MATLAB EXPO 2021

Mission Planning of a Quadcopter Using a Digital Twin

Maria Gavilan

Sara Nambi

MathWorks®

MATLAB EXPO 2021

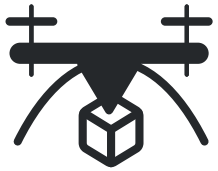
Mission Planning of a Quadcopter Using a Digital Twin

Kritika Ramani

Ameya Rajendra Godbole

MathWorks

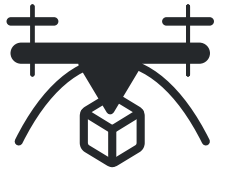
Before we start, let's prepare to participate in this workshop



Use your laptop and a web browser to run exercises

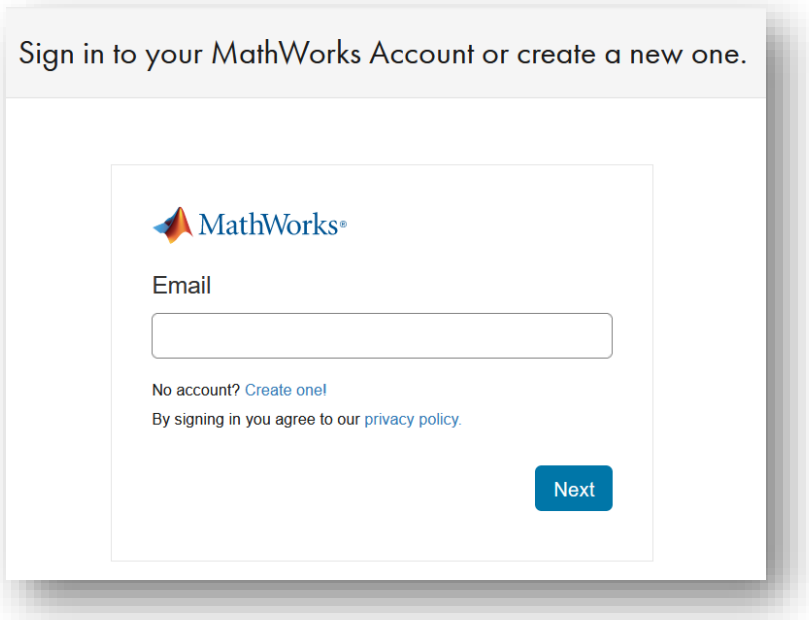
Download instructions using the "Handouts" Tab

A group of TAs will assist with questions



Access MATLAB Online

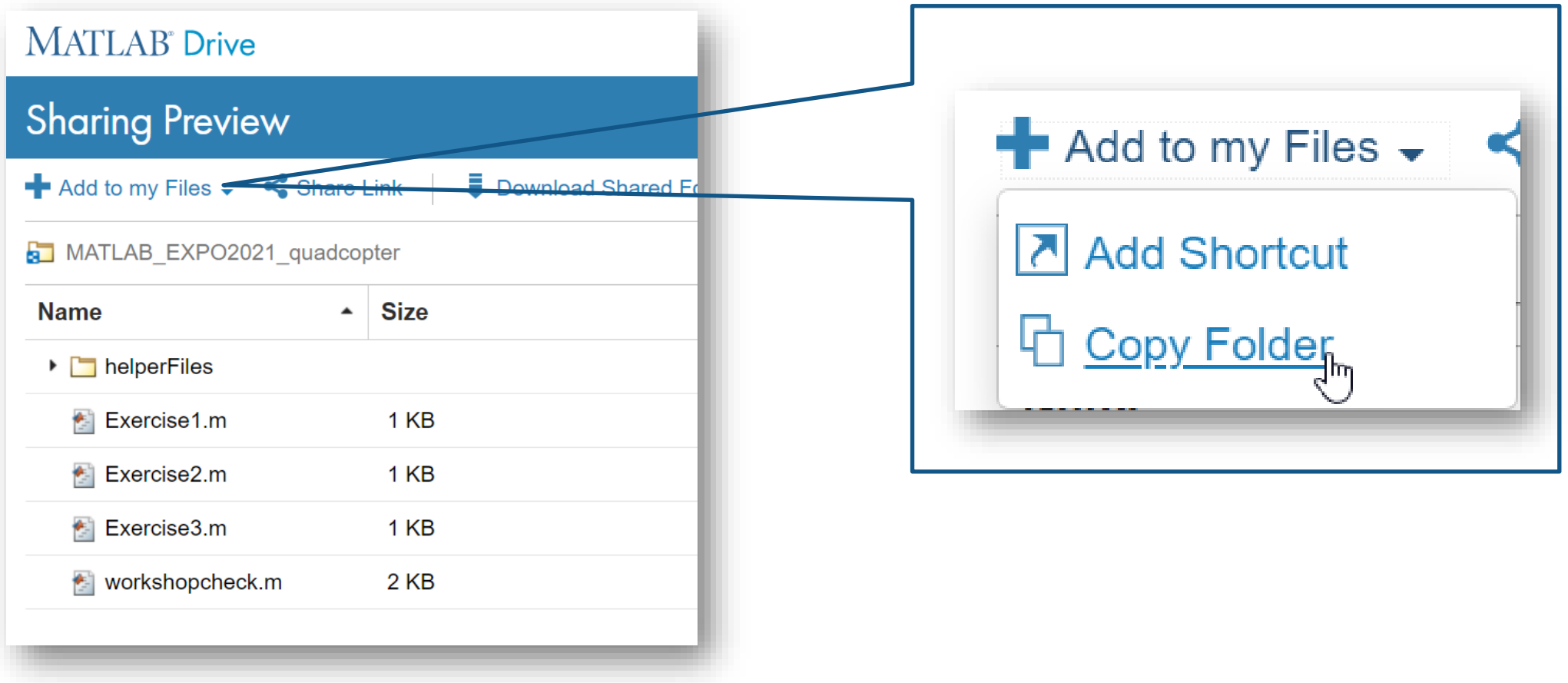
1. Create your MathWorks account



2. Access your license https://tinyurl.com/DigitalTwinWorkshop

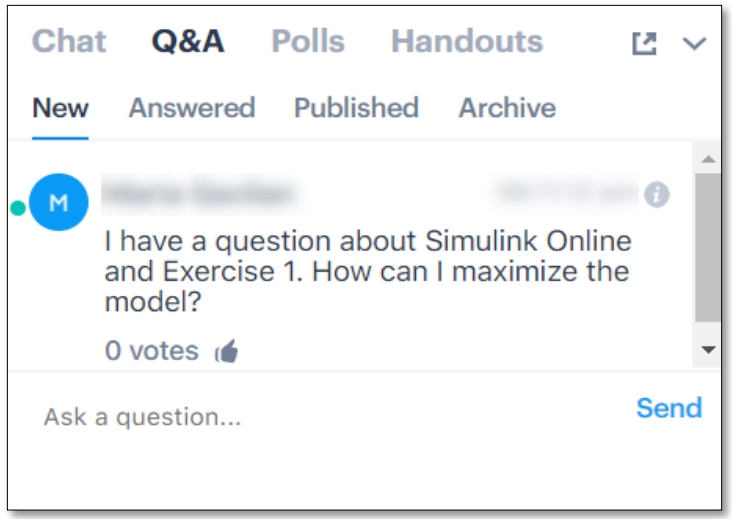
Access workshop files in MATLAB Drive

https://tinyurl.com/DigitalTwinWorkshopFiles

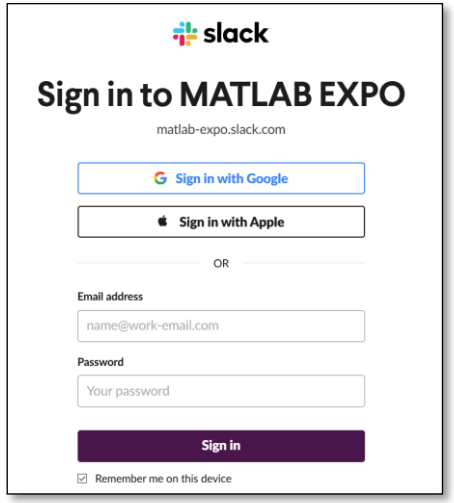


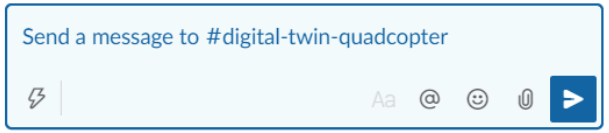
How to get assistance during the workshop

BigMarker
(**use Q&A**)



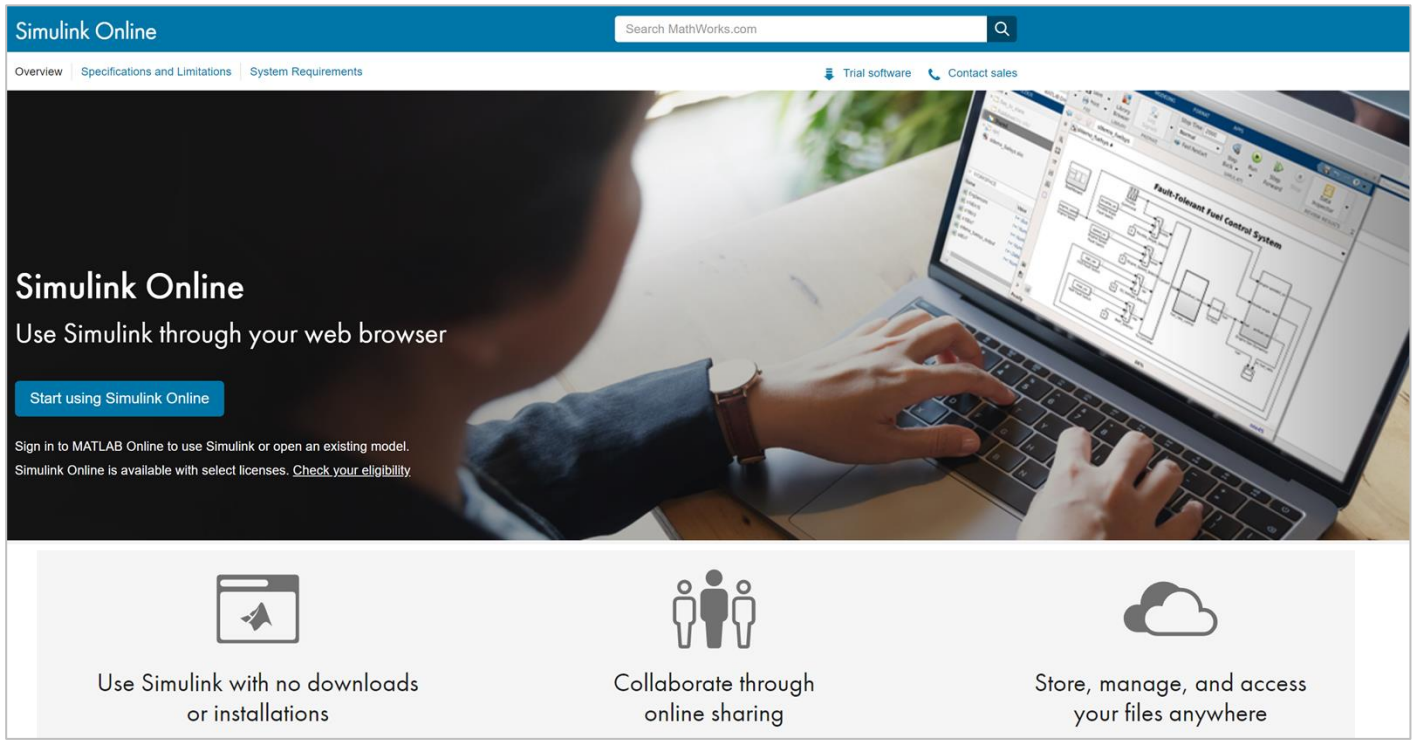
Slack

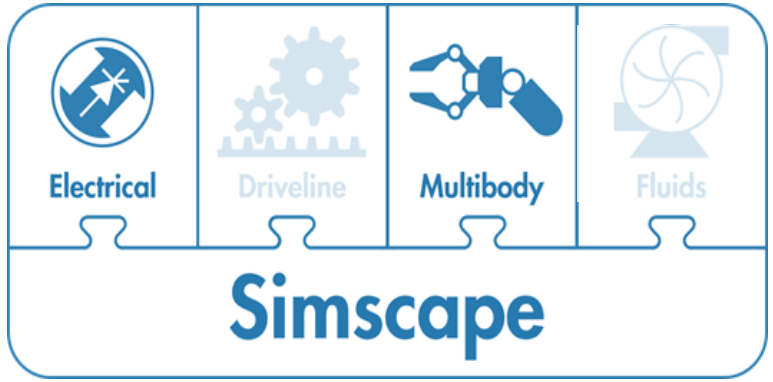




Products used in this workshop

Today we will be using **Simulink Online**





Navigation Toolbox™

Predictive Maintenance Toolbox™

The problem we'll be tackling in this workshop

Design a delivery drone

Valuable cargo

What if the need is too critical and failure is not an option?

How to "fail fast" so we can address issues before deploying to real devices?

The problem we'll be tackling in this workshop

Design a delivery drone

Valuable cargo

Digital Twin

Workflow

Use your data to build models and predict failures

Data

Collect Data
Create Datastores

(both real + digital models)

Model

Physical Modeling
(digital twin)

Behavior Modeling

Act

Predict
Fault Detection, RUL

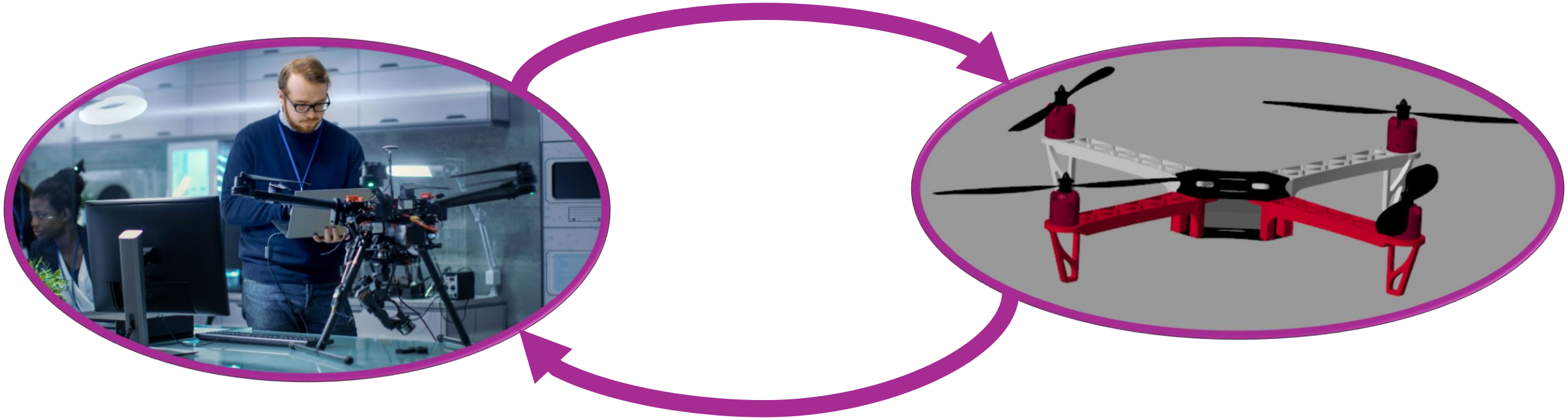
Change Control

Integrate

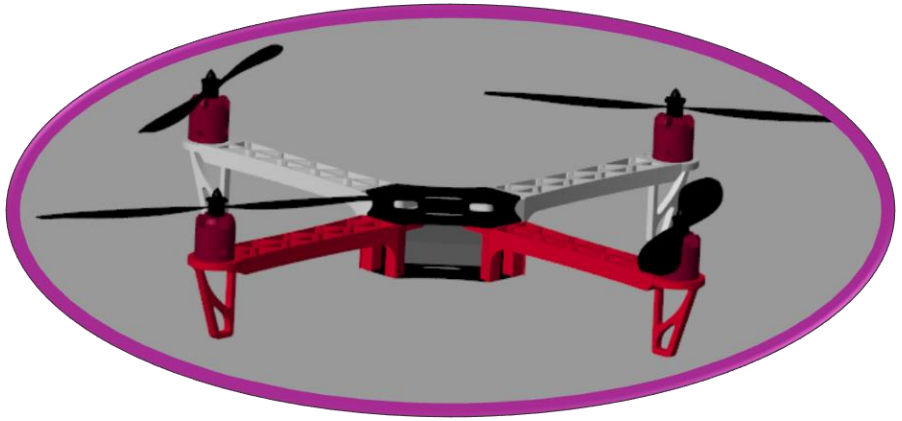
Code generation
Deploy

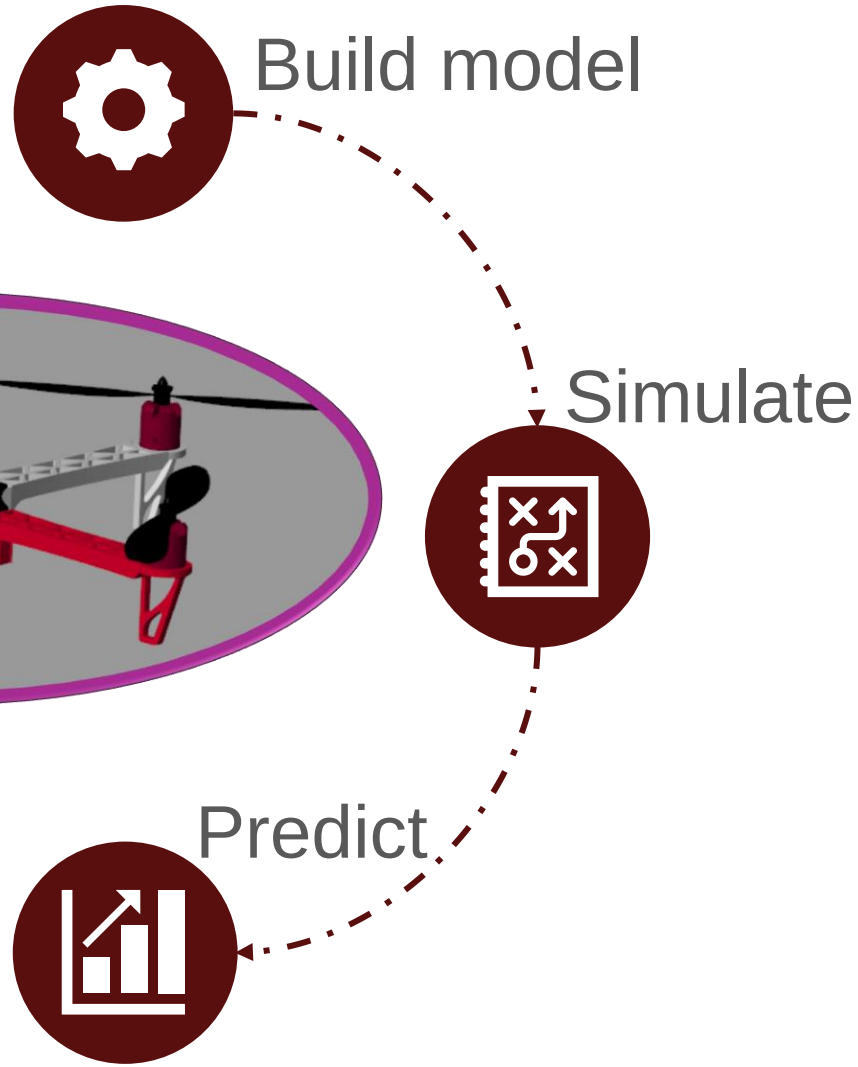
Digital twins connect the virtual world of simulation to real world operation.

