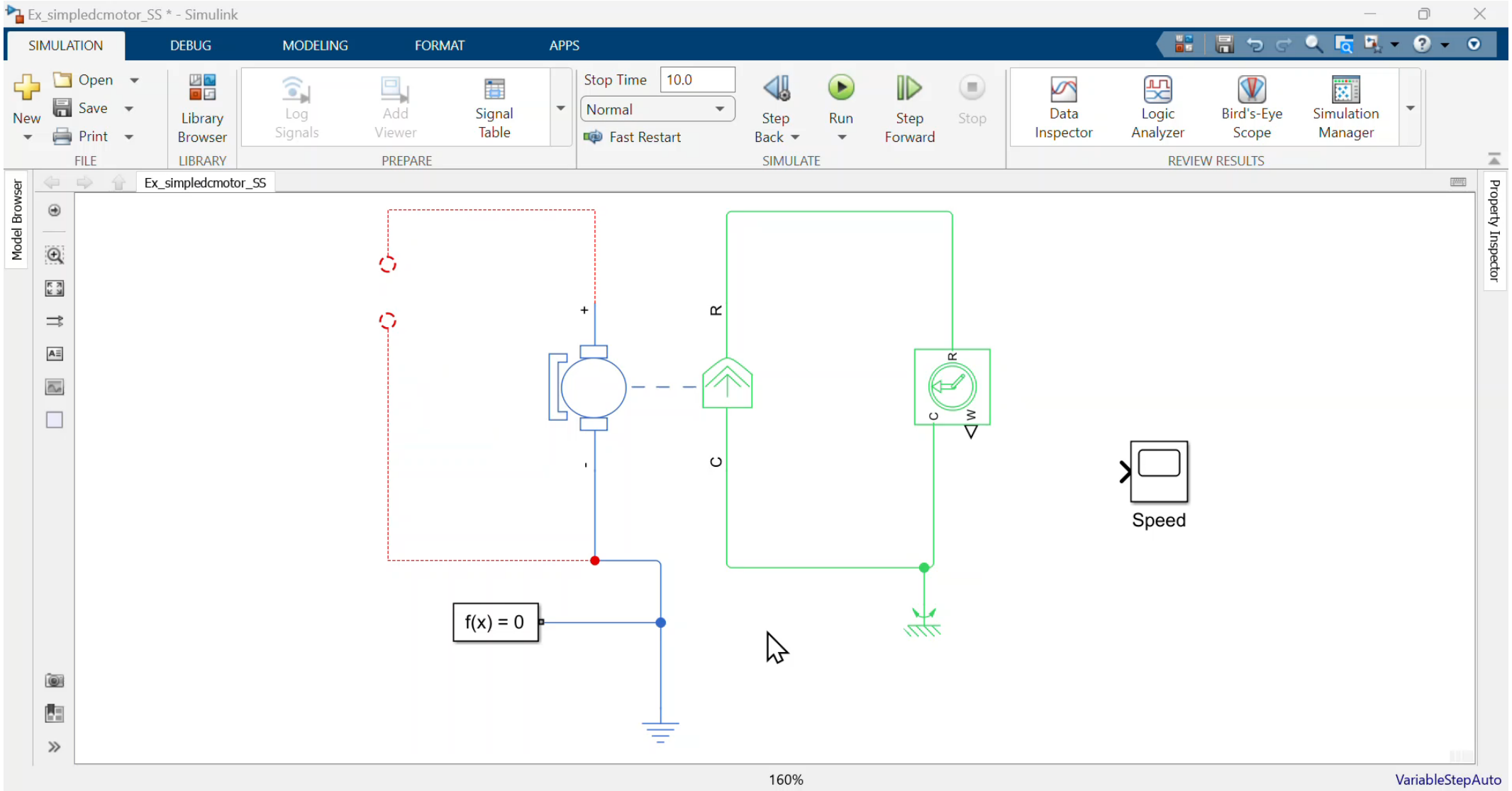
Simscape makes it easier to Model & Simulate Physical Systems

- Physical modeling (acausal)
- Multi-domain
- Built-in and custom components
- Import your 3D models
- Plays nicely with MATLAB & Simulink

