

# MATLAB EXPO

## Simulate and Deploy UAV Applications with SIL and HIL Workflows

*Mihir Acharya, MathWorks*



*Ronal George, MathWorks*



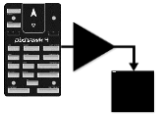
*Julia Antoniou, MathWorks*



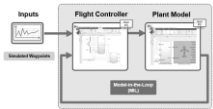
# Agenda



Introduction



PX4 with Simulink



MIL, SIL and HIL Workflows



Scenario Simulation



HIL with Scenario Simulation



Summary and Resources

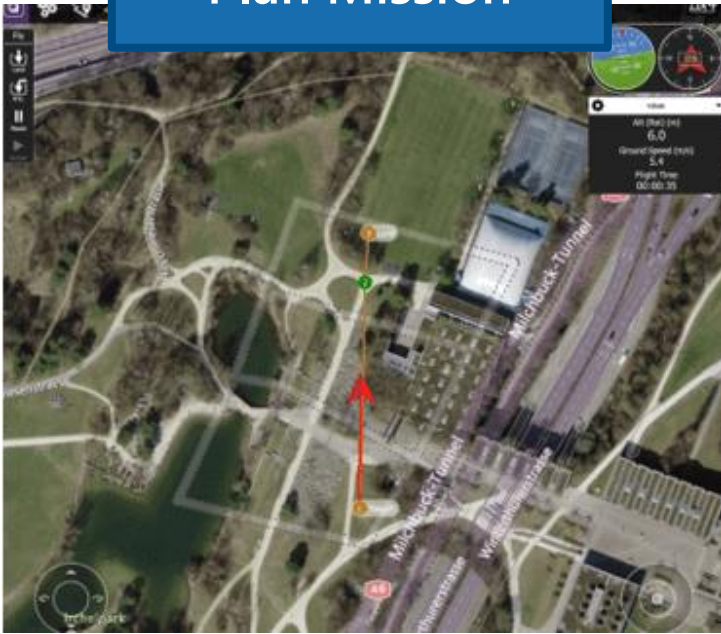