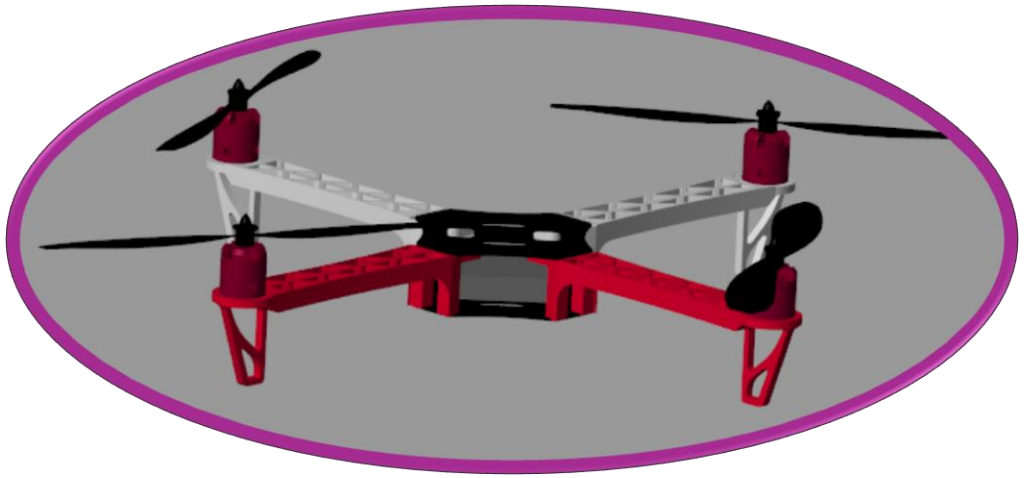
Real world data informs simulation, and simulation data informs operation.



You can use digital twin simulation data to build data-driven behavioral models.



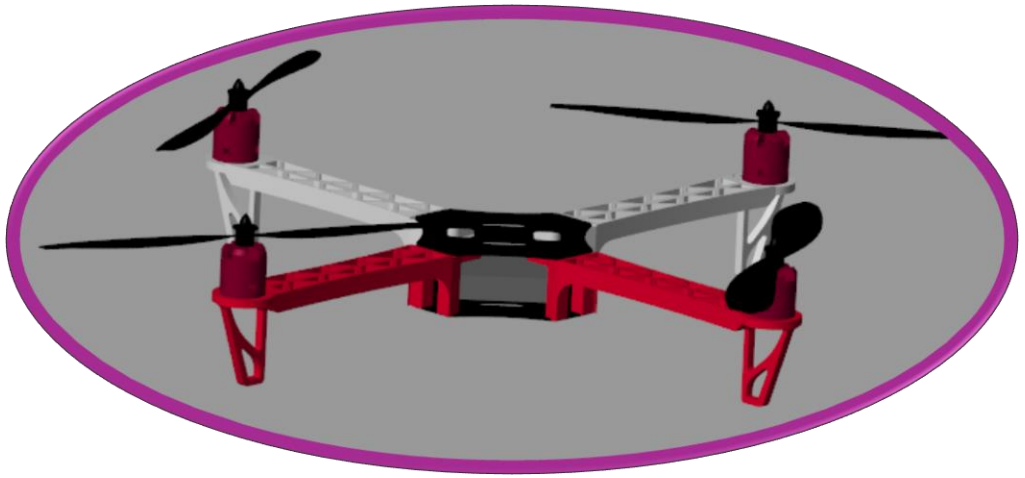




Exercise 1: Meet the Digital Twin

Exercise 2: Plan the Mission

Exercise 3: Fault Detection

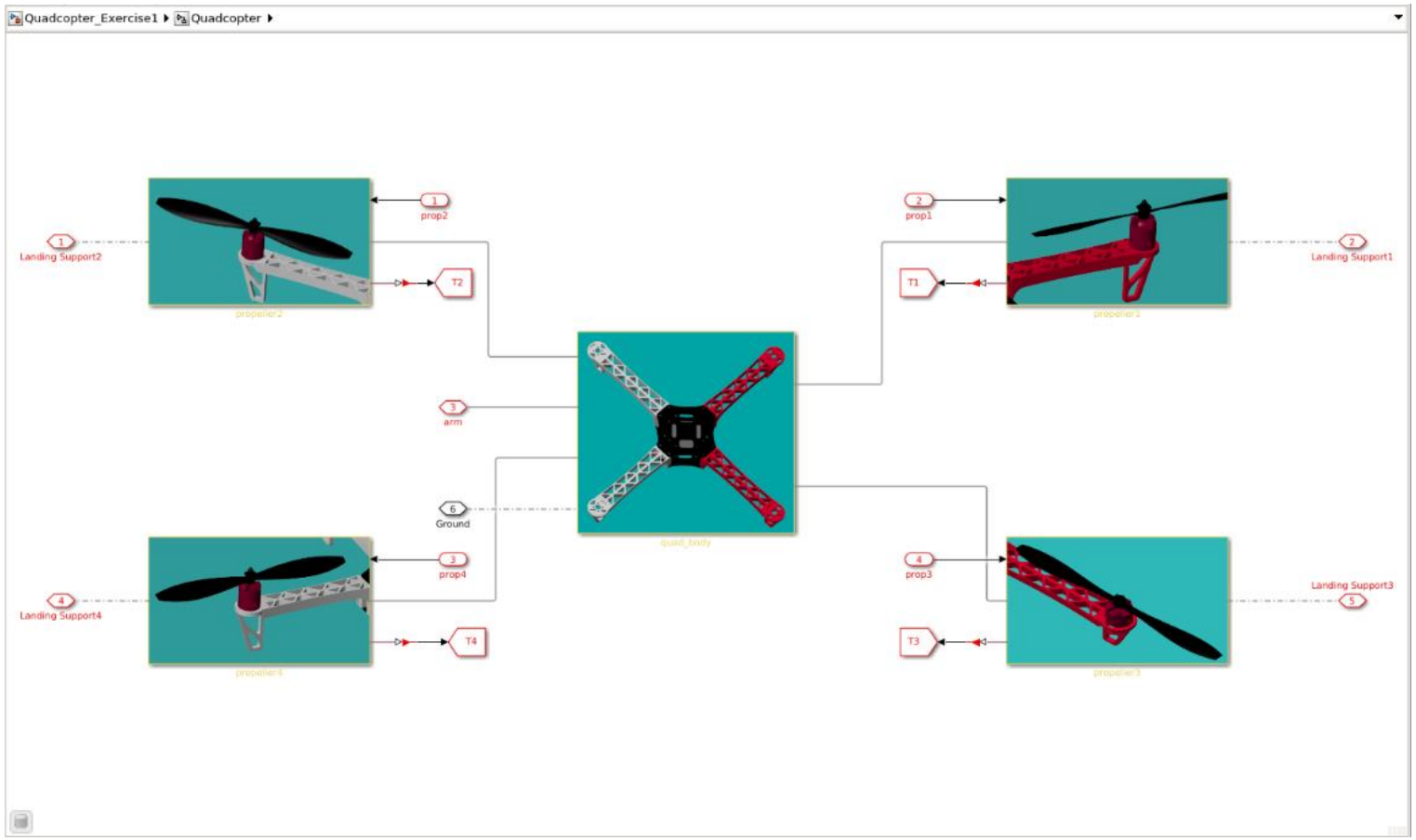


Exercise 1: Meet the Digital Twin

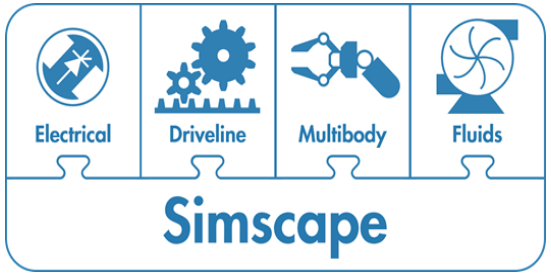
Exercise 2: Plan the Mission

Exercise 3: Fault Detection

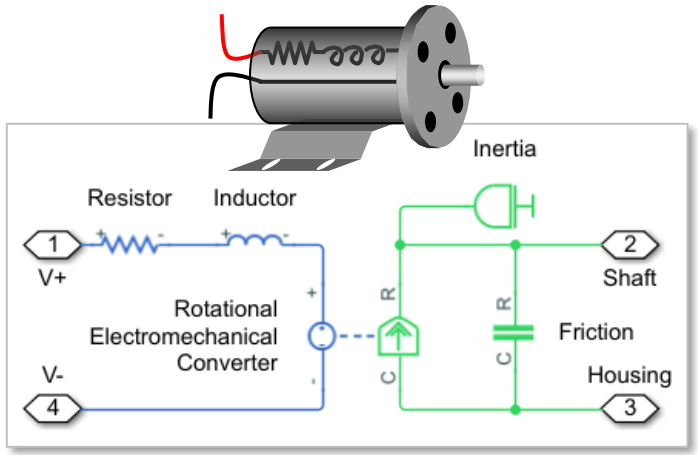
Modeling the Quadcopter

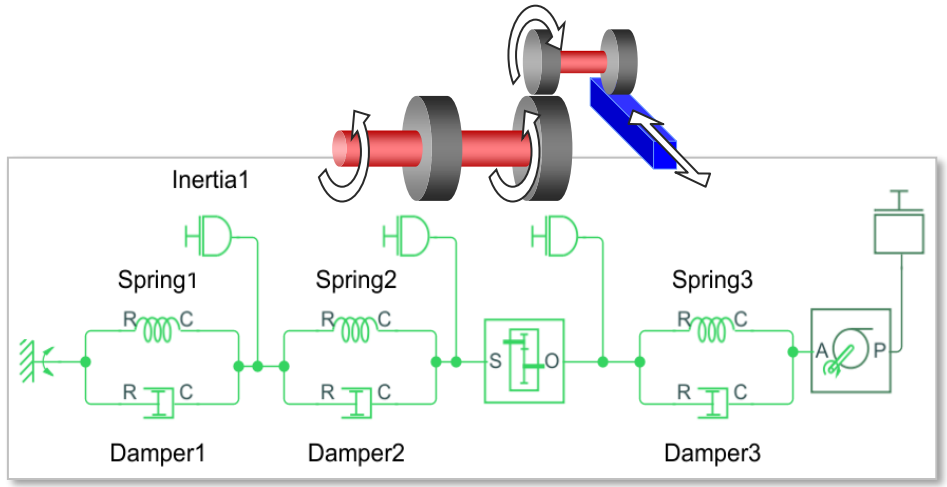


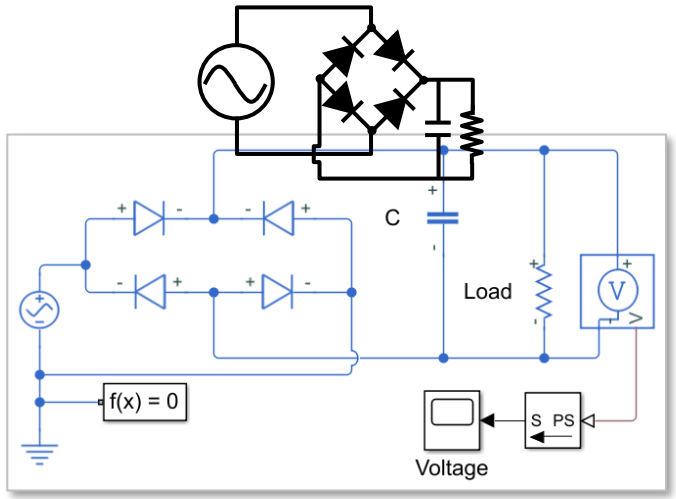
We used Simscape to build the digital twin of our quadcopter



Simscape allows us to model a multidomain system as a physical network that reflects the structure of the actual system.



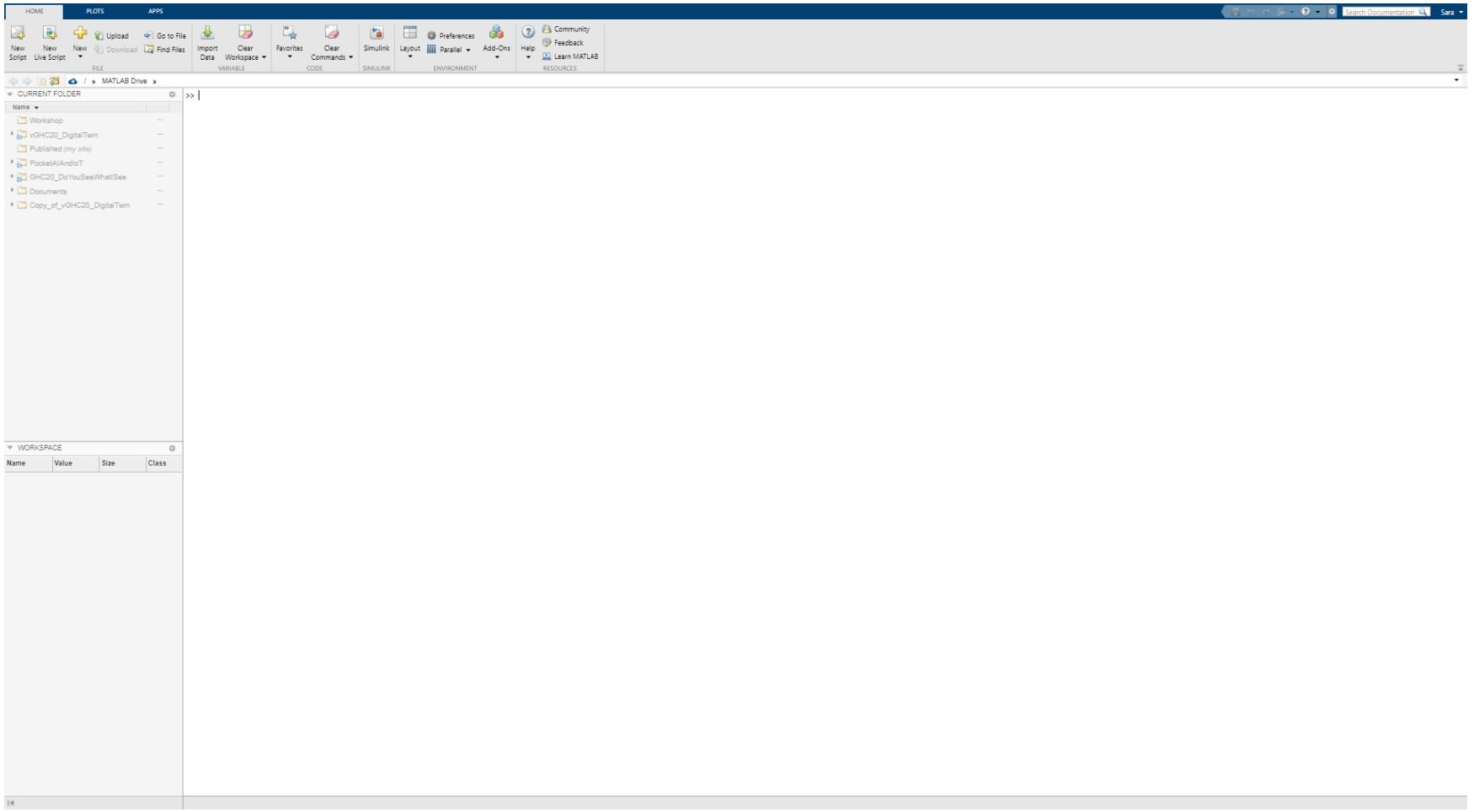




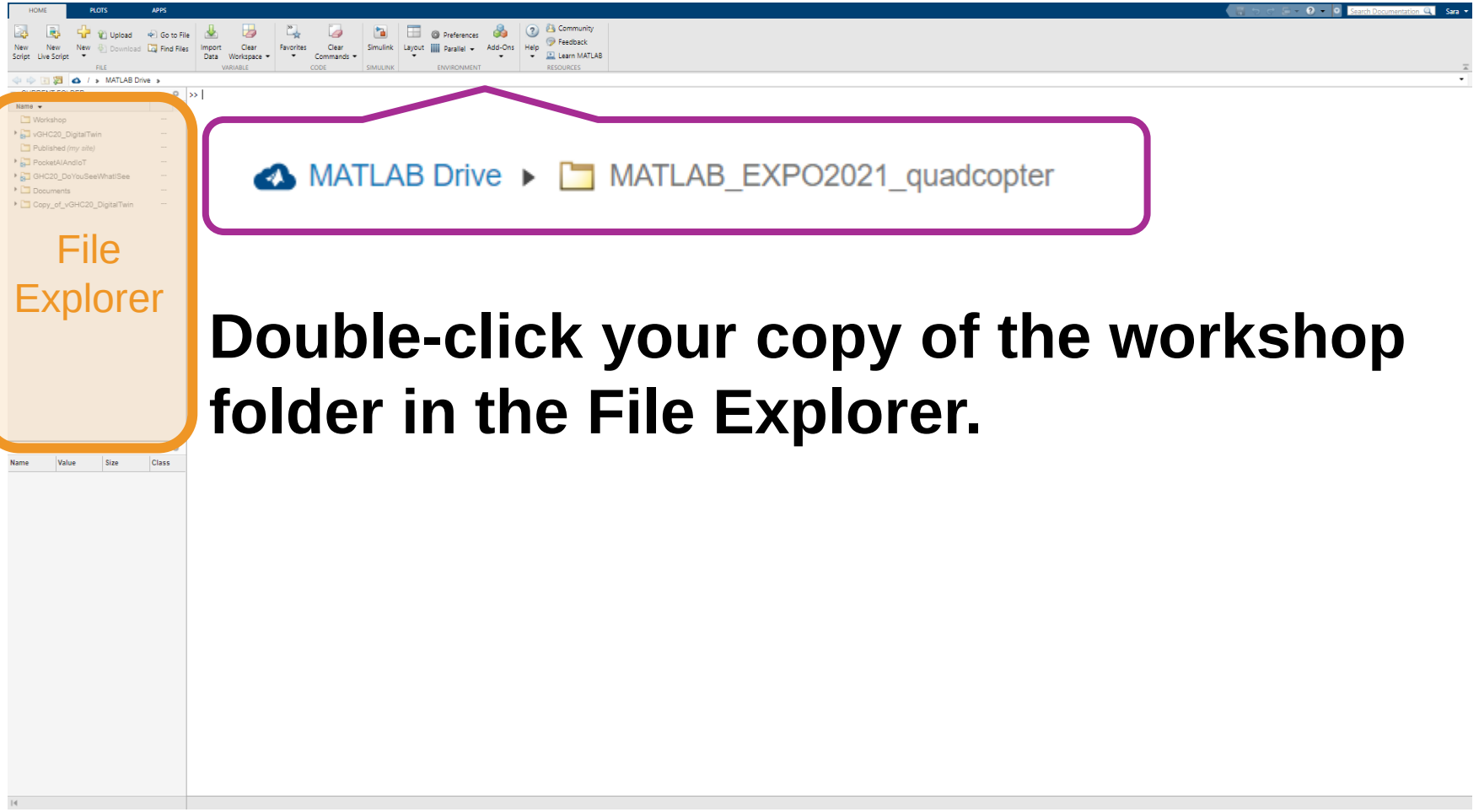
Exercise 1

In your browser, navigate to:

https://tinyurl.com/DigitalTwinWorkshop

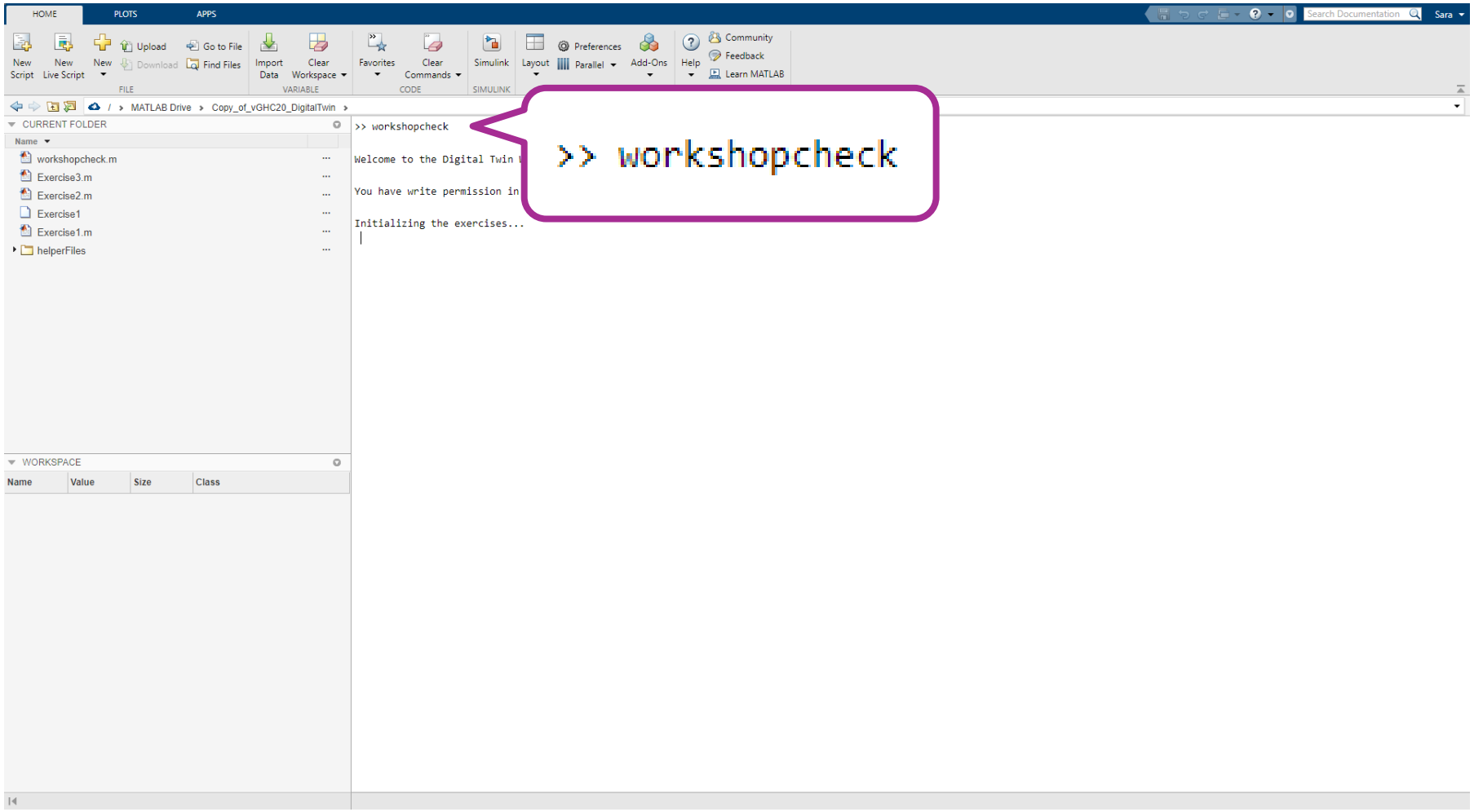


Navigate inside the copy you made of the workshop folder.