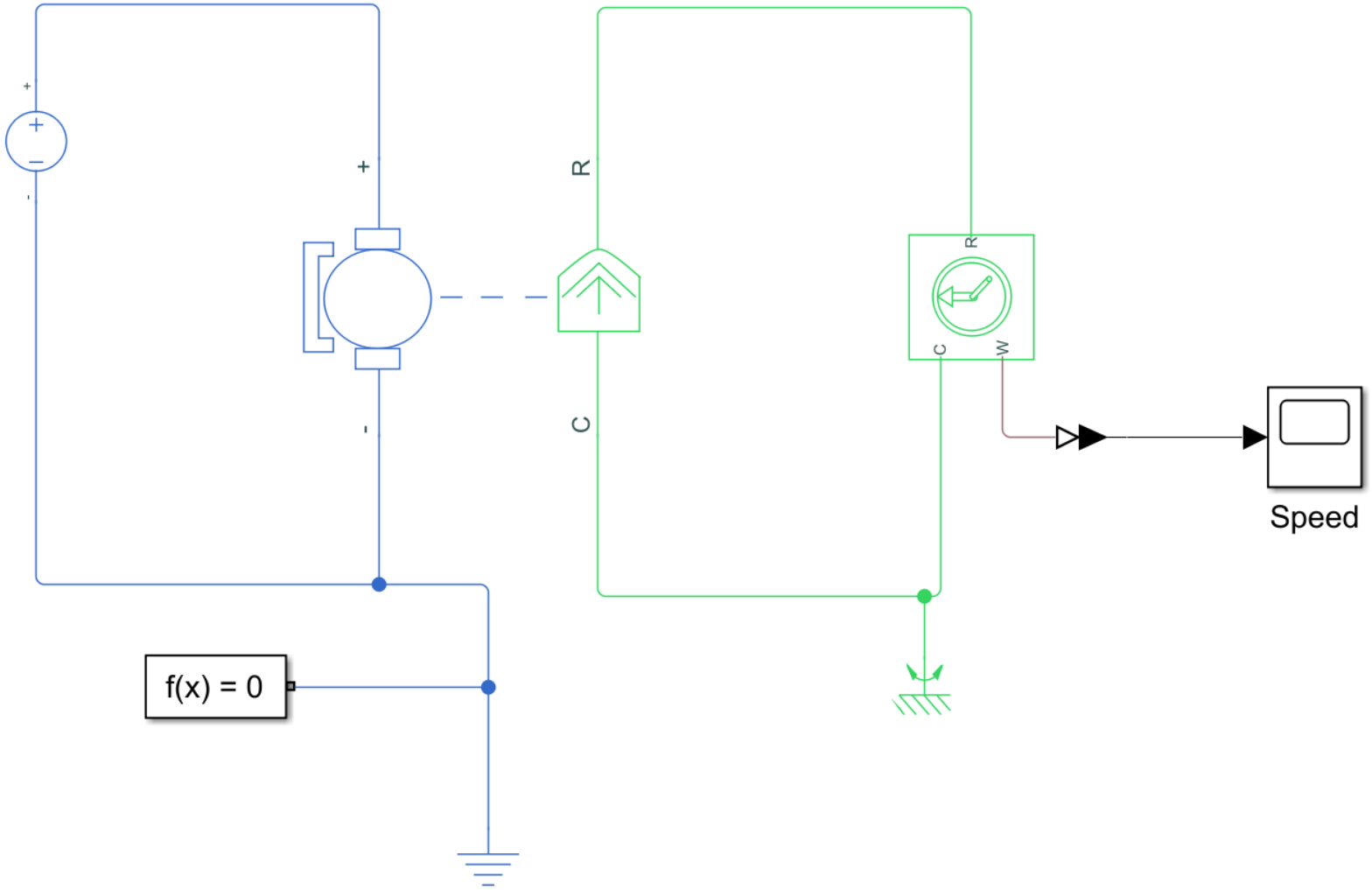




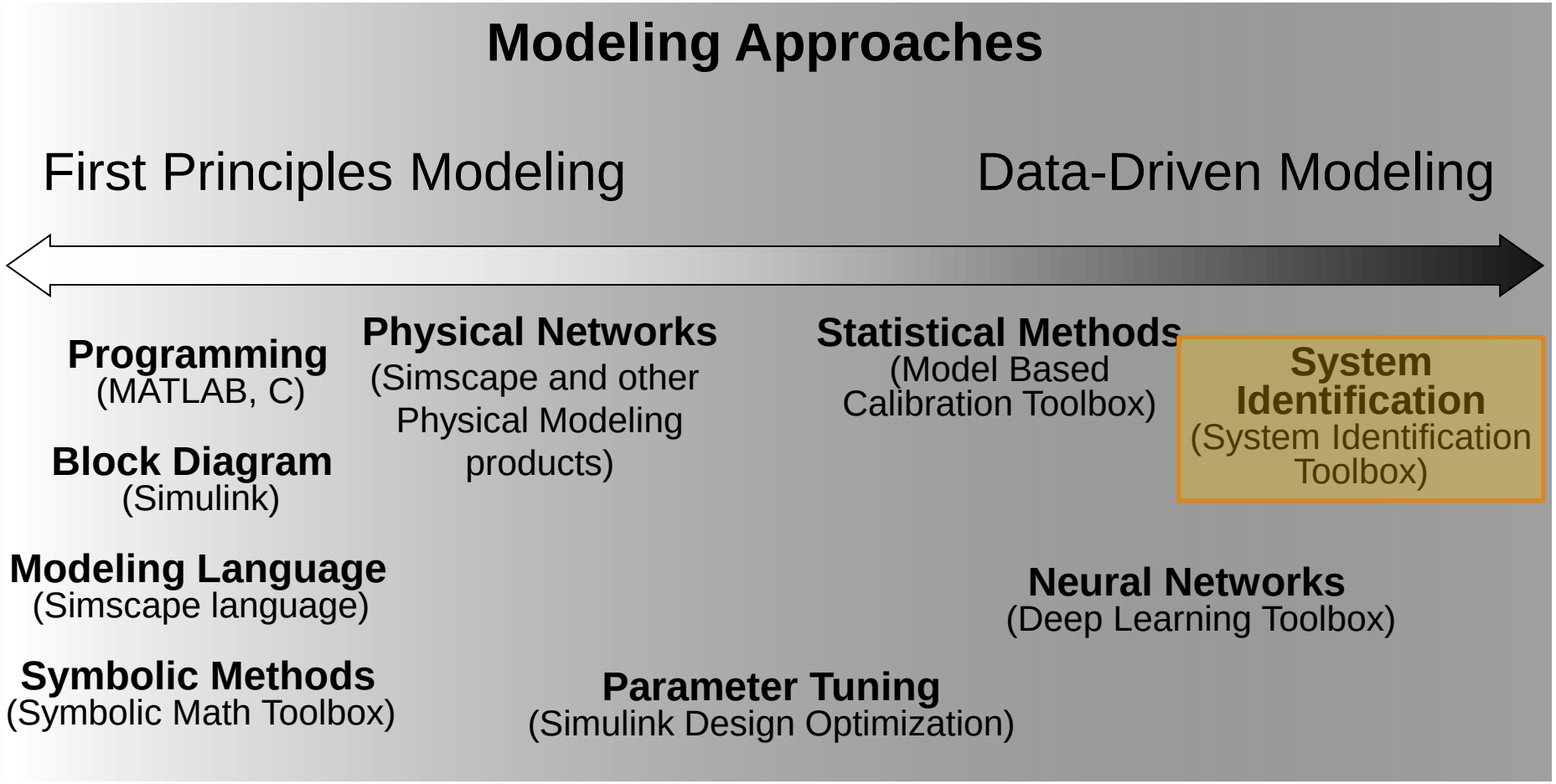
Physical Modeling of DC Motor with Simscape