# Fly a Drone Through a City Block



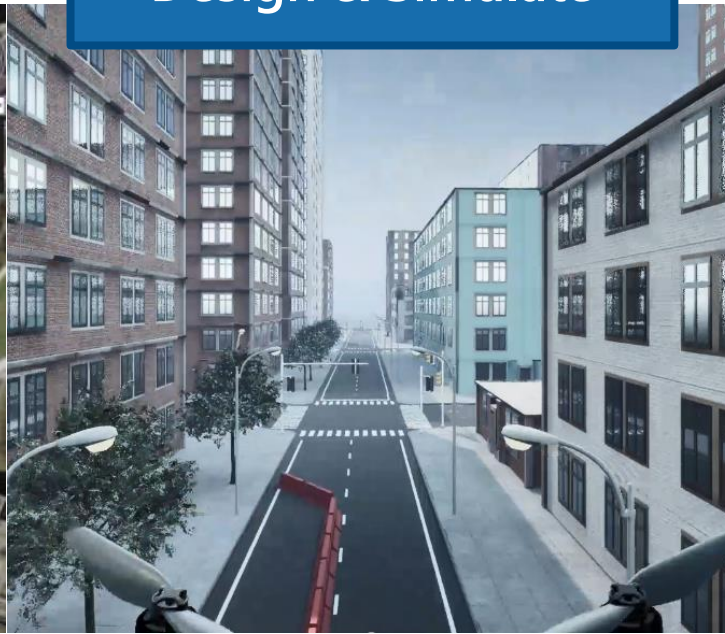


# Simulation in a Virtual Scenario

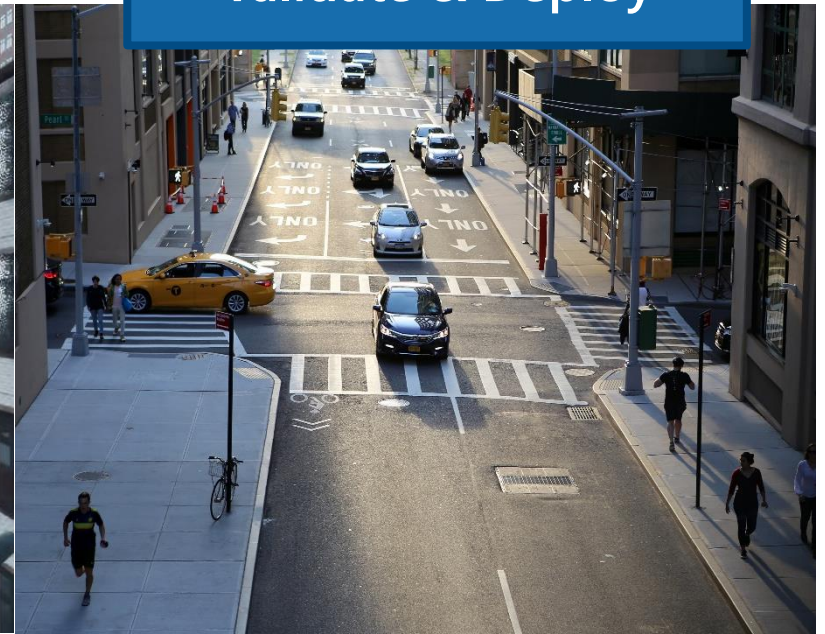
Plan Mission



Design & Simulate



Validate & Deploy

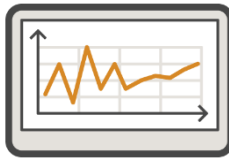


# Building Blocks for UAV Simulation

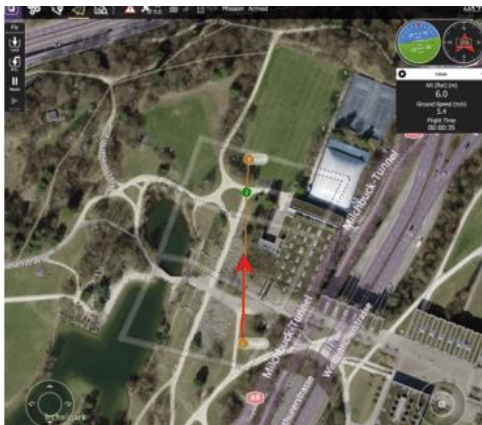
## Plan Mission

Generate flight path for the mission

Simulated Waypoints