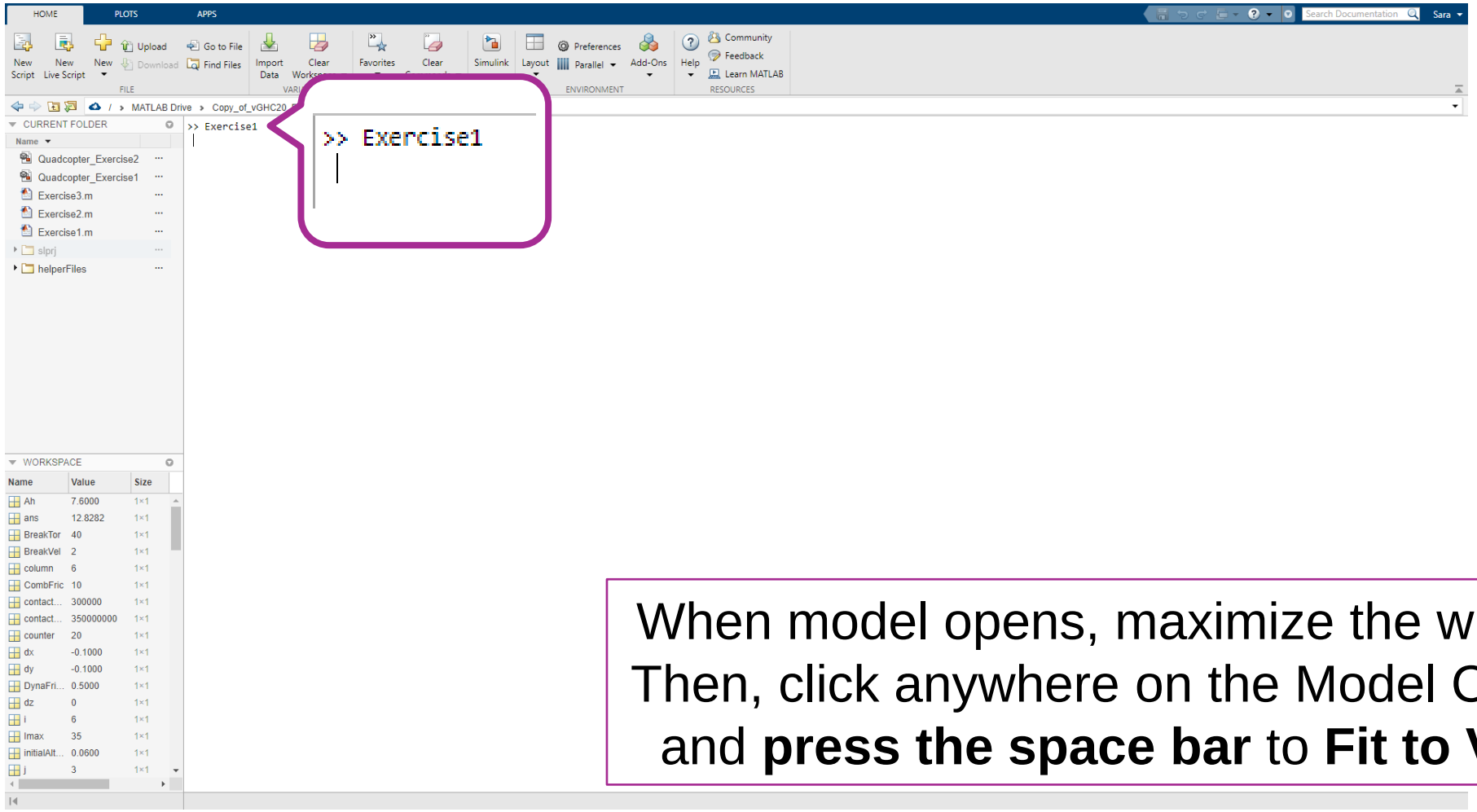


Double-click your copy of the workshop folder in the File Explorer.

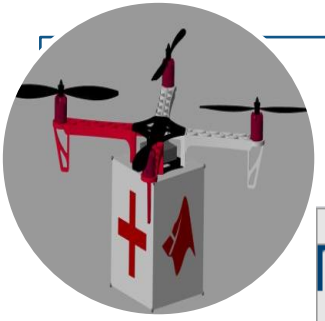
Type `workshopcheck` into the Command Window and press Enter



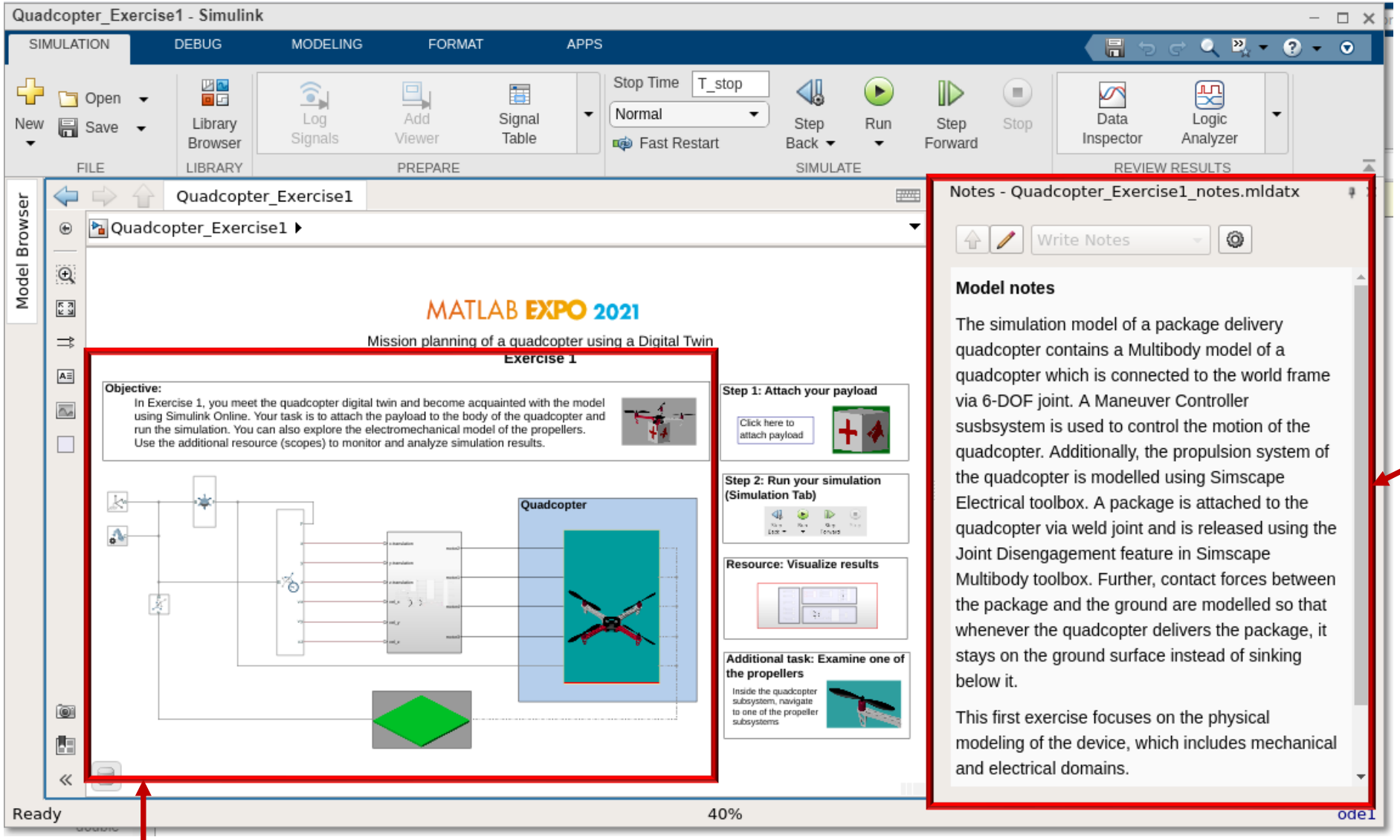
Type `Exercise1` in the Command Window and press Enter



When model opens, maximize the window. Then, click anywhere on the Model Canvas and **press the space bar** to **Fit to View**.

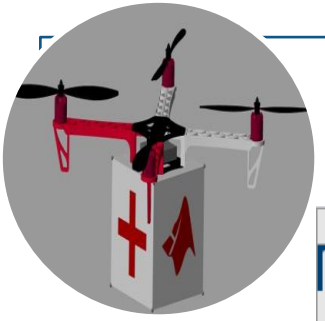


Let's walk through the model for Exercise 1...



Notes provide detailed info about the model

Quadcopter system modeled in Simscape



Let's walk through the model for Exercise 1...

Quadcopter_Exercise1 - Simulink

SIMULATION DEBUG MODELING FORMAT APPS

New Open Save FILE | Library Browser LIBRARY | Log Signals Add Viewer Signal Table PREPARE | Stop Time T_stop, Normal, Fast Restart | Step Back Run Step Forward Stop SIMULATE | Data Inspector Logic Analyzer REVIEW RESULTS

Model Browser

Quadcopter_Exercise1

Quadcopter_Exercise1

MATLAB EXPO 2021

Mission planning of a quadcopter using a Digital Twin

Exercise 1

Objective:

In Exercise 1, you meet the quadcopter digital twin and become acquainted with the model using Simulink Online. Your task is to attach the payload to the body of the quadcopter and run the simulation. You can also explore the electromechanical model of the propellers. Use the additional resource (scopes) to monitor and analyze simulation results.

Step 1: Attach your payload

Click here to attach payload

Step 2: Run your simulation (Simulation Tab)

Resource: Visualize results

Additional task: Examine one of the propellers

Inside the quadcopter subsystem, navigate to one of the propeller subsystems

Quadcopter

Notes - Quadcopter_Exercise1_notes.mldatx

Write Notes

Model notes

The simulation model of a package delivery quadcopter contains a Multibody model of a quadcopter which is connected to the world frame via 6-DOF joint. A Maneuver Controller susbsystem is used to control the motion of the quadcopter. Additionally, the propulsion system of the quadcopter is modelled using Simscape Electrical toolbox. A package is attached to the quadcopter via weld joint and is released using the Joint Disengagement feature in Simscape Multibody toolbox. Further, contact forces between the package and the ground are modelled so that whenever the quadcopter delivers the package, it stays on the ground surface instead of sinking below it.

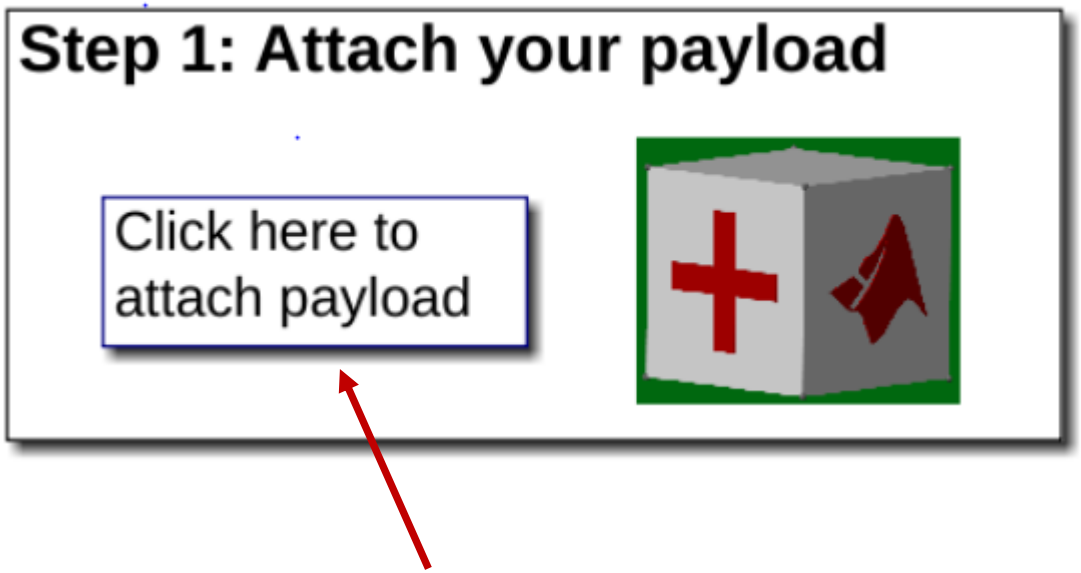
This first exercise focuses on the physical modeling of the device, which includes mechanical and electrical domains.

Ready 40% ode1

Exercise 1 Steps

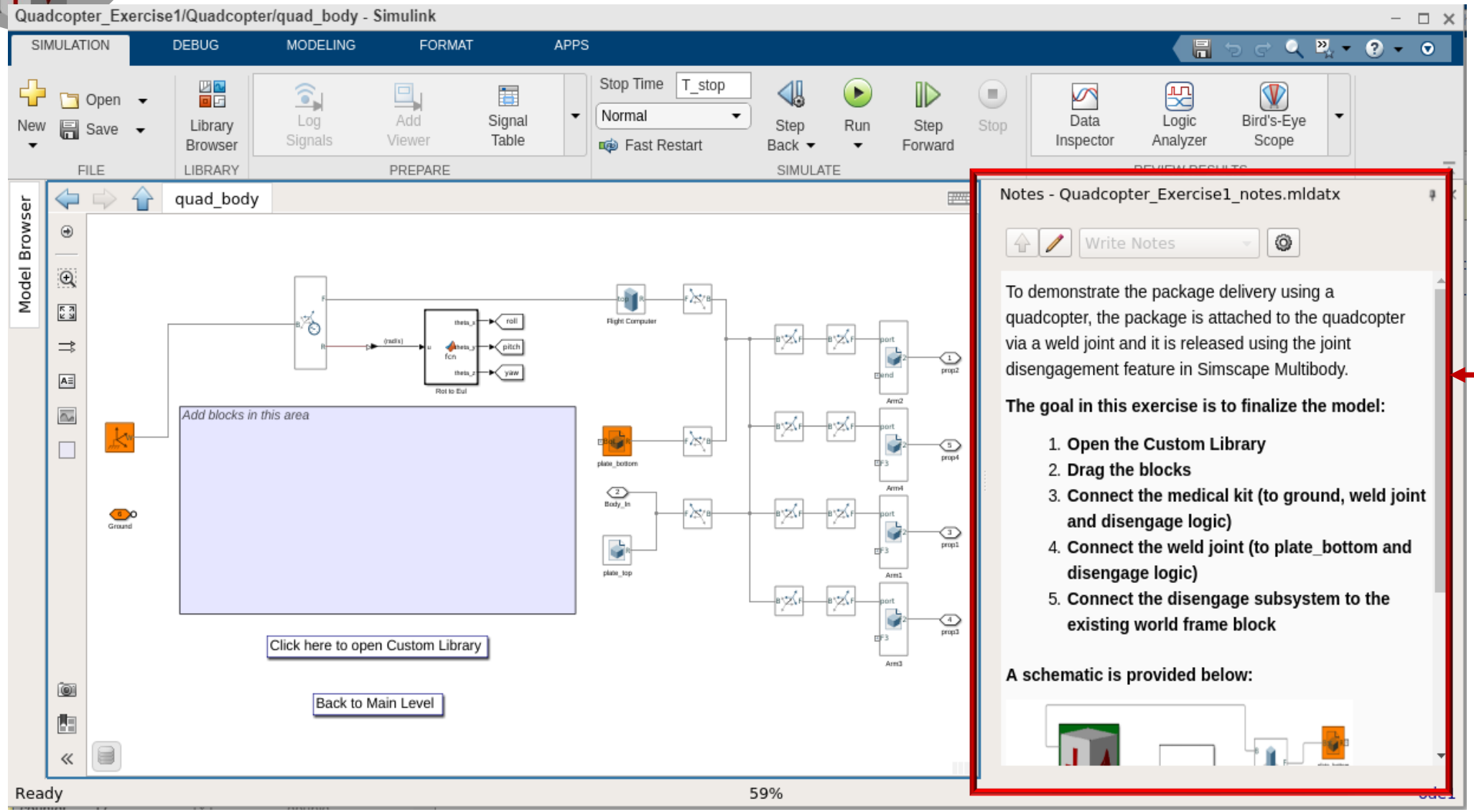
Exercise 1

- **Objective:** Attach the payload to the quadcopter body and run the simulation



Hyperlink opens up the quadcopter body subsystem

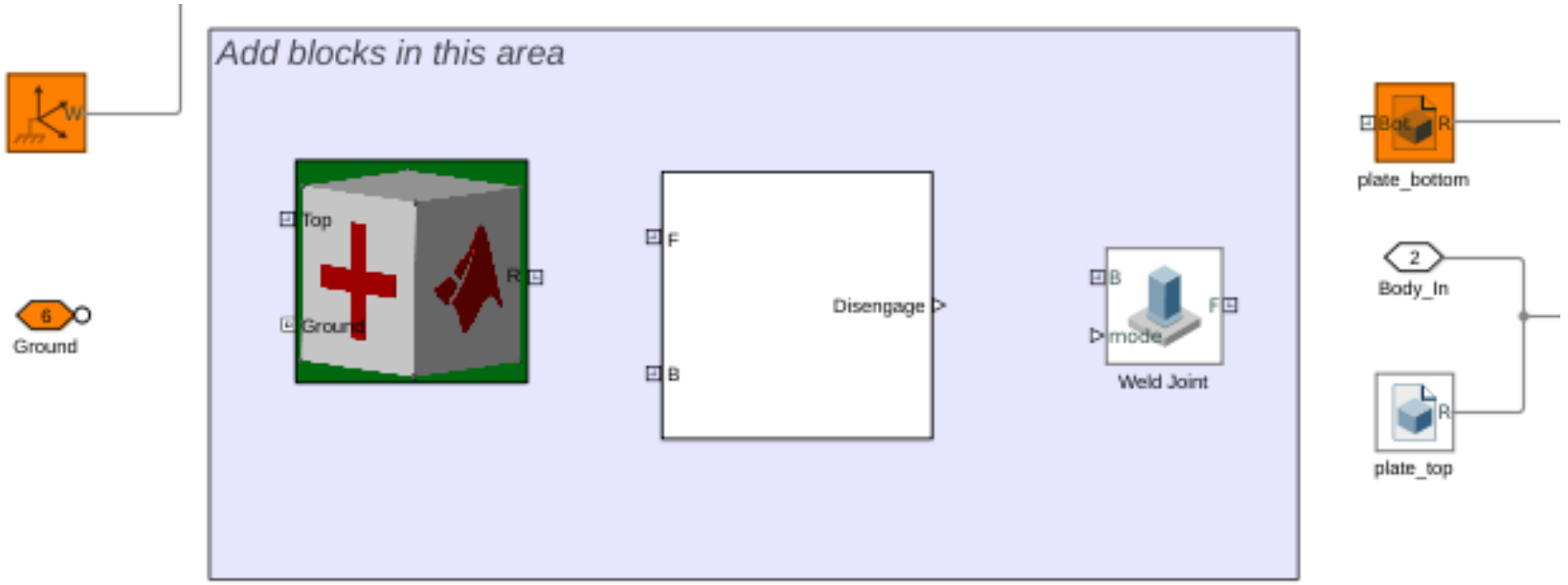
Quadcopter Body Subsystem



Follow these instructions to add and connect the blocks in the correct sequence!