Example: Model Physical Network of DC Motor using Simscape

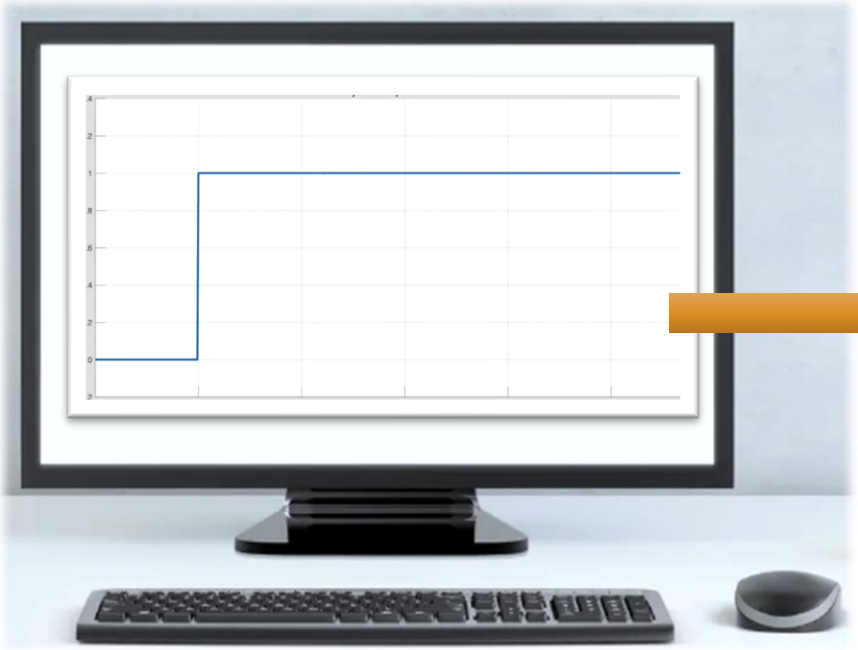


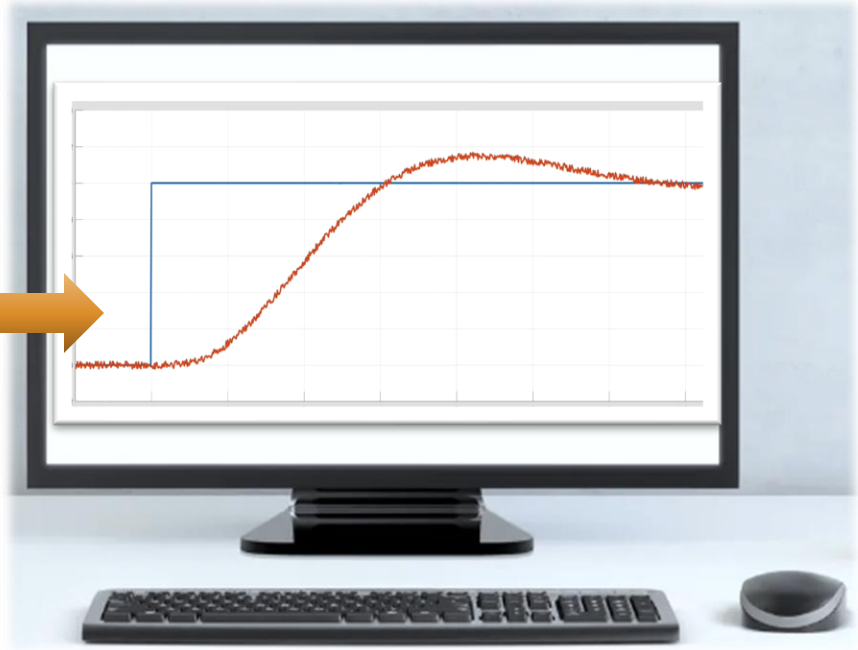
Different Approaches for Modeling Dynamic Systems