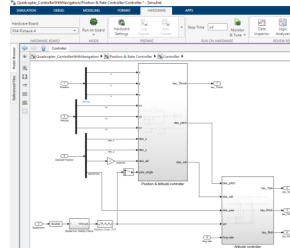
Ground Control Station



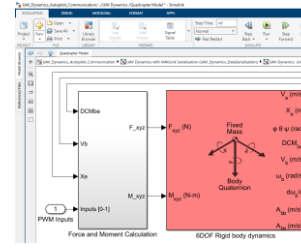
## Design & Simulate

Design flight controller and simulate plant behavior in virtual scenarios

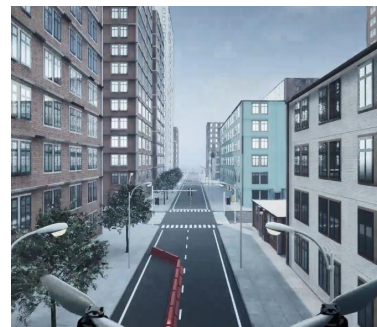
Flight Controller



Plant Model

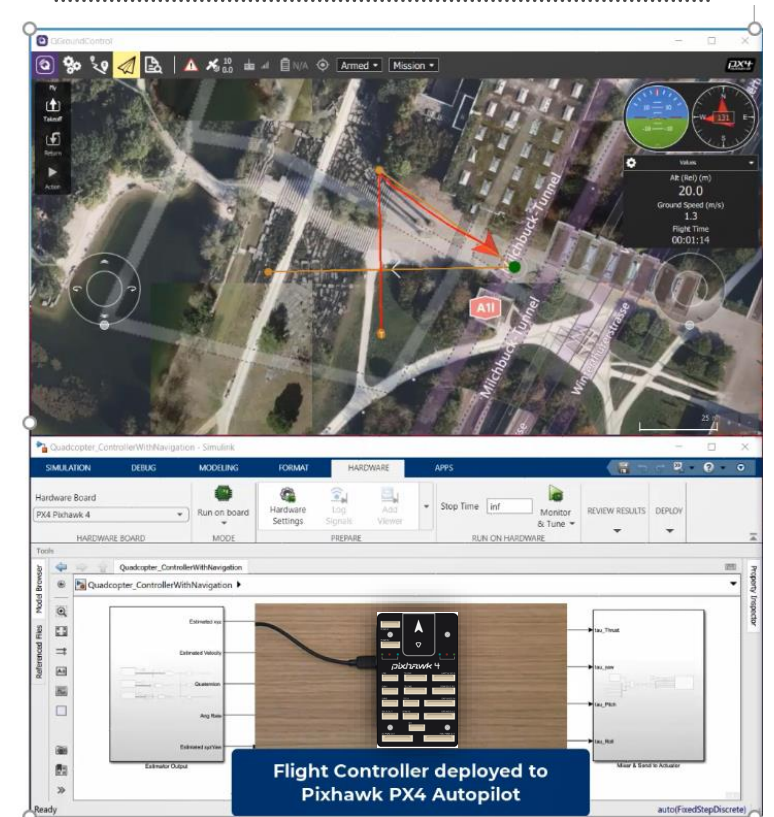


Scenario Simulation

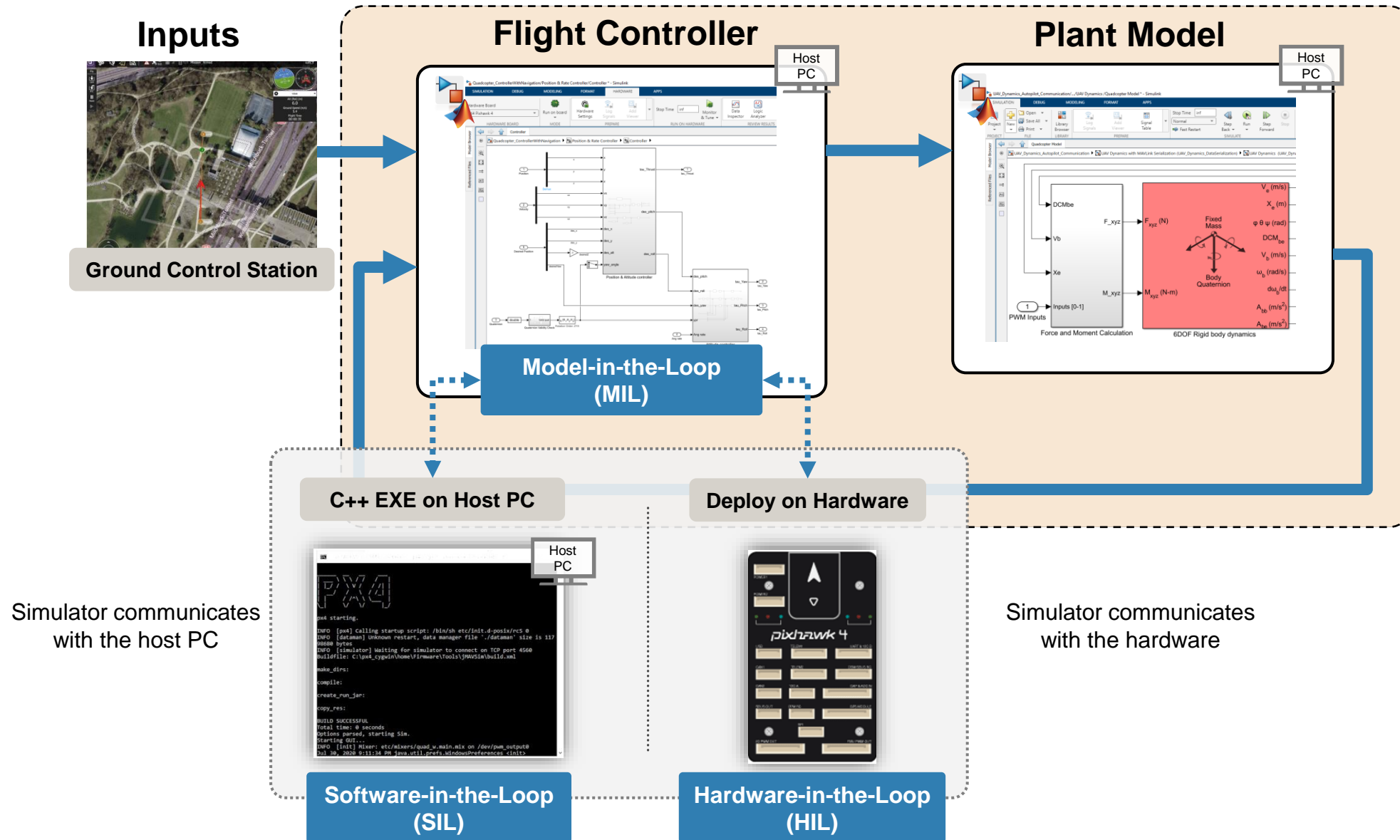


## Validate & Deploy

Deploy flight controller and autonomy algorithms to the platform