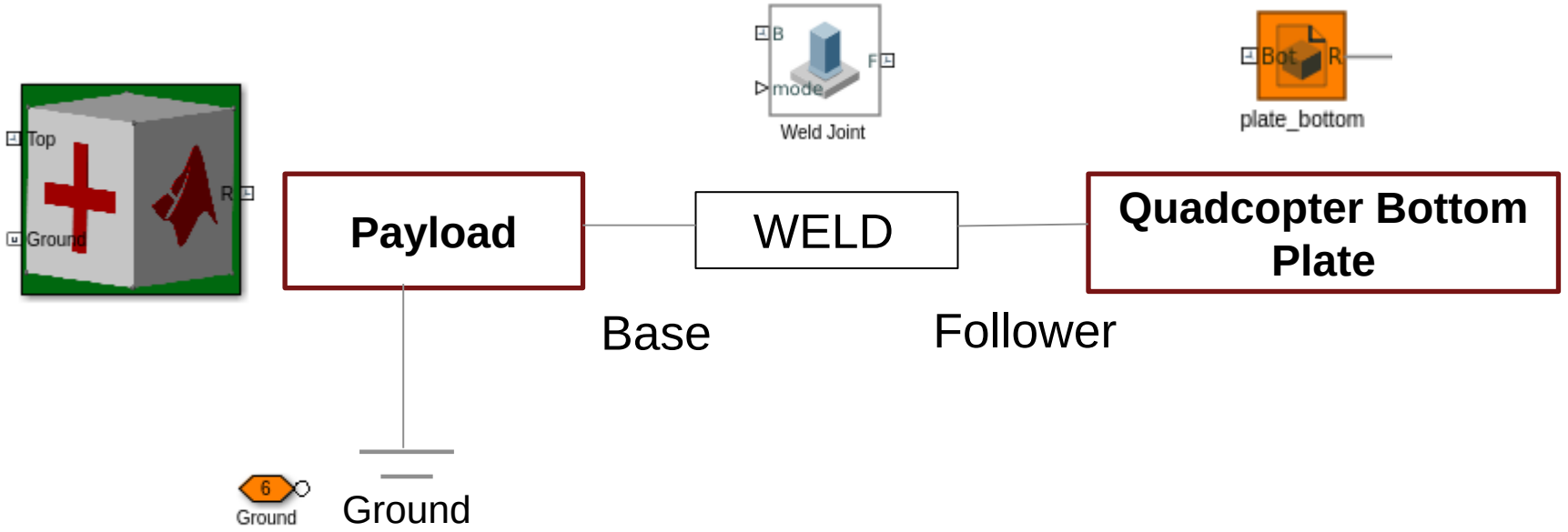
Exercise 1 – Step 1 in more detail

1. Drag all the blocks from the Custom Library into the blue area and get ready to make the connections



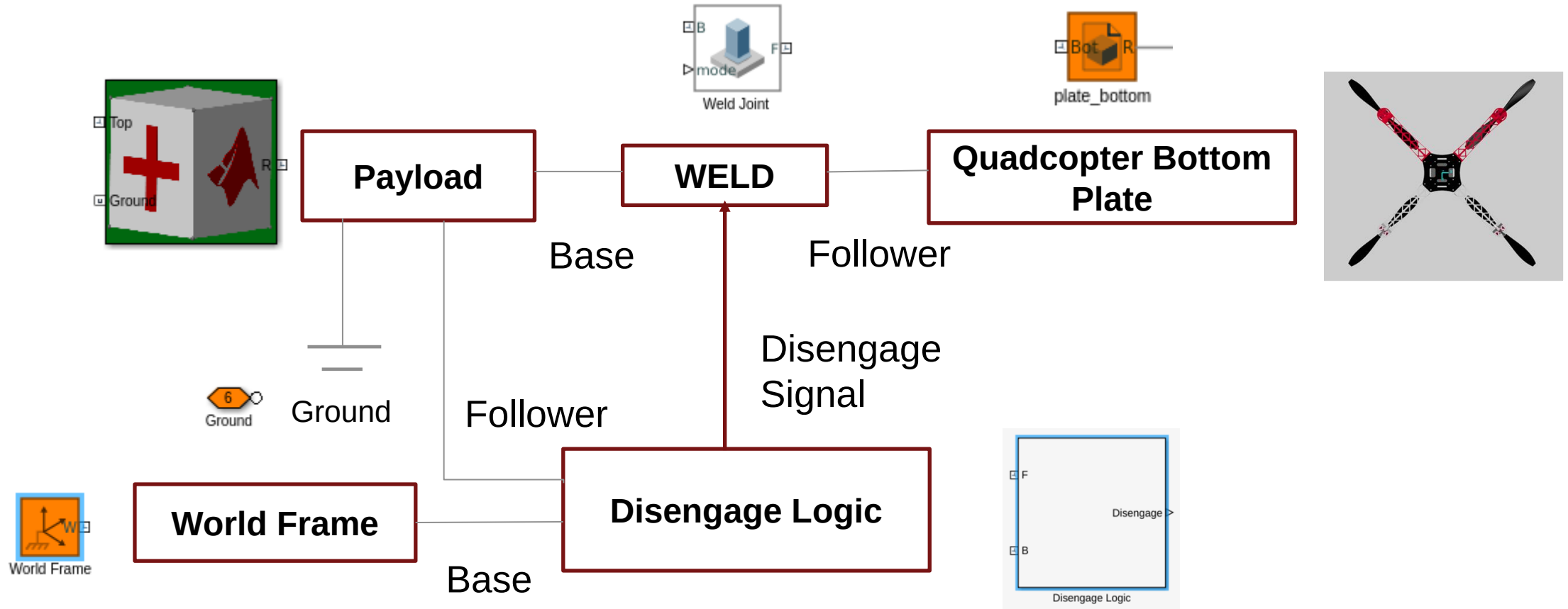
Exercise 1 – Step 1 in more detail

2. Connect the Payload Top to the ground and to the Quadcopter Bottom Plate via the Weld Joint



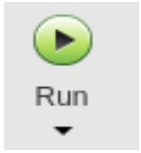
Exercise 1 - Step 1 in more detail

3. Ensure the Weld Joint can be disengaged when Payload reaches near its destination



Once you are done connecting the blocks

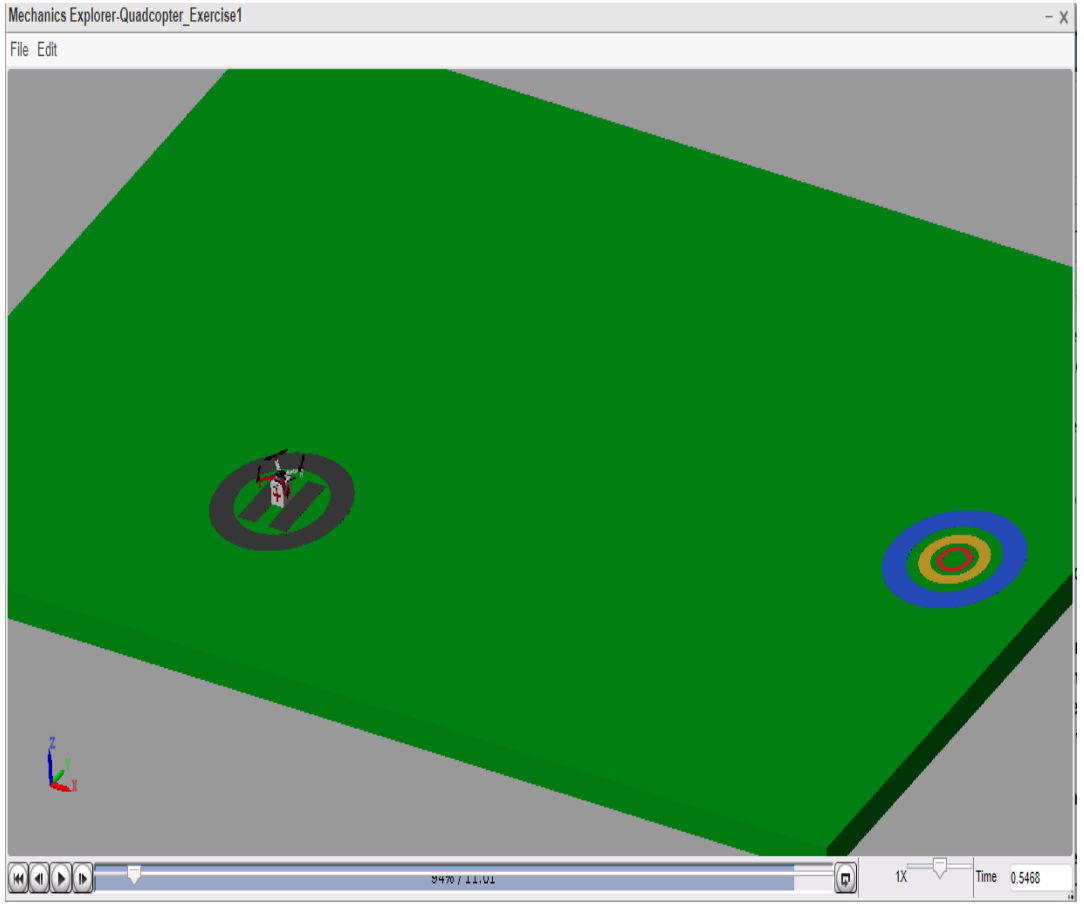
- Click “Run” to simulate



- Animation opens up in a new window

Rotate	Click and hold the mouse scroll wheel. Move the mouse in the direction you want to rotate the model
Zoom	Use the mouse scroll wheel to zoom in/out.

- You can also visualize the results using the provided scopes

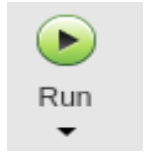


Exercise 1 Summary

- **Objective:** Attach the payload to the quadcopter body and run the simulation

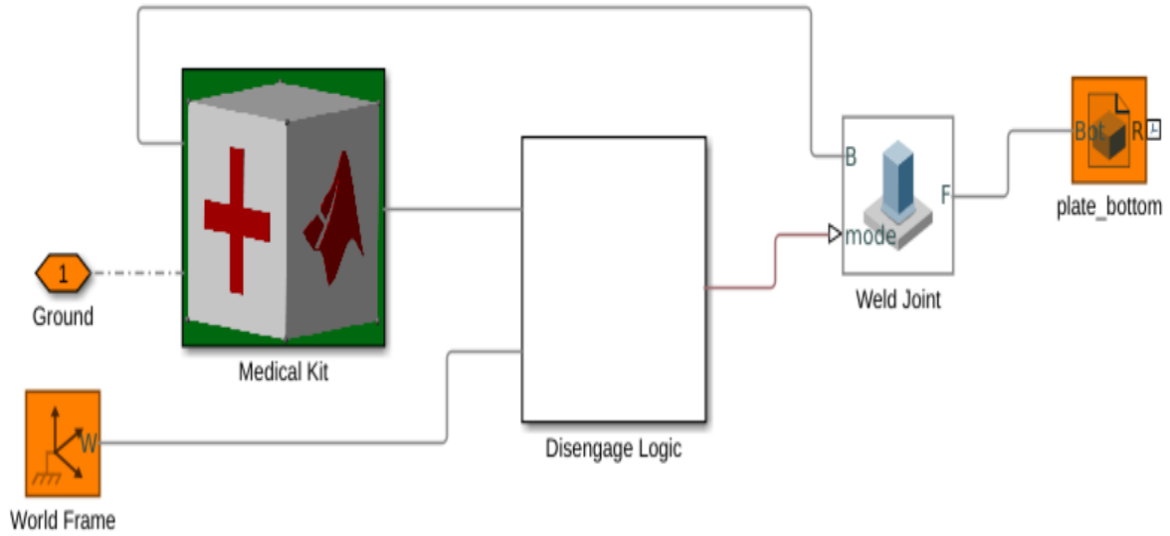
Steps:

1. Click on the hyperlink in **Step 1 : Attach your Payload**
2. Follow the instructions in the quad_body subsystem
3. Once you are done connecting the package, click “**Run**” to simulate



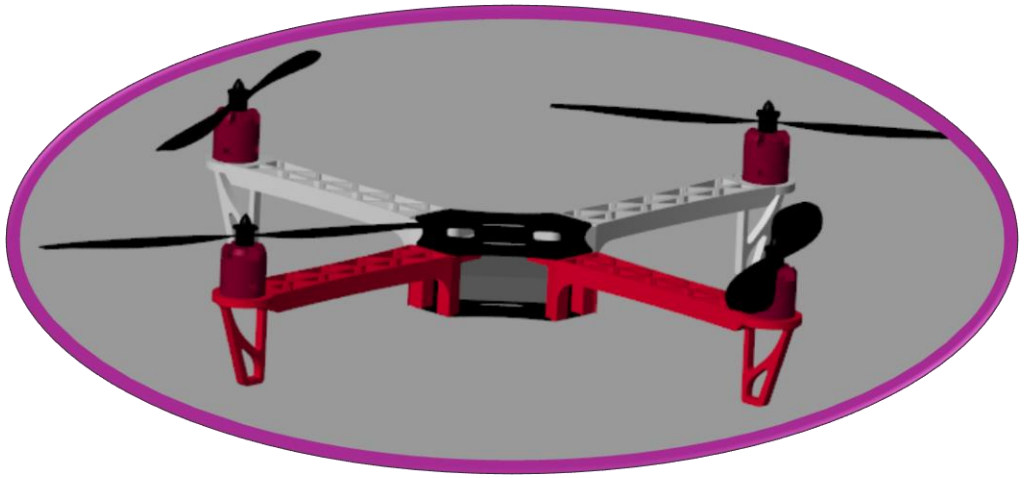
4. View the animation to confirm pickup and delivery

Schematic:



What did you observe?

- Did the quadcopter pickup the package?
- Did it drop the package to its destination?
- Anything else?



Exercise 1: Meet the Digital Twin

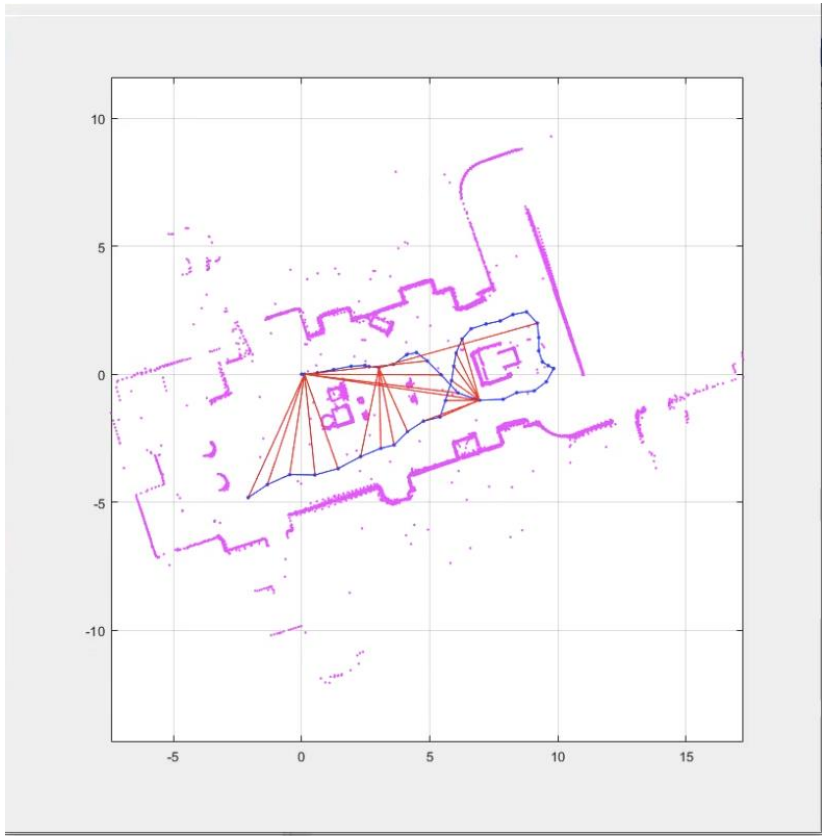
Exercise 2: Plan the Mission

Exercise 3: Fault Detection

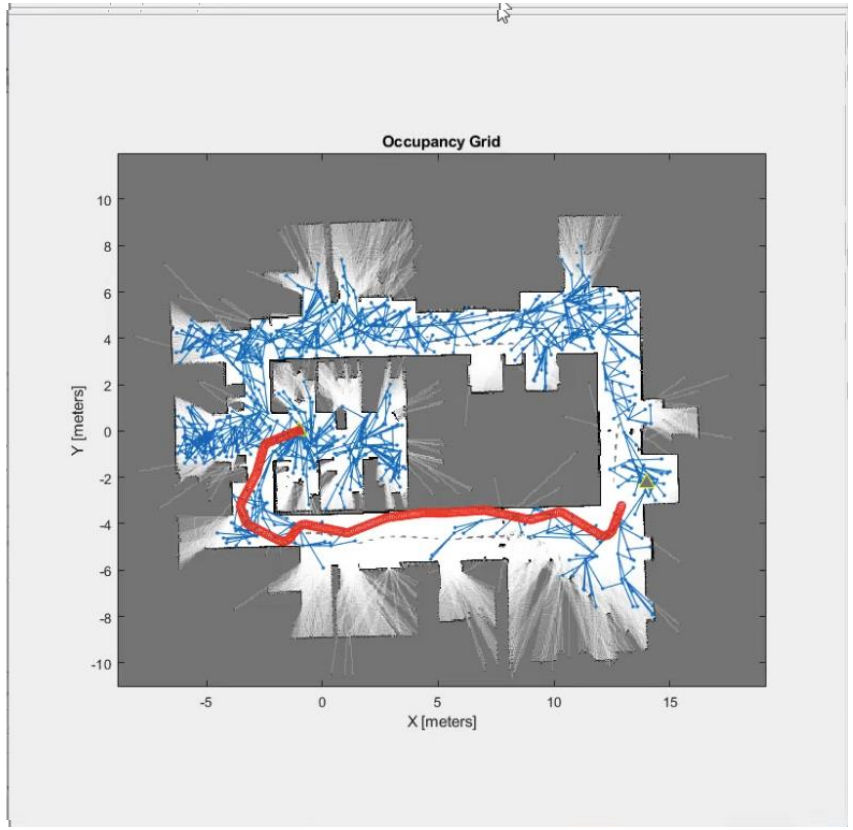
Use navigation to plan your route

Fully autonomous navigation has no human in the loop

Autonomous navigation is complex in changing environments.