System Identification to go from data to model

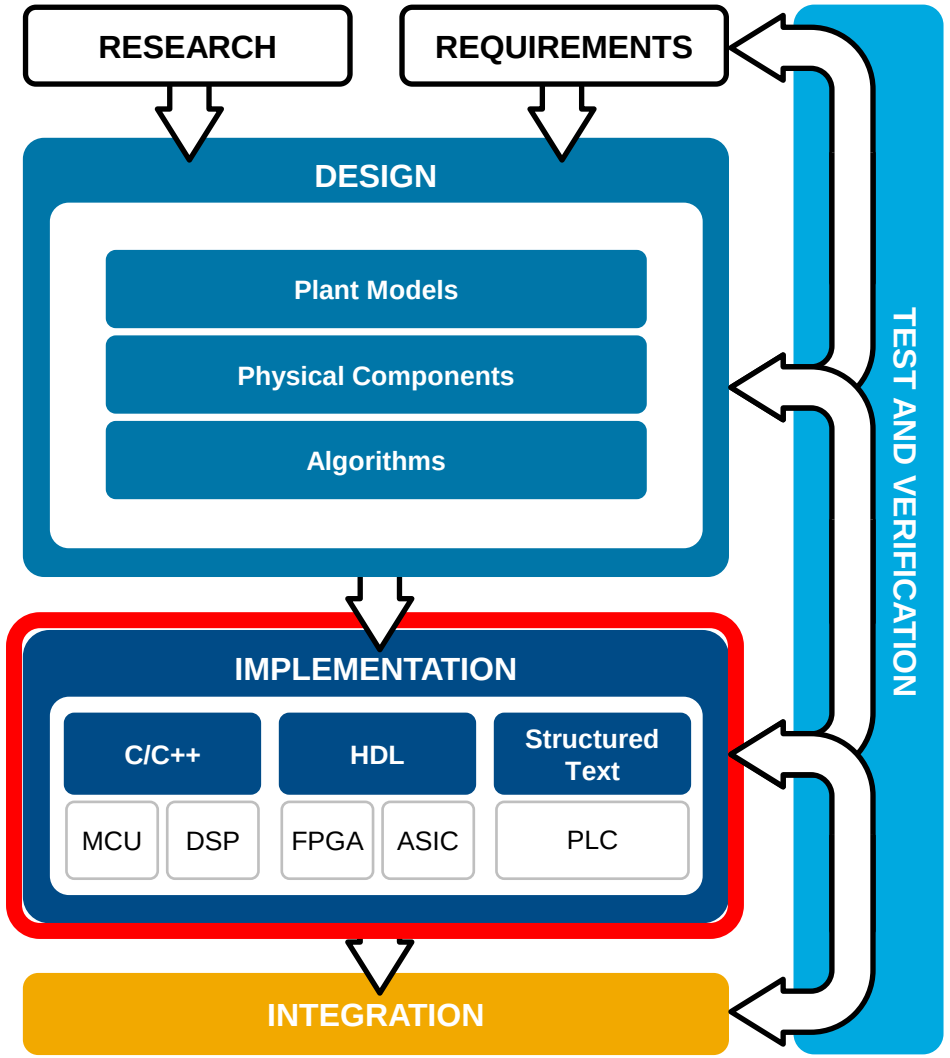
System Dynamics





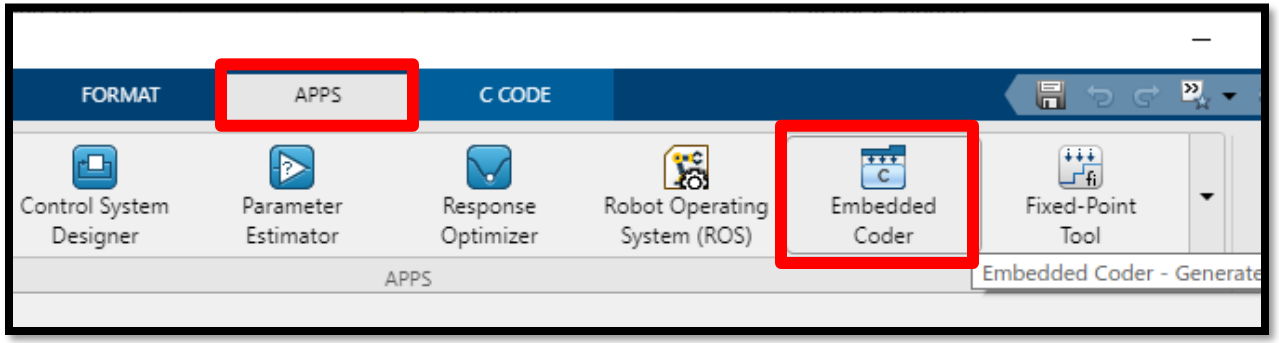
Transfer Function
Linear/Non-linear/Hybrid
Frequency Response
Neural Network…

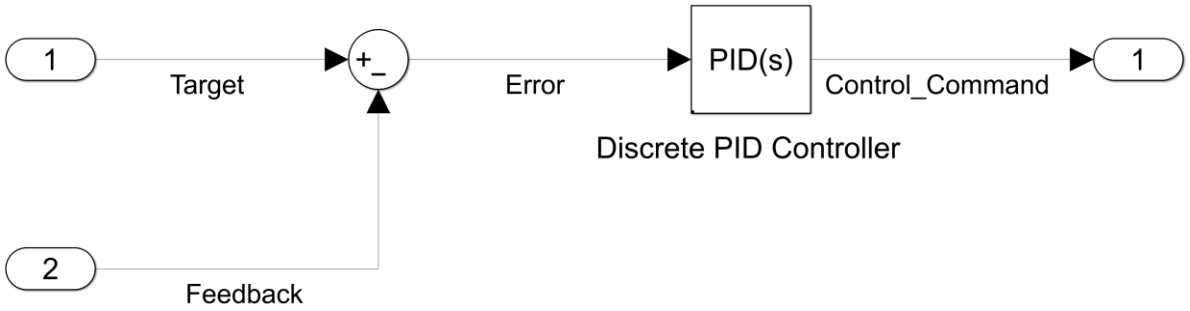
Model-Based Design Workflow



- **Deploy** your algorithms to the real world.
- Speed up the process with **Code Generation**.