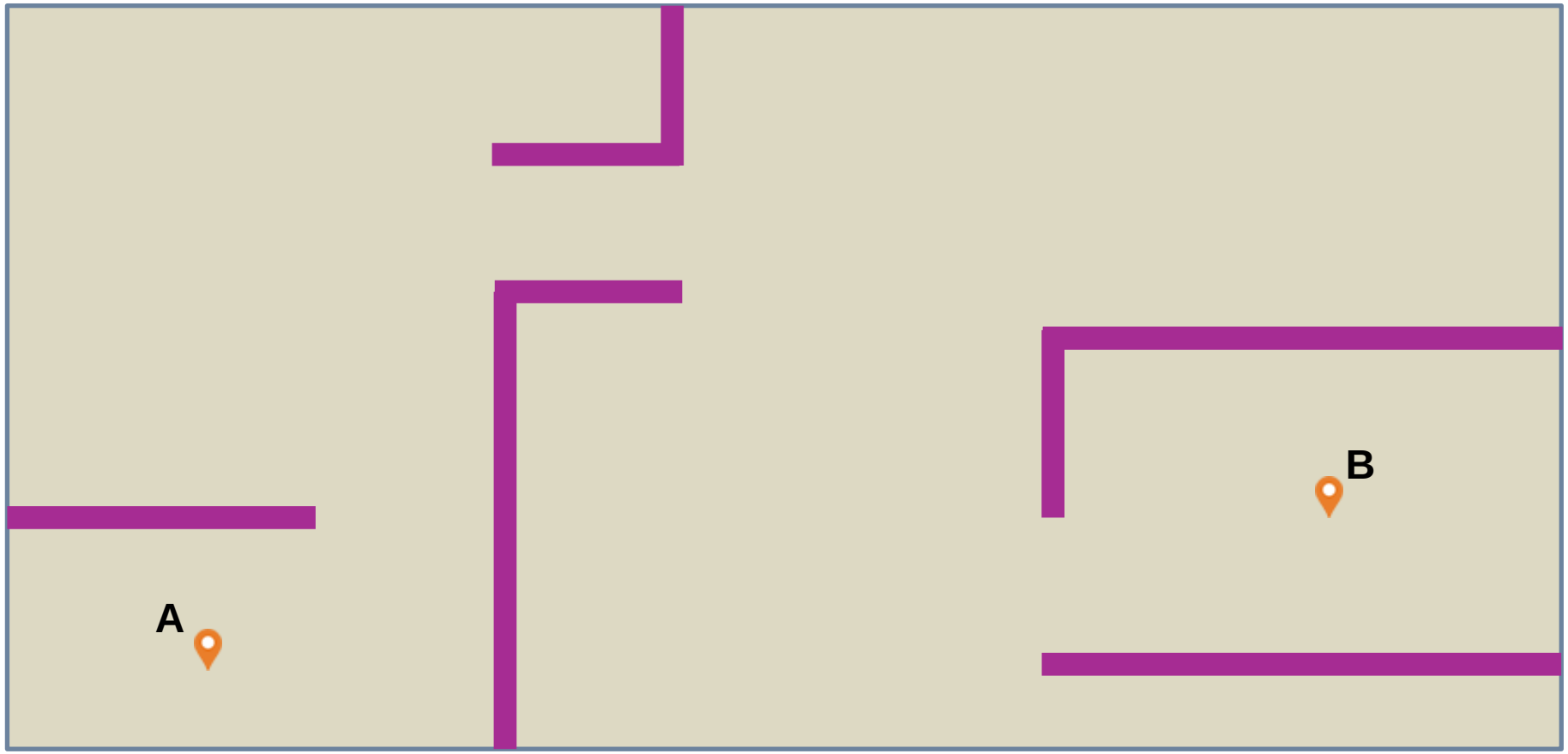


Simultaneous Localization and Mapping (SLAM)

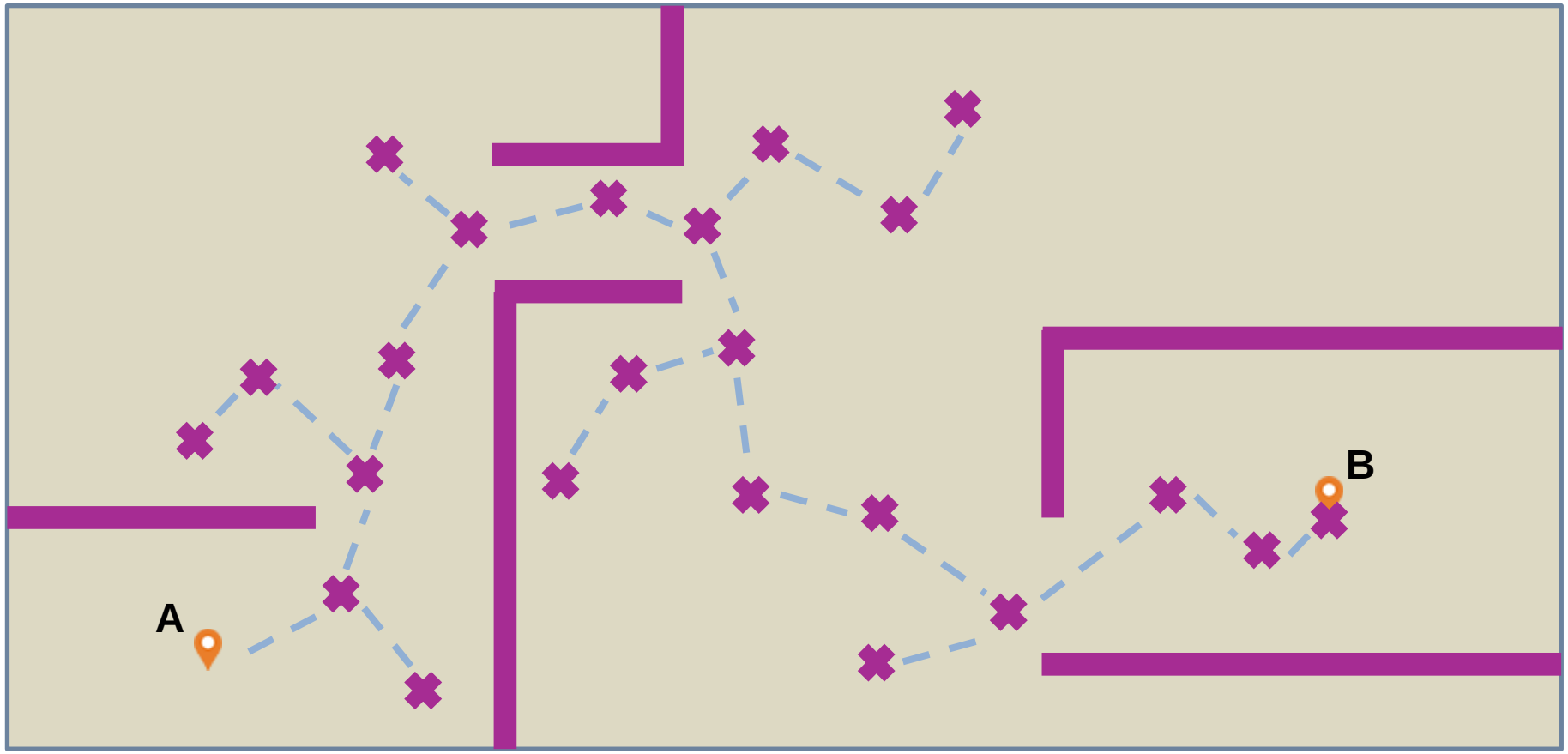


Static Environment and Preplanned Path

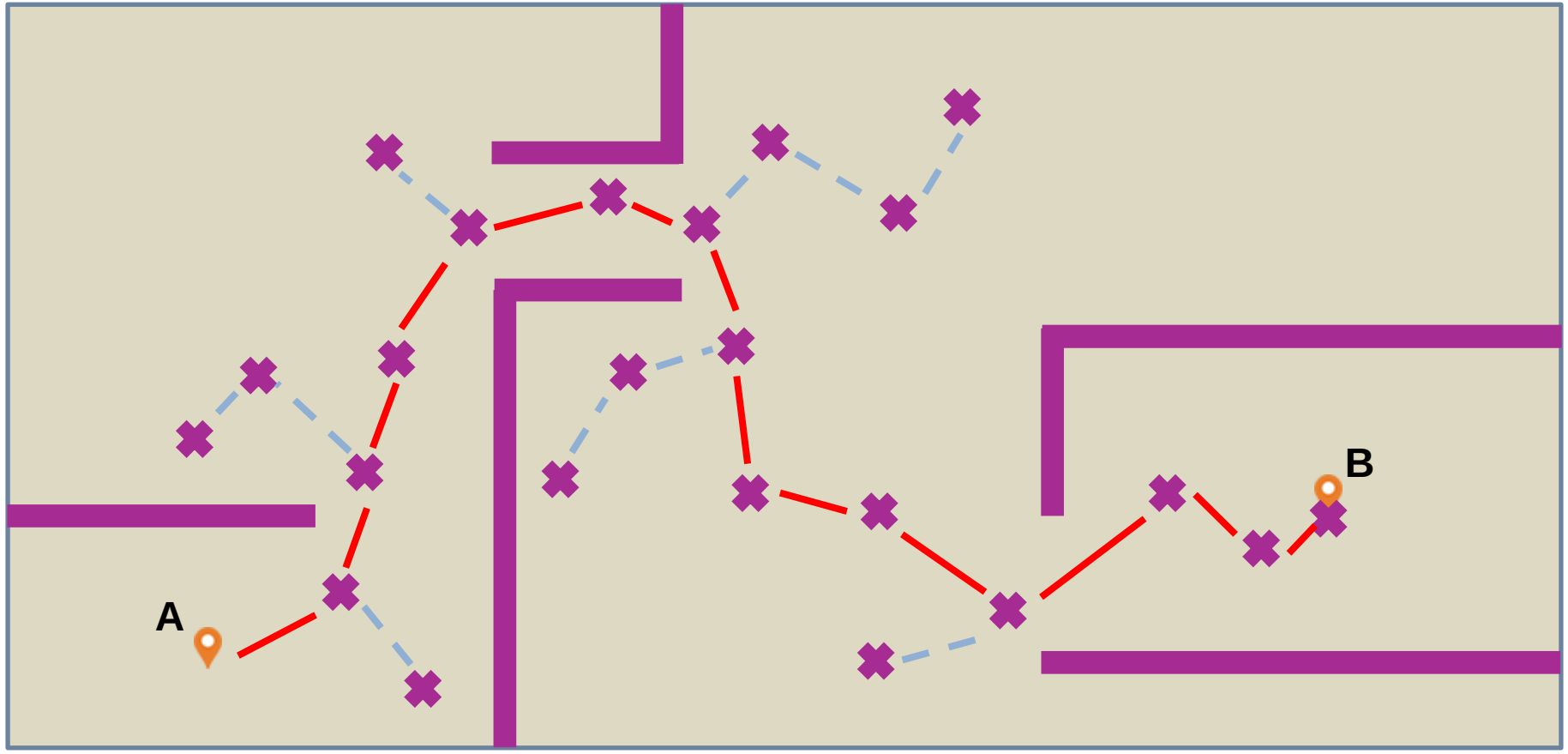
Path Planning: Get from point A to point B.



Path Planning Algorithms: Find an optimal path



Path Planning Algorithms: Find an optimal path and select waypoints

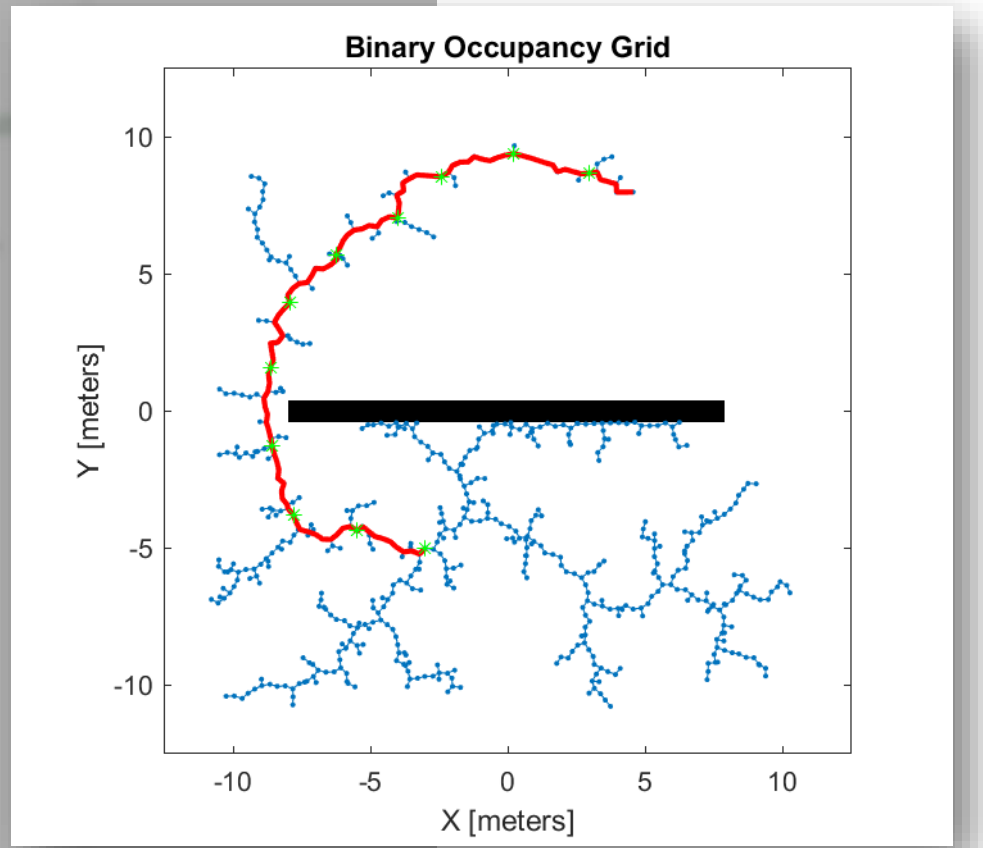


You will use an RRT planner to generate the optimal path for the quadcopter.

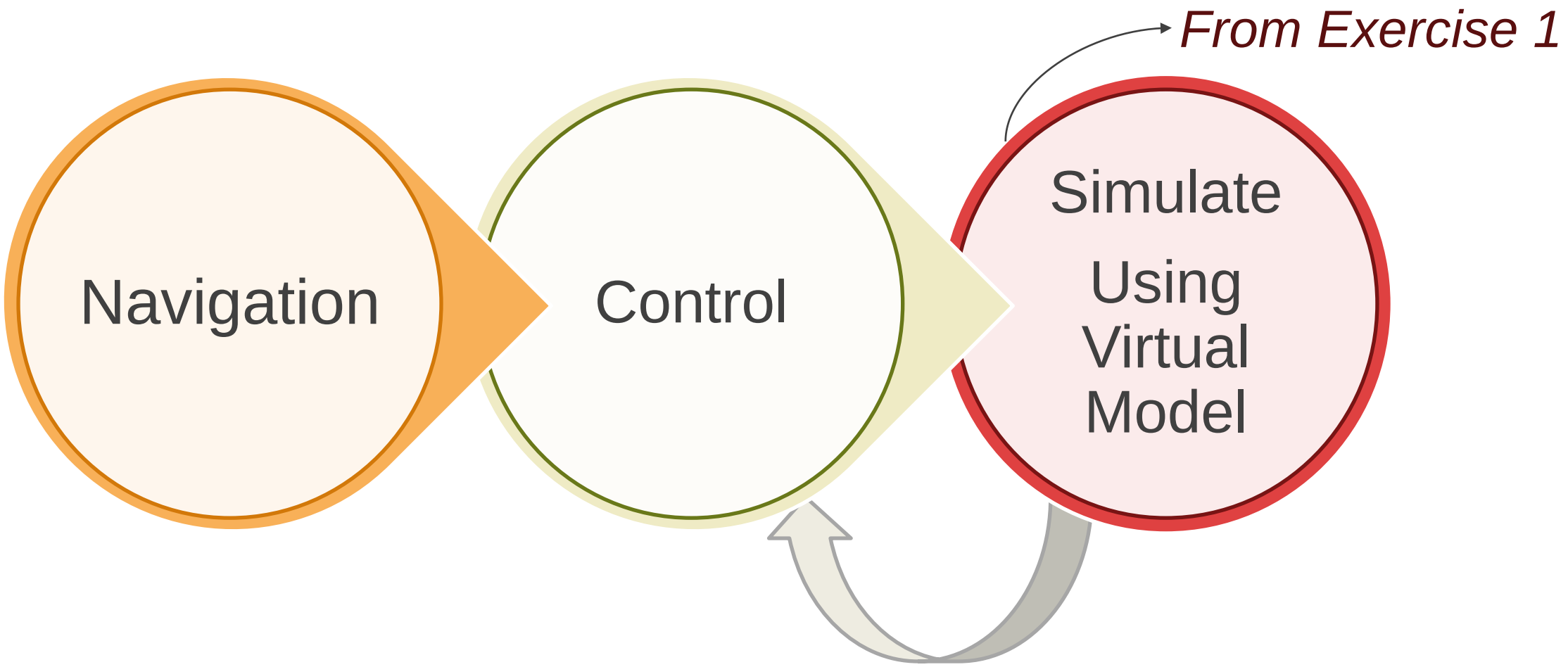
pathplanning.m

```
image = imread(scenario);
bwimage = rgb2gray(image) < 0.5;
grid = binaryOccupancyMap(bwimage,10);


ss = StateSpaceSE2;
sv = validatorOccupancyMap(ss);
sv.Map = grid;
planner = plannerRRT(ss,sv);
```

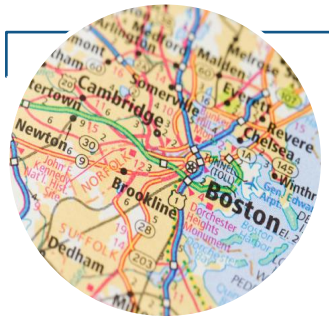


Navigation is just the beginning – control and simulation are next!

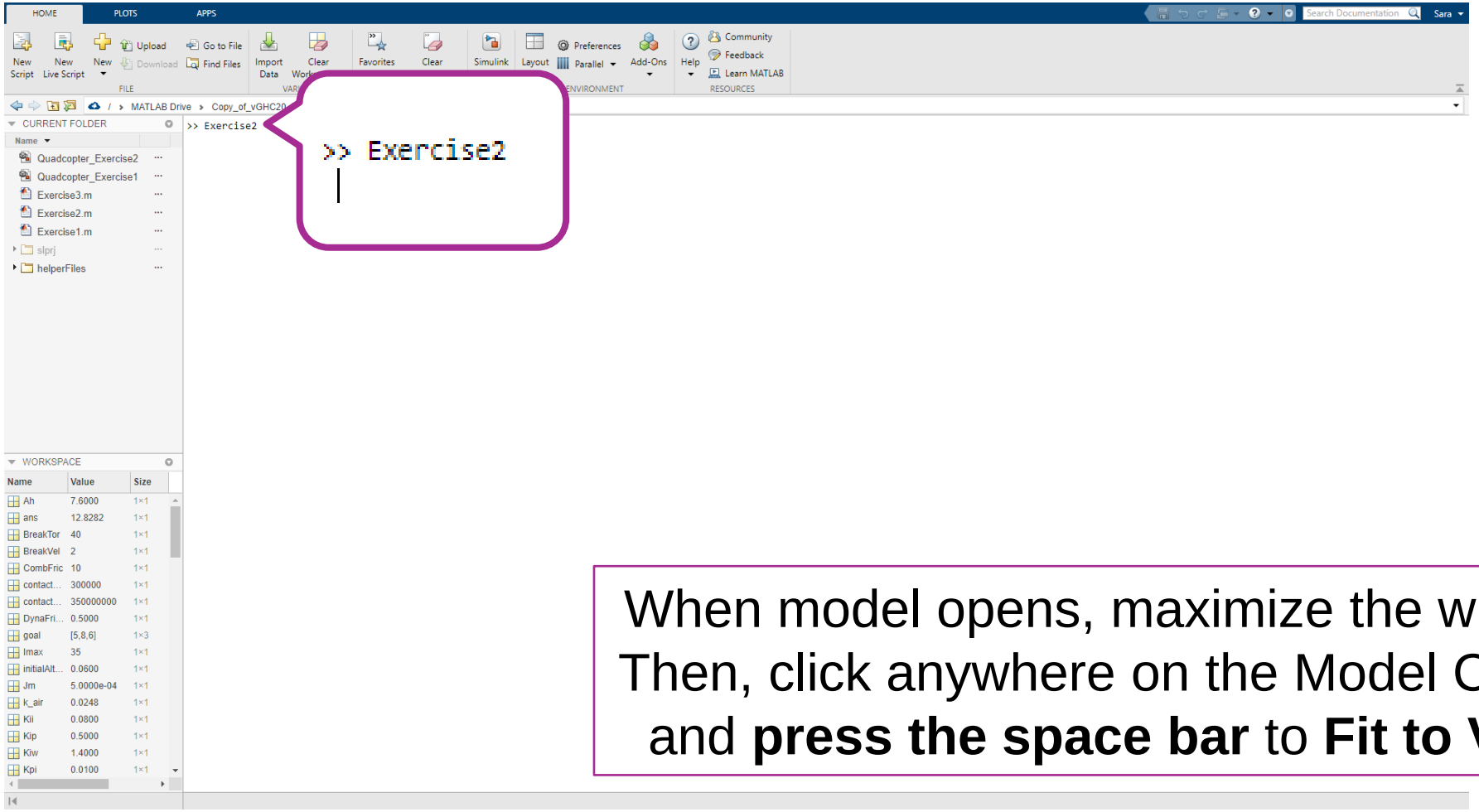



Cambridge
Somerville
Malden
Melrose
Newton
Chelsea
Revere
Brookline
Boston
Dedham

Exercise 2



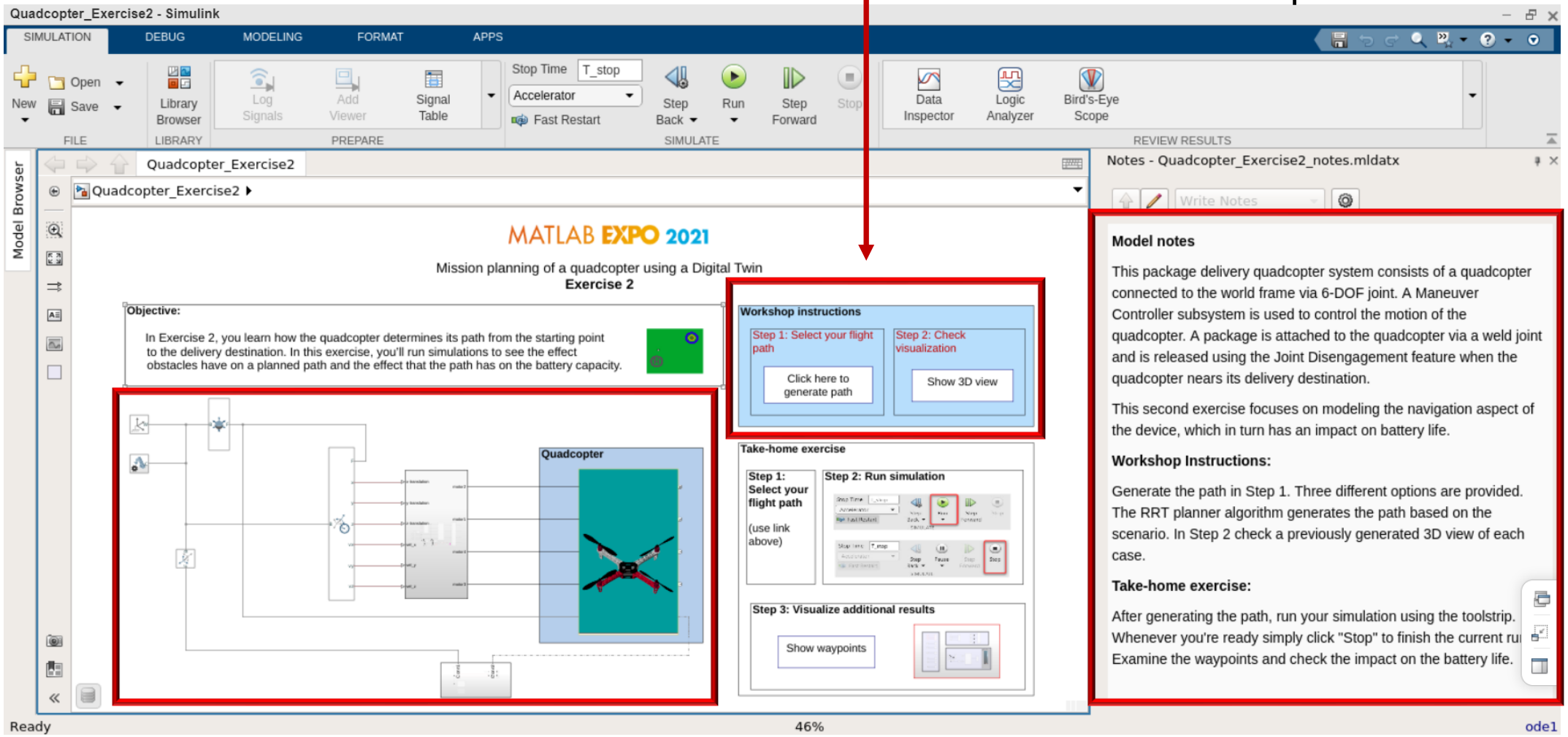
Type **`Exercise2`** in the Command Window.



When model opens, maximize the window. Then, click anywhere on the Model Canvas and **press the space bar** to **Fit to View**.

Let's walk through the model for Exercise 2

Exercise 2 Steps



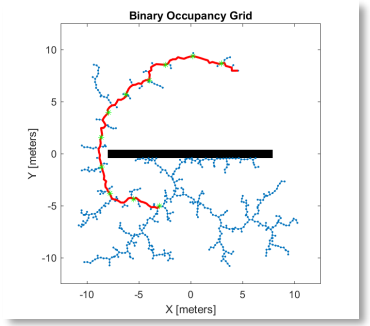
Exercise 2 Summary

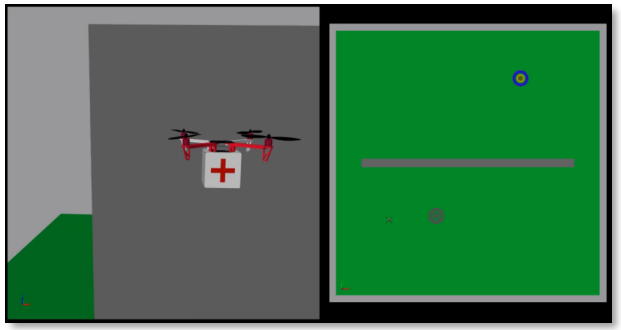
- **Objective:** Check the effect of different flight paths

Steps:

1. Click on the hyperlink in Step 1 open a new window to generate the flight path.
2. In the new window select the scenario and click “Generate path.” When ready, click “Close” to close this window.
3. Check the 3D view for each case.

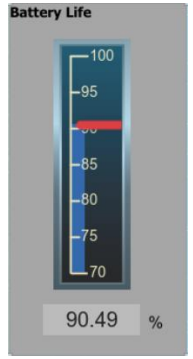
Monitor Results:

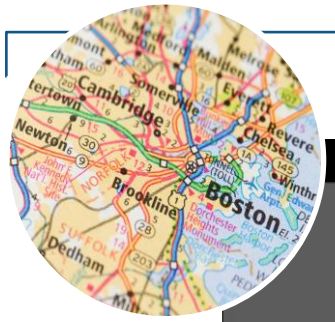


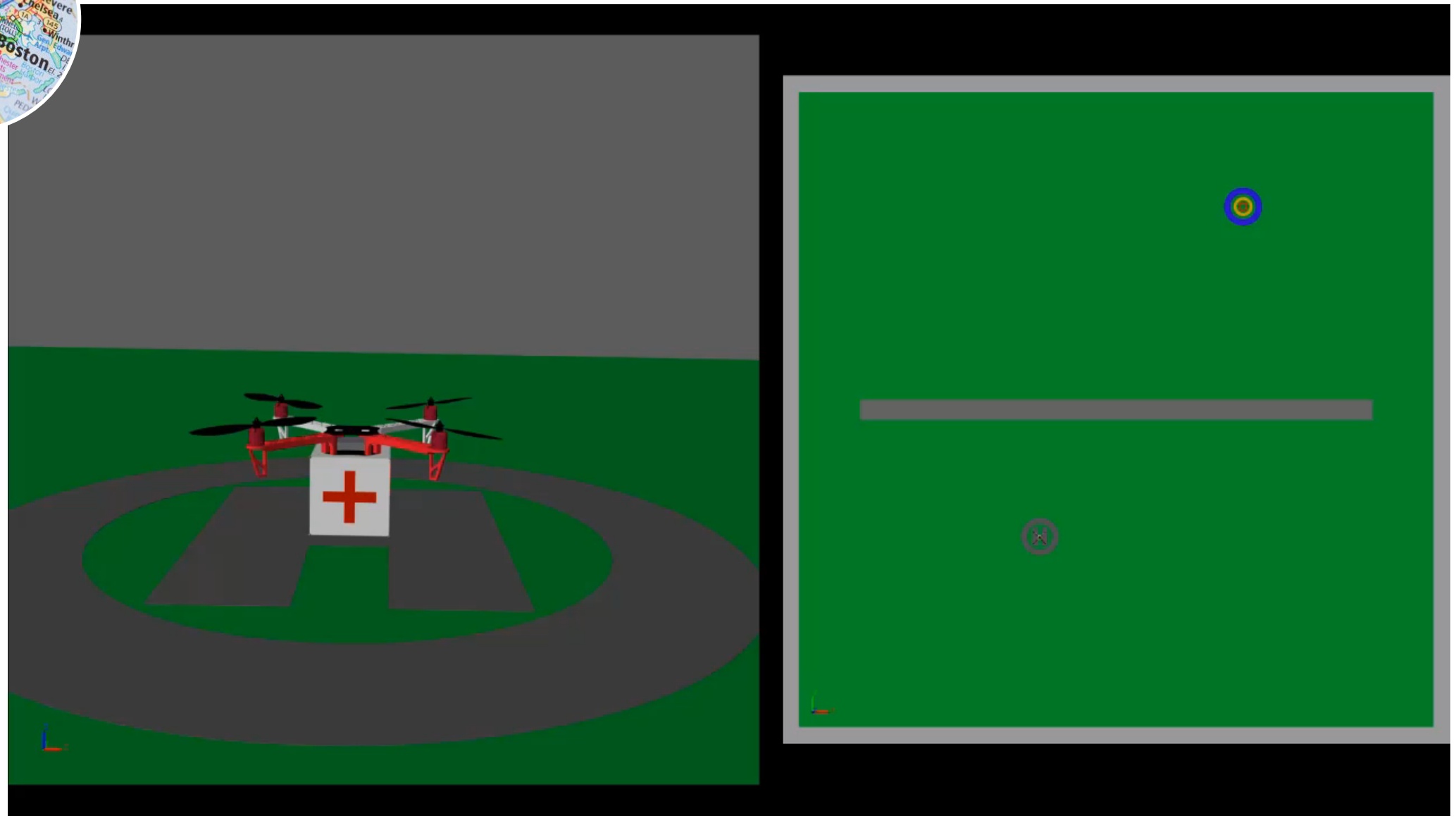


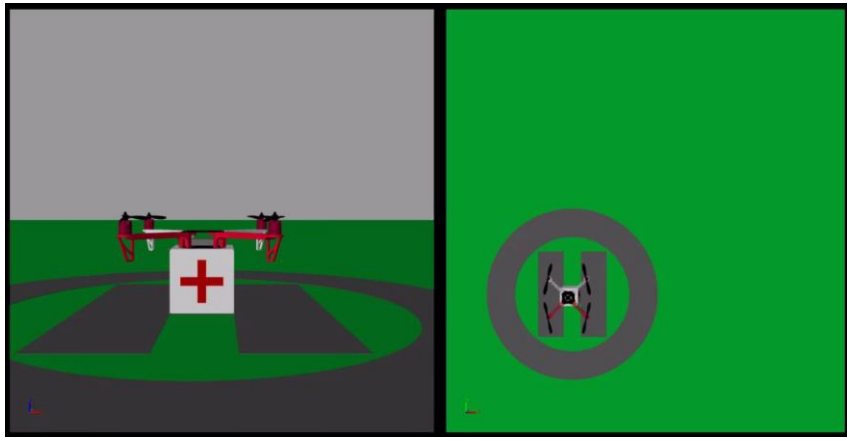
Take-home exercise:

- In the toolstrip click the Run button to simulate. Allow simulation to run at least for a few seconds. Use Stop to end the simulation at any time.
- Monitor additional results

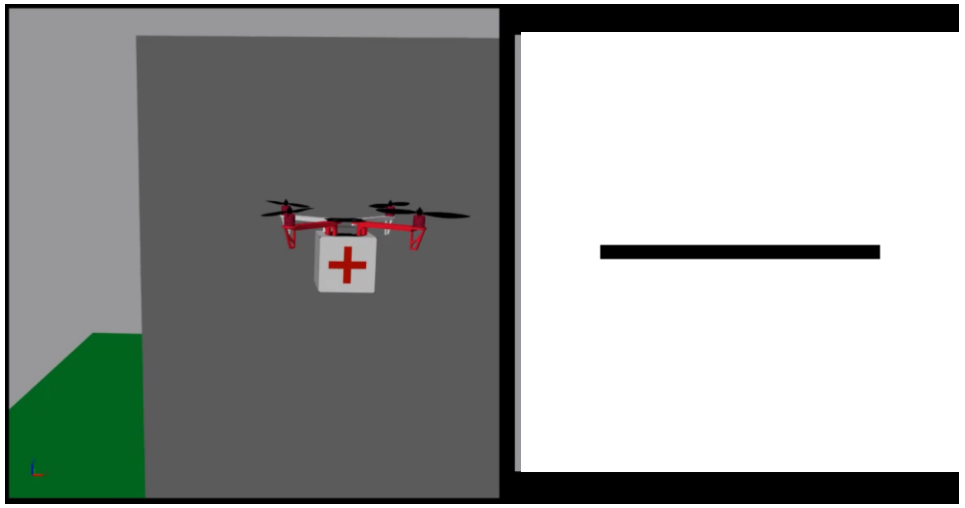


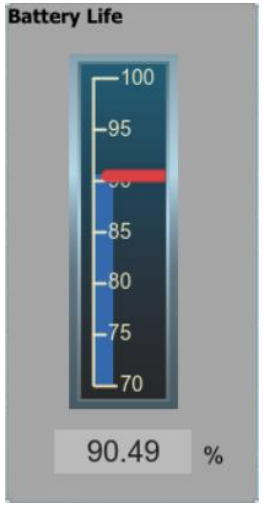

Cambridge
Somerville
Everett
Chelsea
Revere
Newton
Brookline
Boston
Dedham

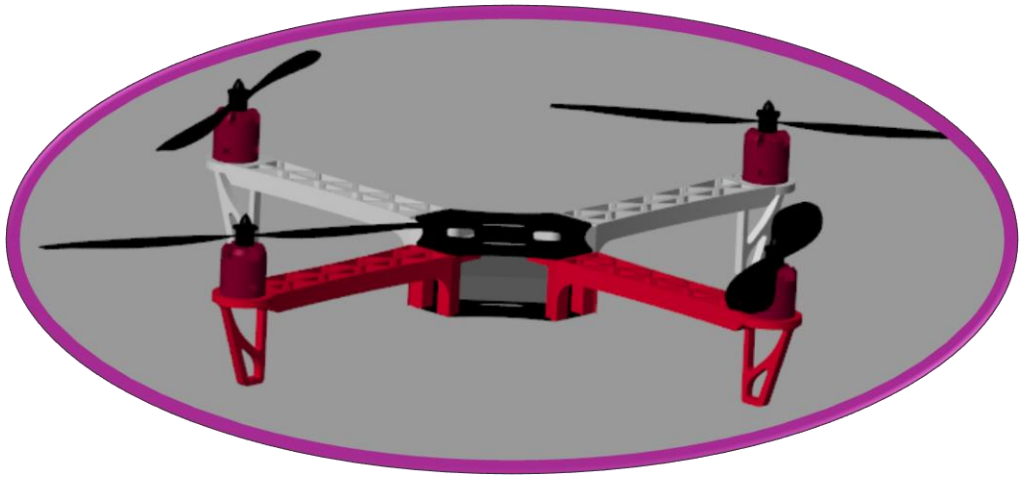




Now that we can plan a mission for the digital twin, how can we test failing scenarios?





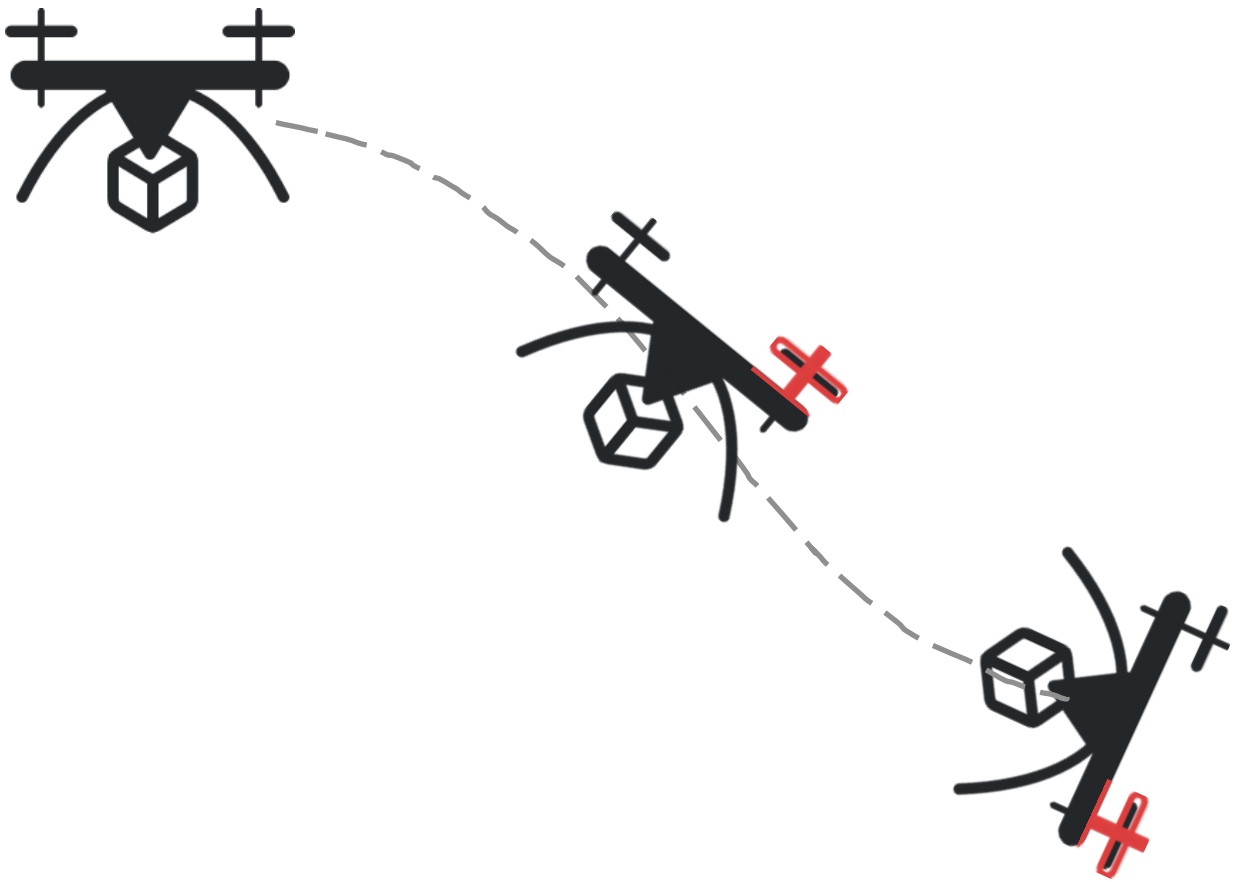


Exercise 1: Meet the Digital Twin

Exercise 2: Plan the Mission

Exercise 3: Fault Detection

Predictive Maintenance can be used to detect faults in machines

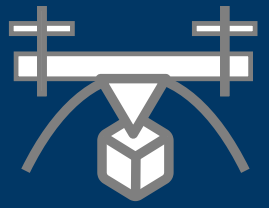


Where did the Fault Occur?