Automate Implementation with Code Generation





Access code generation tools from the Embedded Coder App

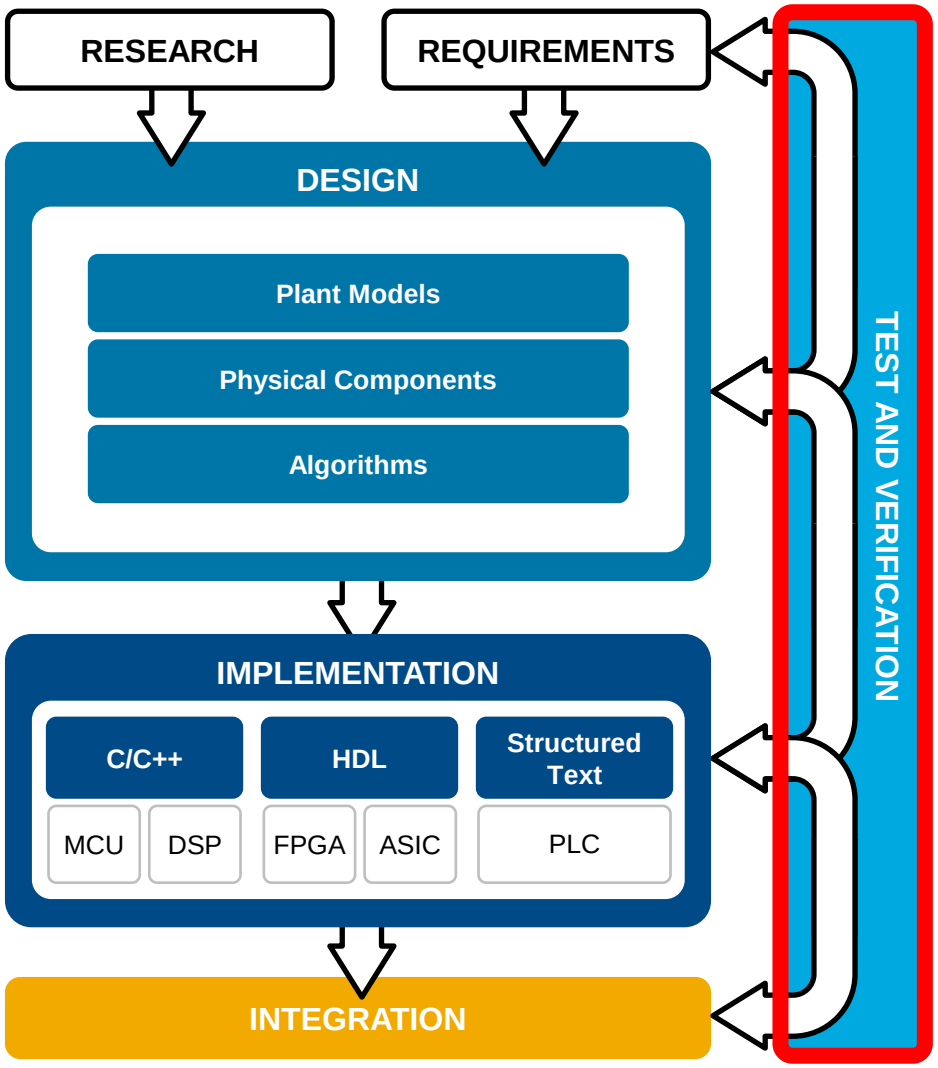
```
/* Model step function */
void codegen_example_step(void)
{
  real_T rtb_Error;
  real_T rtb_Tsamp;

  /* Sum: '<Root>/Sum' incorporates:
   *  Inport: '<Root>/Feedback'
   *  Inport: '<Root>/Target'
   */
  rtb_Error = rtU.Target + rtU.Feedback;

  /* SampleTimeMath: '<S30>/Tsamp' incorporates:
   *  Gain: '<S27>/Derivative Gain'
   *
   * About '<S30>/Tsamp':
   *  y = u * K where K = 1 / ( w * Ts )
   */
  rtb_Tsamp = rtP.DiscretePIDController_D * rtb_Error * rtP.Tsamp_WtEt;

  /* Outport: '<Root>/Control_Command' incorporates:
```

Model-Based Design Workflow



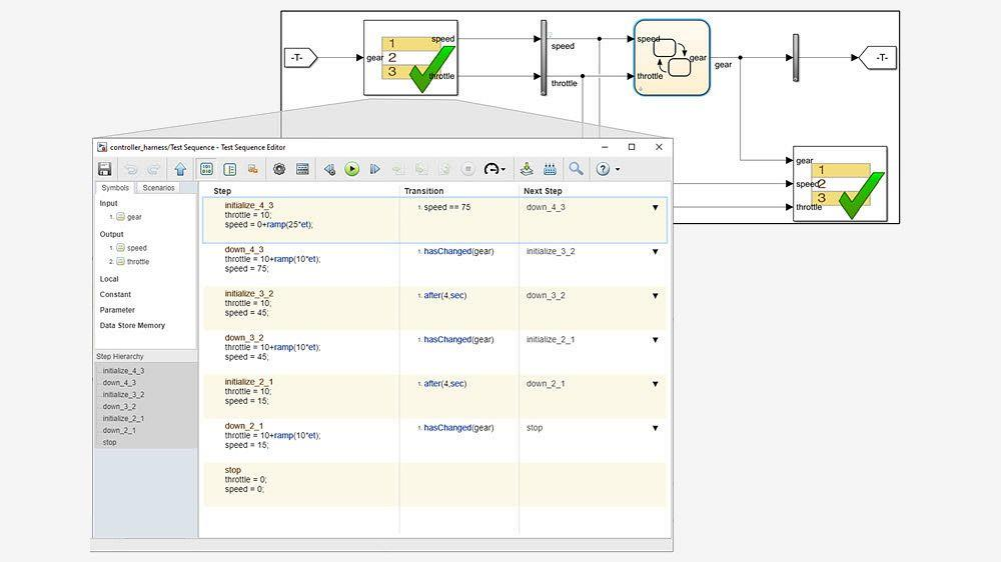
- Modeling and Simulation is **not the real world**.
- Test and verify with **Simulink Test** and **Hardware in-the-Loop (HiL)**.