Fault Detection

Motor

Connecting both worlds of Physical Modeling and Predictive Maintenance

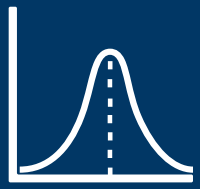


Physical Model

Run multiple simulations

Datastores

Collect, store & preprocess Data



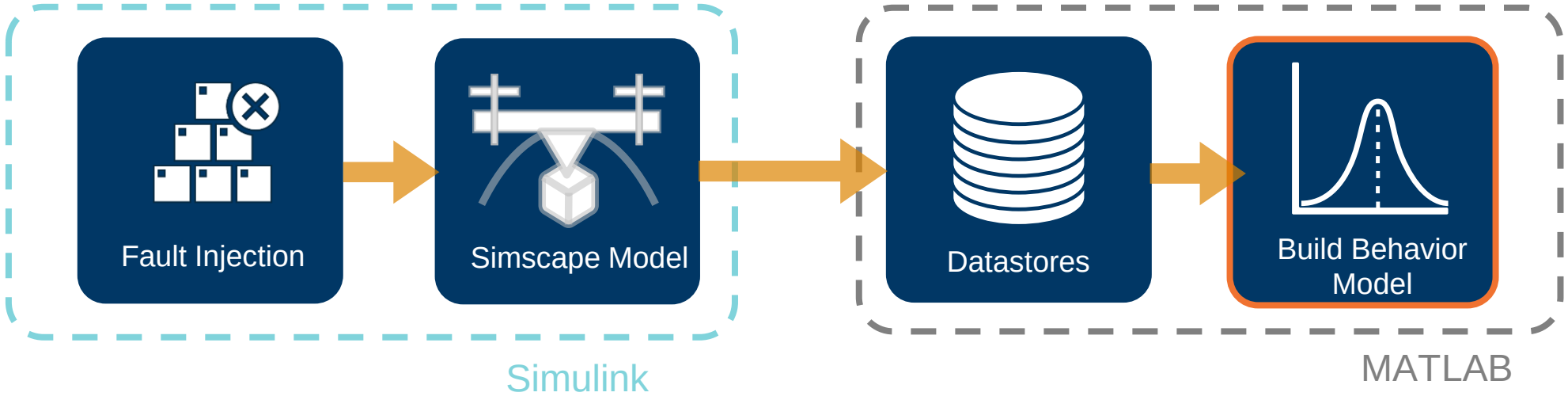
Machine Learning Models

Build Models for specific behaviors

Build and train models using Predictive Maintenance Toolbox

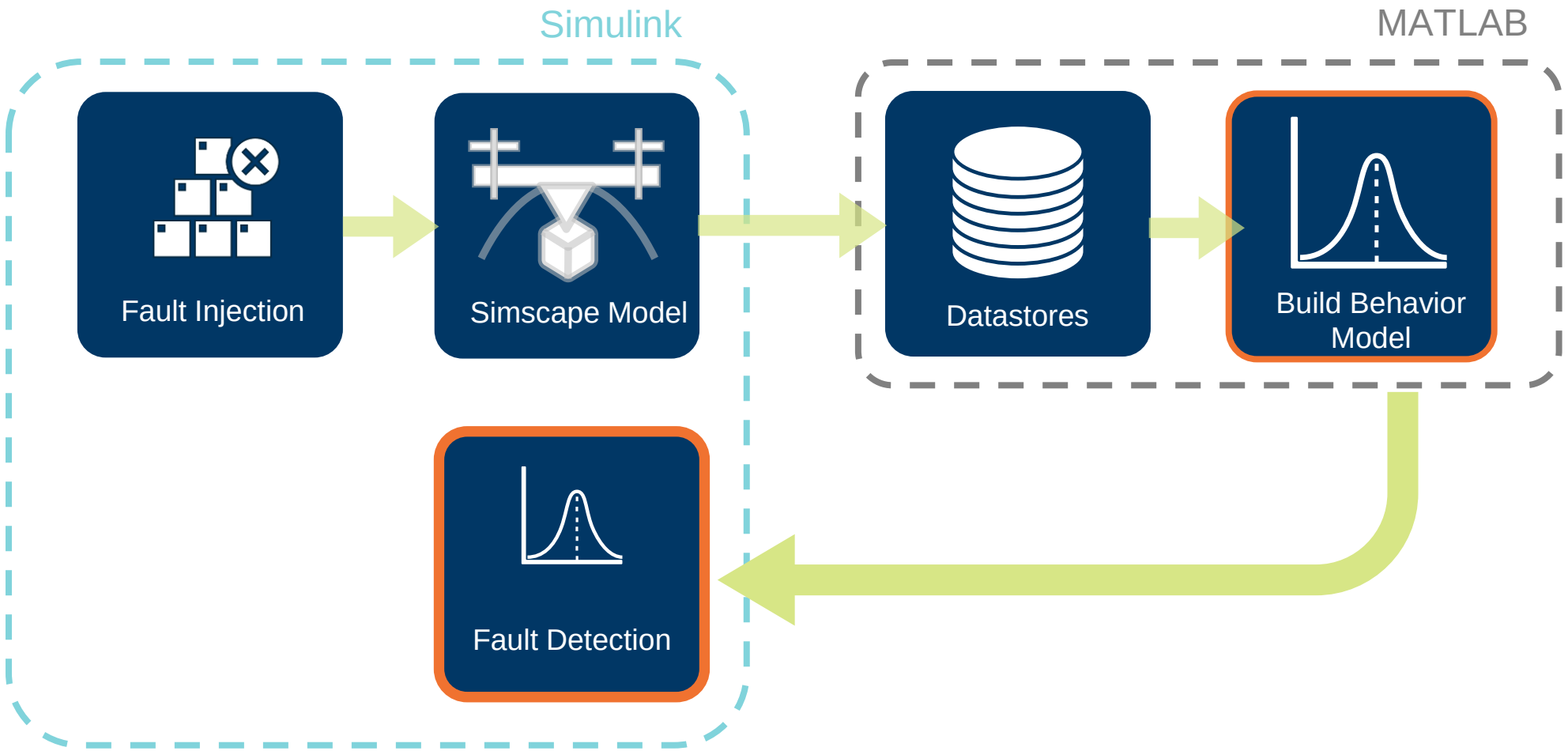
Today's scenario:

- Potential failure of one of the motors
- Offline modeling in MATLAB using data and Predictive Maintenance Toolbox

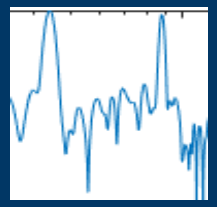


Pre-trained ML models can be exported to Simulink

Export Model to Simulink using Embedded MATLAB function



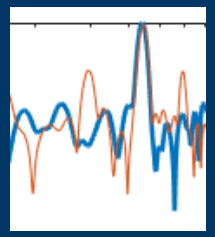
Build a Fault Detection Model using Simulated Data



Preprocessing Data

- Remove outliers
- Remove noise

Your model is only as good as your data



Extract Features

- Identify condition indicators

Time series data

Train & Validate

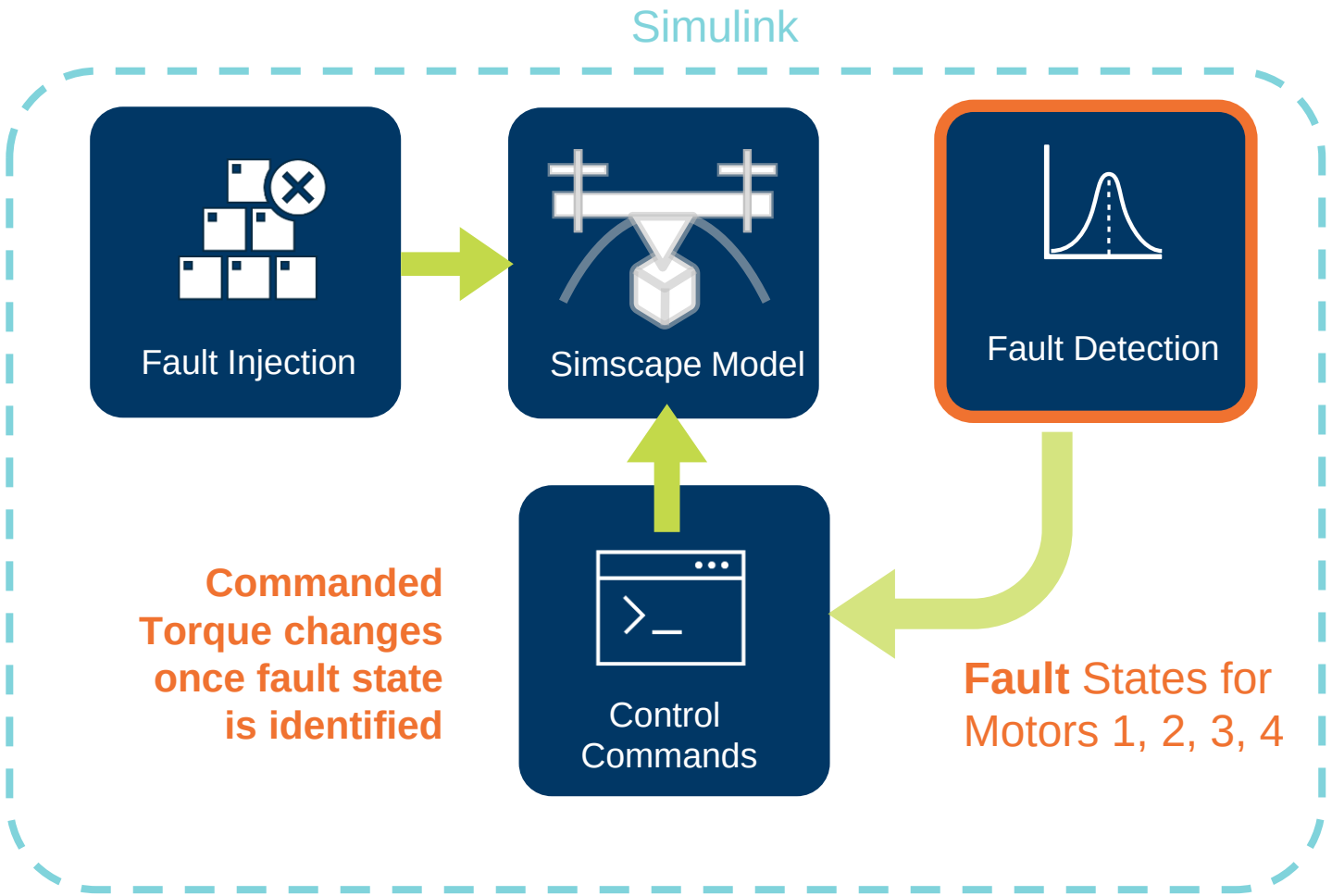
- Classifiers

Export to Simulink

- Use Embedded MATLAB functions

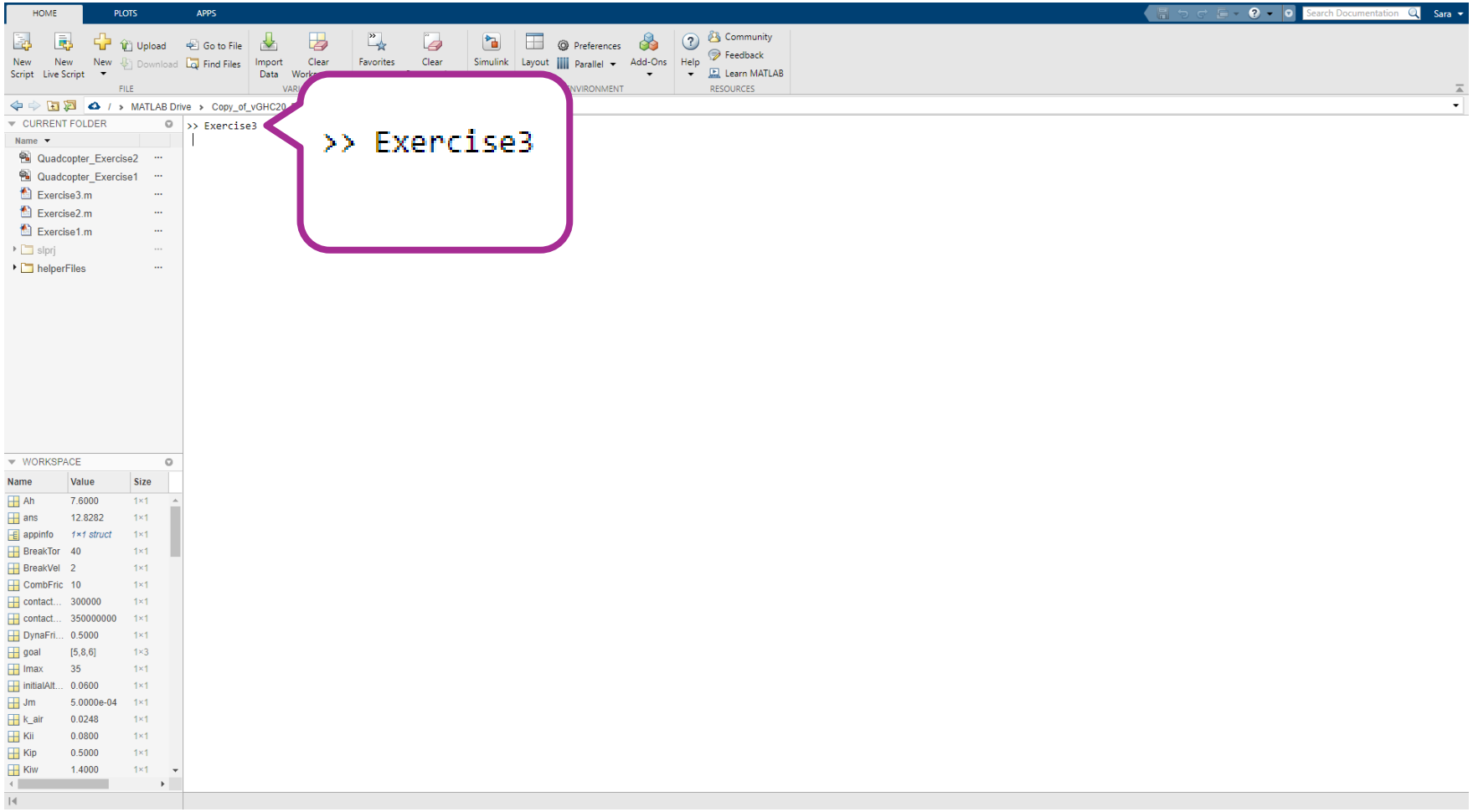
Fail fast and design fault tolerant systems

Today's scenario: Potential failure of one of the motors



Exercise 3

Type `Exercise3` in the Command Window



Exercise 3

Click on Inject Fault

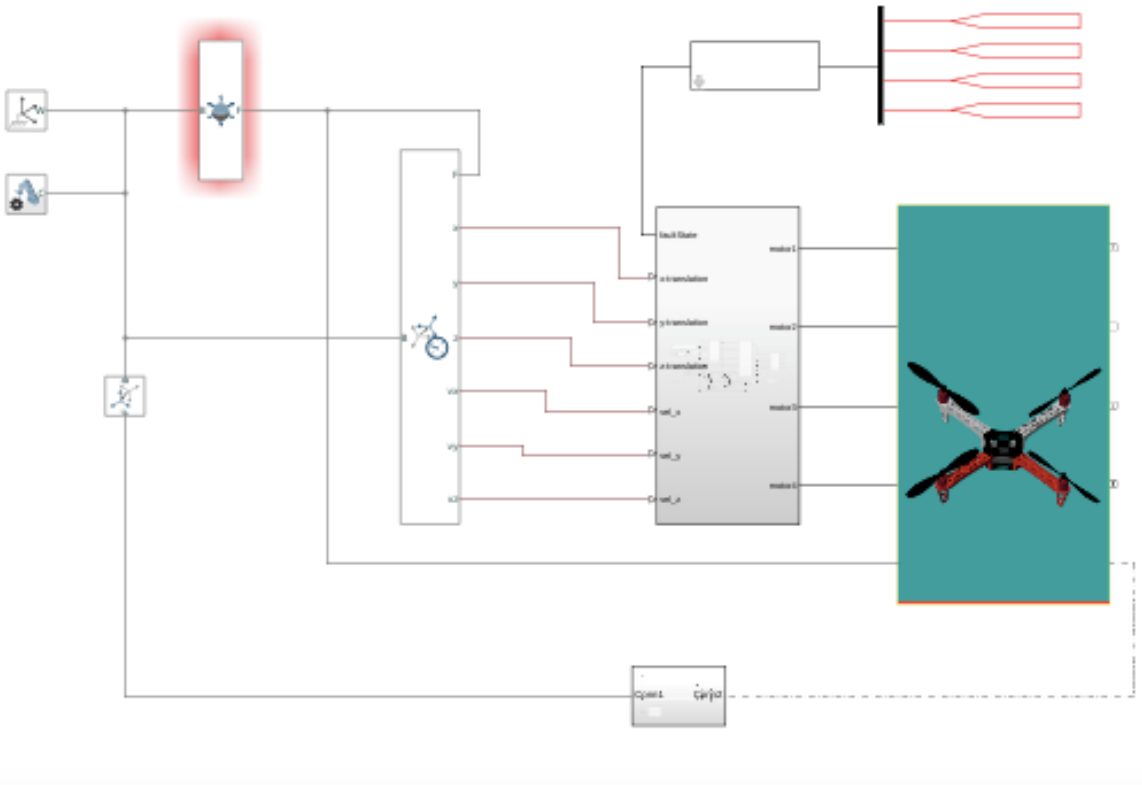
MATLAB EXPO 2021

Mission planning of a quadcopter using a Digital Twin

Exercise 3

Objective:

In Exercise 3, you will understand how to run multiple simulations and create a behavior model to predict the faults that could happen in one of the motors. Your task is to inject faults and observe the failure, following which you will also turn on Fault Detection and observe how the system safely soft crashes.