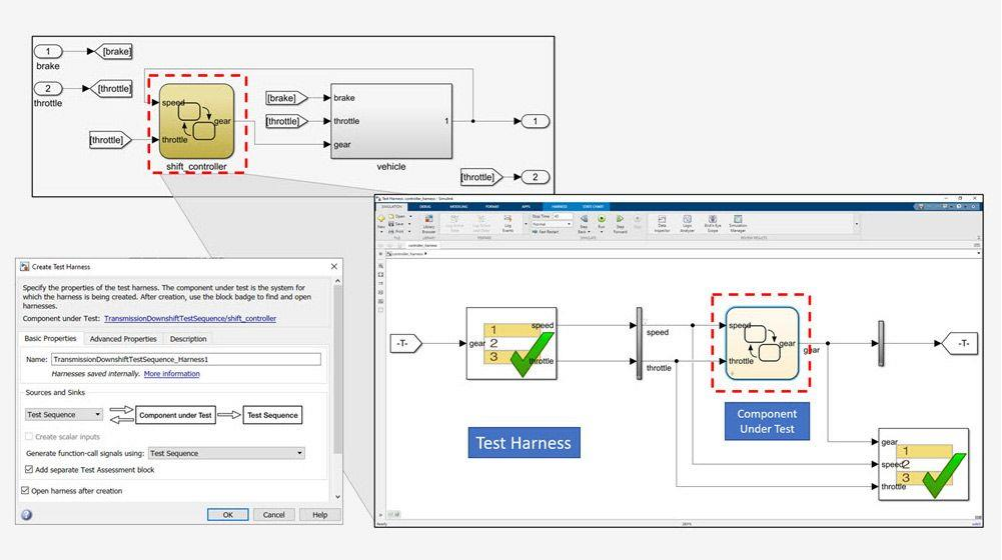
Simulink Test

- Author tests and assess simulation results with step-based and temporal test sequences

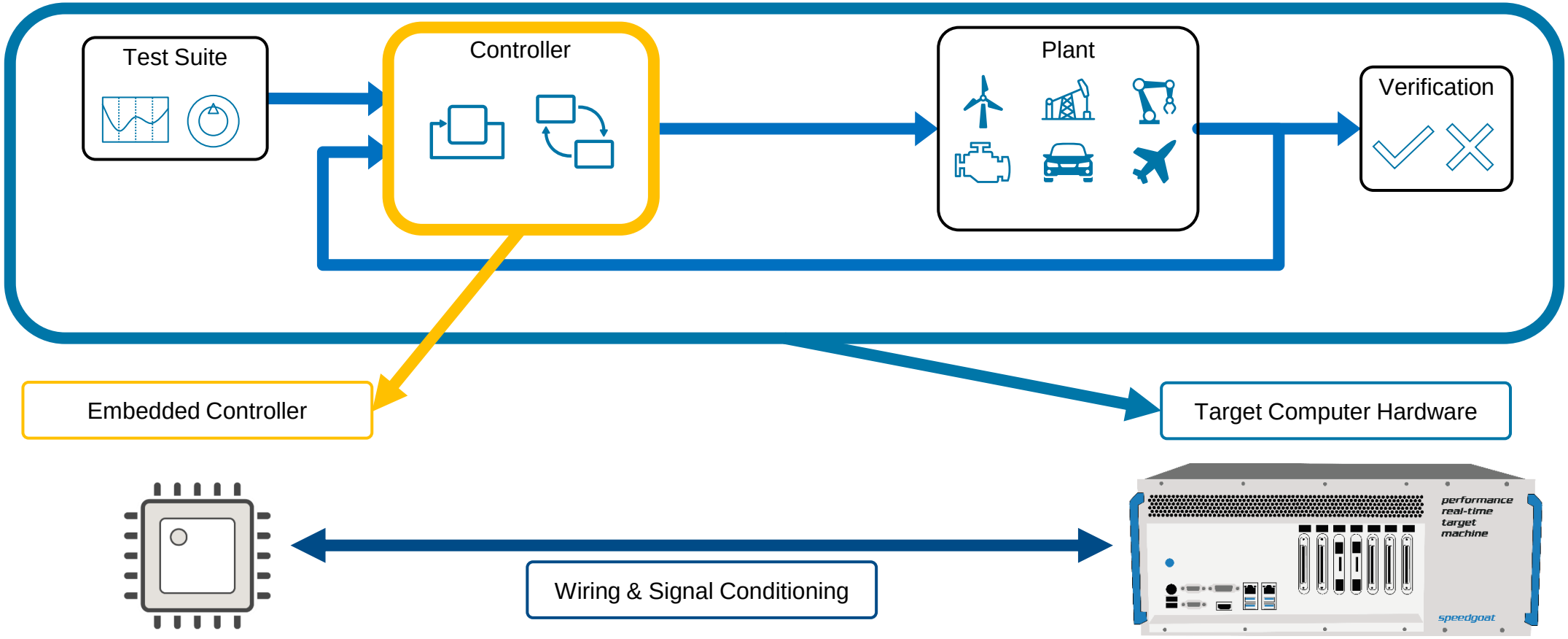
- Run test-specific simulations on models or model components while synchronizing design changes between the model and test harnesses