Step 1: Inject your faults

Inject Fault on Motor

Step 2: Run your simulation (Simulation Tab)

Step 3: Turn on Fault Detection

Turn ON Fault Detection

Step 4: Run your simulation again (Simulation Tab)

Additional Resource: Visualizations

Exercise 3

Inject Fault at a given “time” T secs

Step 1: Inject your faults

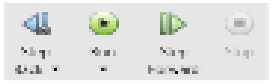
Inject Fault on Motor

Step 2: Run your simulation (Simulation Tab)

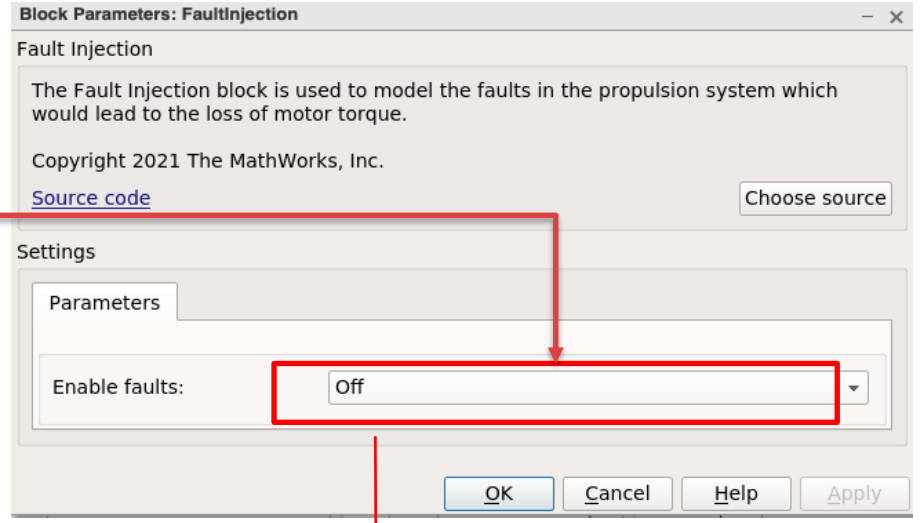
Step 3: Turn on Fault Detection

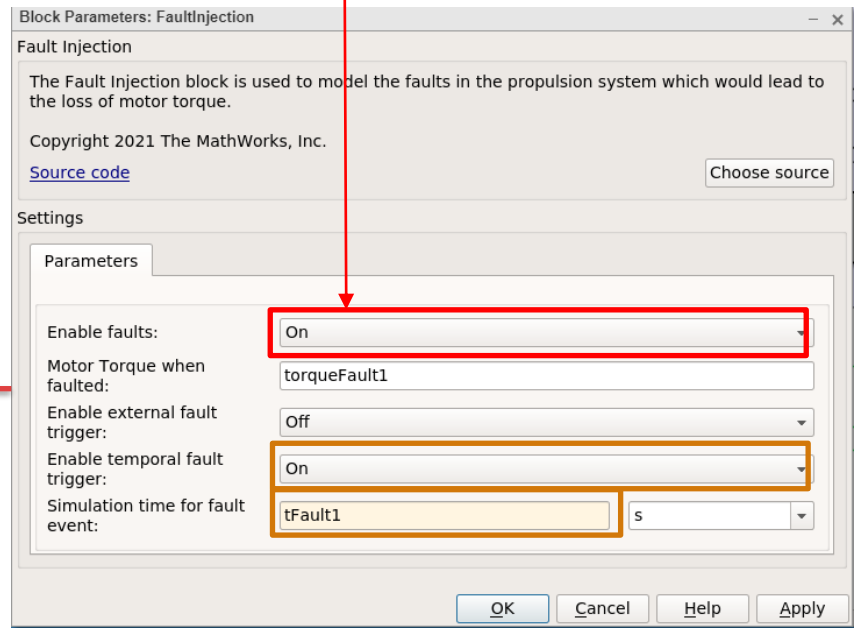
Turn ON Fault Detection

Step 4: Run your simulation again (Simulation Tab)



Additional Resource: Visualizations





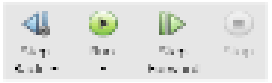
Time to run this part of Ex3-a: 3mins

Exercise 3 Turn ON Fault Detection

Step 1: Inject your faults

Inject Fault on Motor

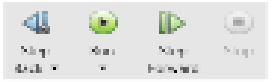
Step 2: Run your simulation (Simulation Tab)



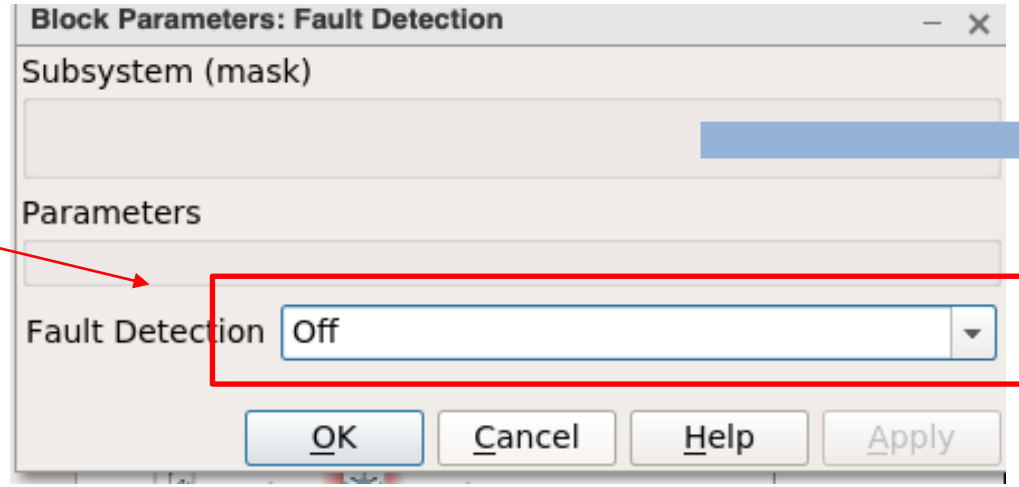
Step 3: Turn on Fault Detection

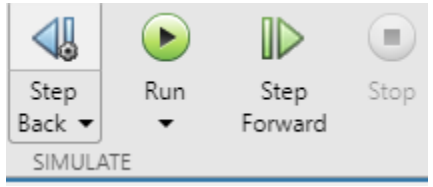
Turn ON Fault Detection

Step 4: Run your simulation again (Simulation Tab)



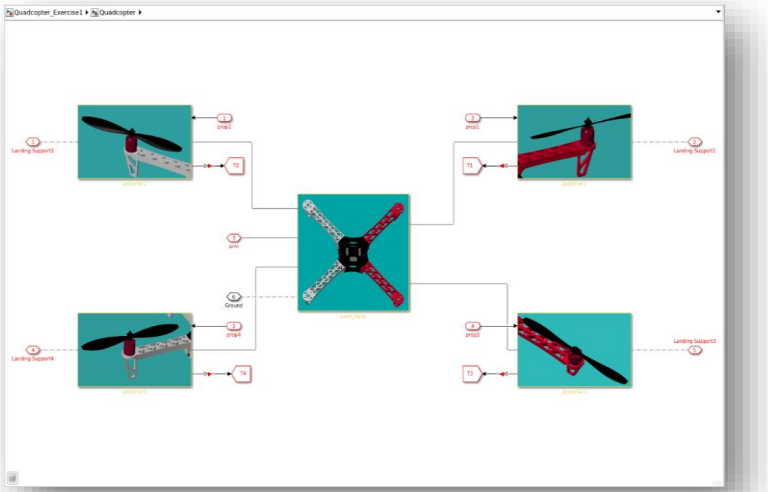
Additional Resource: Visualizations



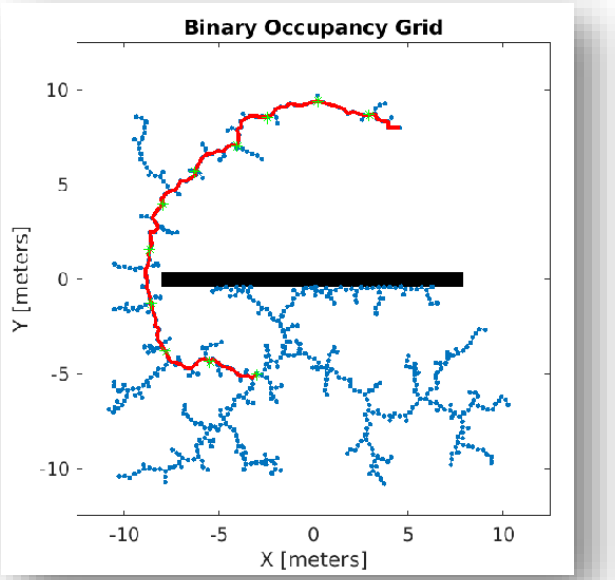


Time to run this part of Ex3-b: 4mins

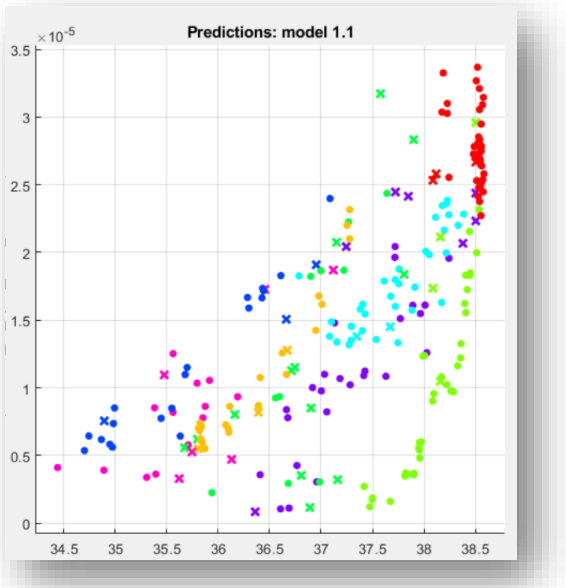
Key takeaways



Physical Modeling (Digital Twin)



Path planning in autonomous systems



Predictive Maintenance for Digital Twins

Predictive Maintenance evolves within a problem and over applications

Where did the Fault Occur?

Fault Detection

Motor

What was the type of fault?

Condition Monitoring

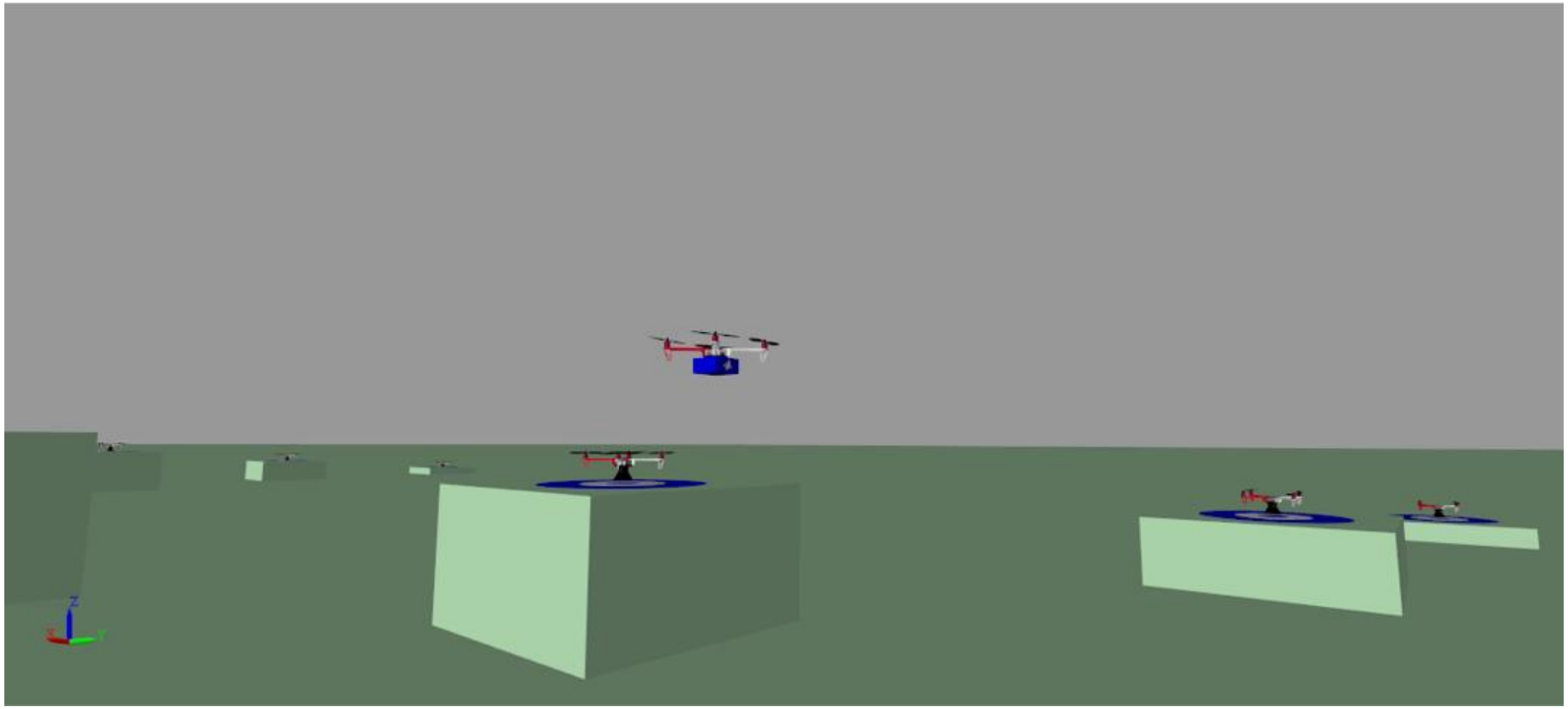
Motor had iron losses

How long can the machine operate?

Remaining Useful Life

Potential Motor Failure in 2 days

Digital twins join the fleet to meet delivery challenges.

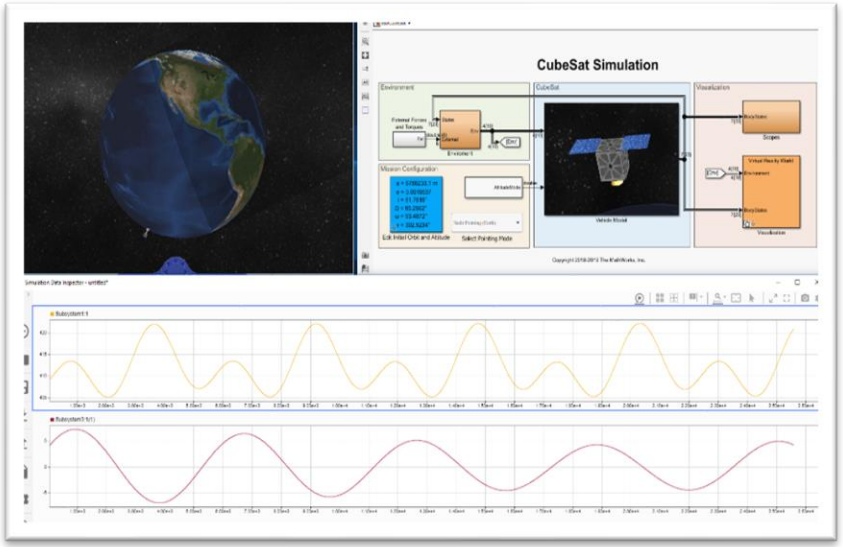


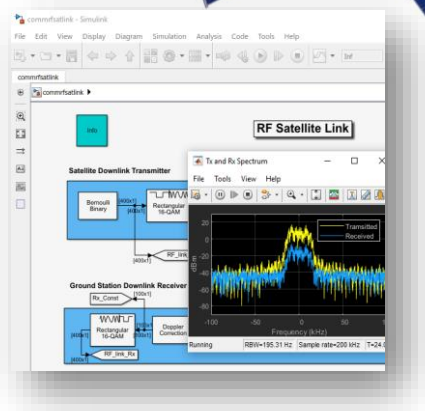
Digital twin is not novel, has been used for expensive assets where reliability is essential.

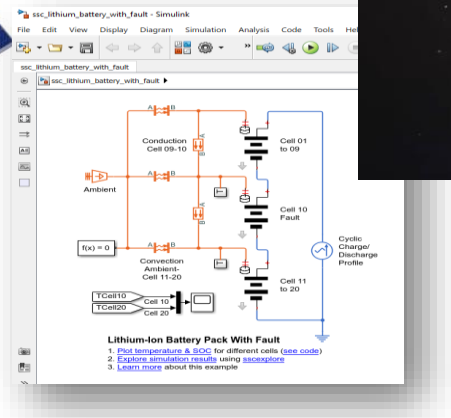
Long-Range Communications

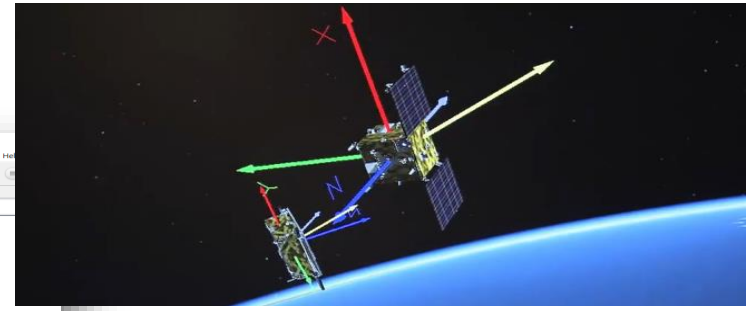
Asset Management

OT Infrastructure









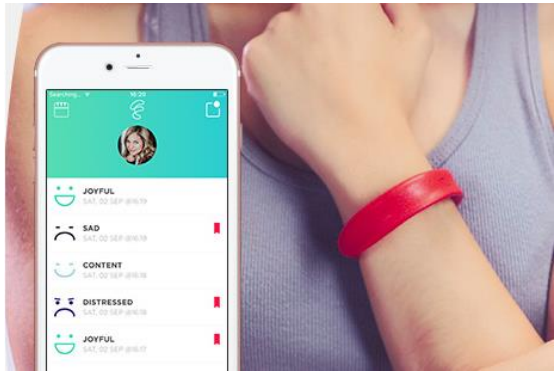
Digital twins transform technology to be safer, better and cleaner.

Industrial Automation

Automotive

Utilities & Energy

Medical



Aerospace

Robotics

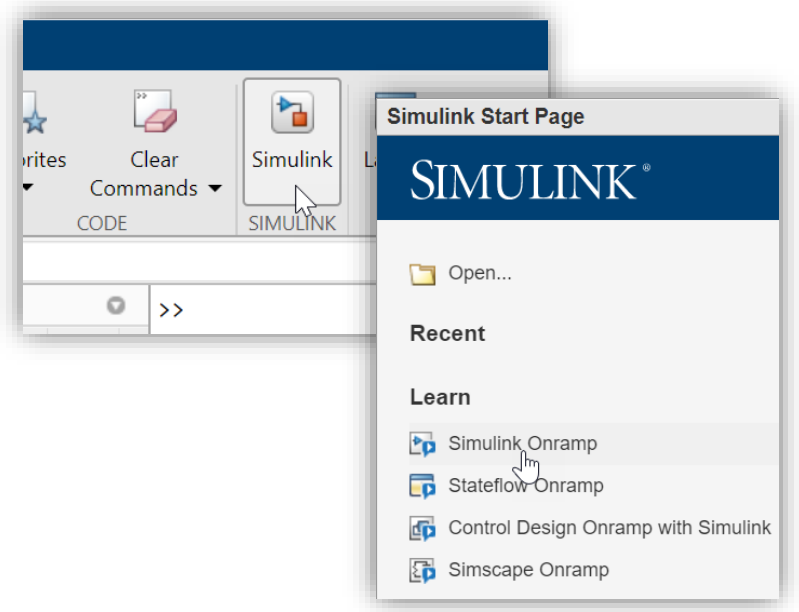
Additional Resources

Learn more:

What Is a Digital Twin?
www.mathworks.com/digital-twin

Robotics and Autonomous Systems
https://www.mathworks.com/solutions/robotics.html

Predictive Maintenance with MATLAB and Simulink
https://www.mathworks.com/solutions/predictive-maintenance.html



#matlabexpo #digitaltwin #workshop

MATLAB EXPO 2021

Thank you