- Tests in normal simulation, accelerator, software-in-the-loop (SIL), processor-in-the-loop (PIL), or real-time hardware-in-the-loop (HIL) mode with Simulink Real-Time





Hardware-in-the-Loop (HIL) Systems



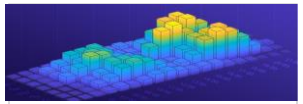
HIL systems have many advantages, including being able to run thousands of tests automatically without any human intervention, and allowing us to test situations that would be too dangerous or too expensive

Key Takeaways

- The real world is full of complex, multi-domain systems
- MBD leads to higher efficiency in development
- MATLAB, Simulink, and Simscape enable MBD
- Use the many resources available to get started!

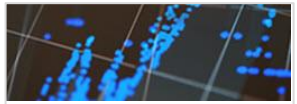
How can I get started?

100+ hours of Online Training

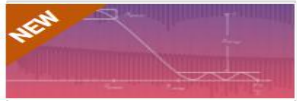


MATLAB Fundamentals

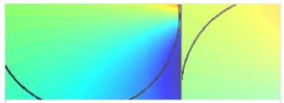
Simulink Fundamentals



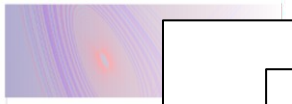
MATLAB for Data Processing and Visualization



Signal Processing with MATLAB



Solving Nonlinear Equations with MATLAB



Solving Or Differen Equations MATL

Deep Learning with MATLAB

Machine Learning with MATLAB

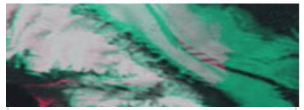
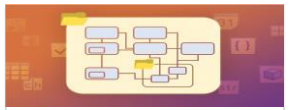


Image Processing with MATLAB



MATLAB Programming Techniques

Introduction to Statistical Methods with MATLAB

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Deep Learning with MATLAB

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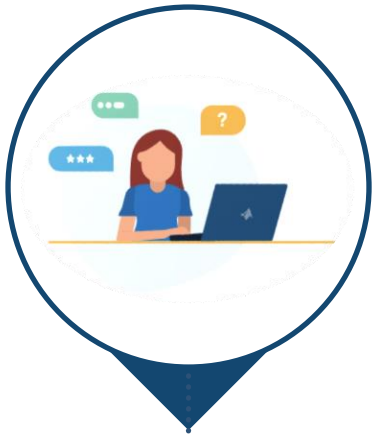
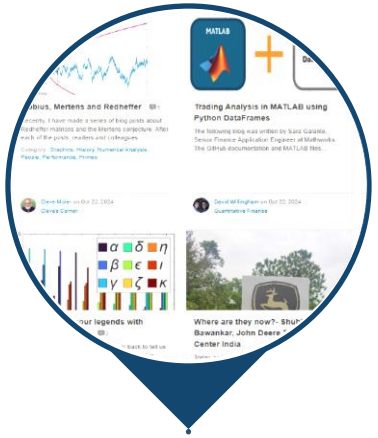


Open-source MATLAB code Publish yours to help others

Experiment, generate draft code, answer questions

Get the inside view on MATLAB and Simulink



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