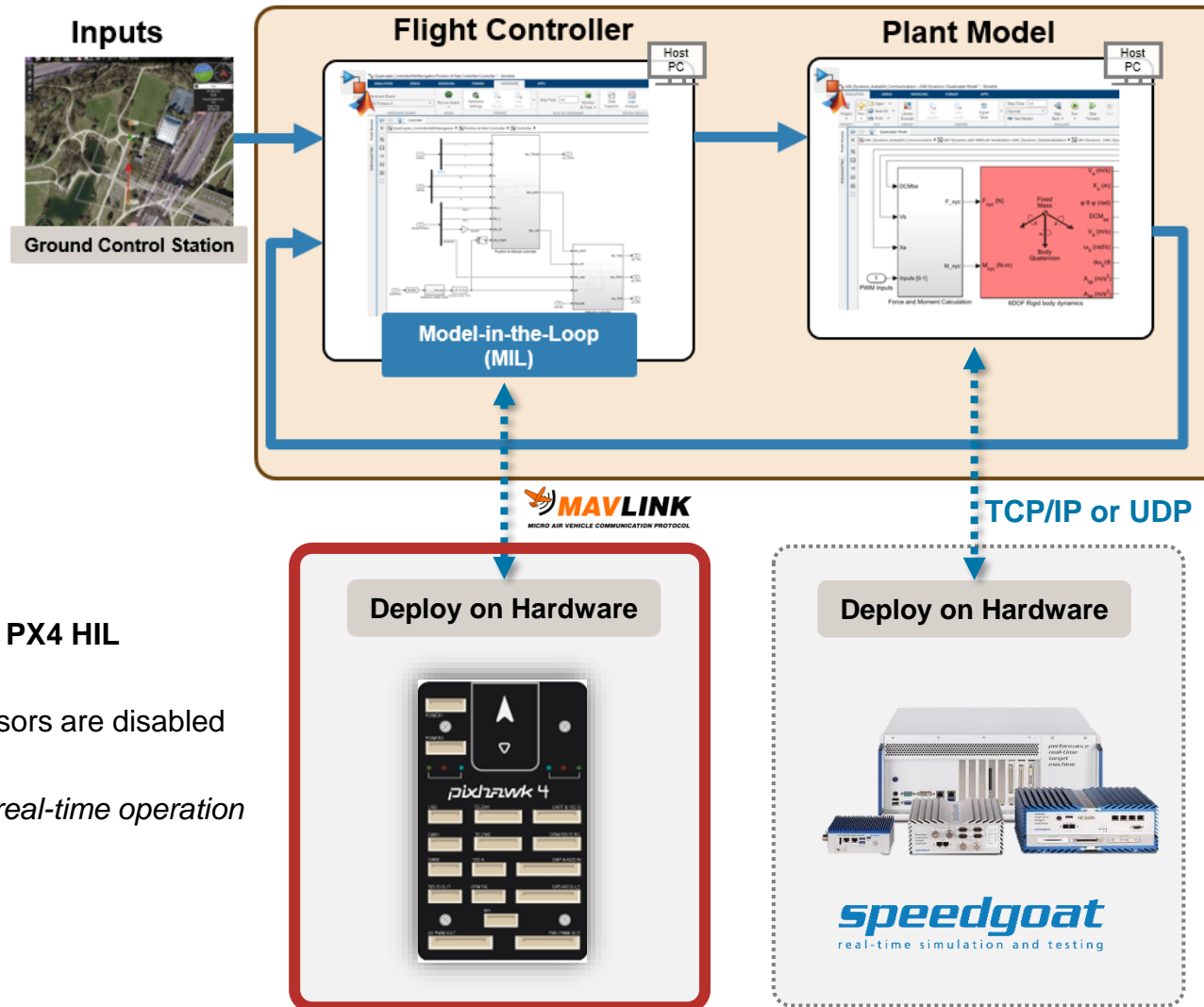


# MIL, SIL and HIL Workflows for UAV Simulation





# HIL with Flight Controller Deployed on PX4



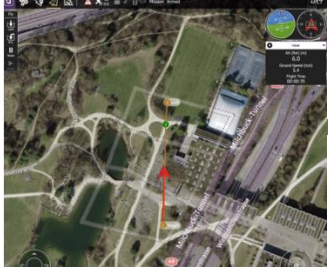
- PX4 HIL**
- PX4 sensors are disabled
  - *Pseudo real-time operation*

**Focus of this talk**

- Full HIL Workflow**
- Communicates with actuators, sensors and the drone peripherals
  - *Real-time operation*

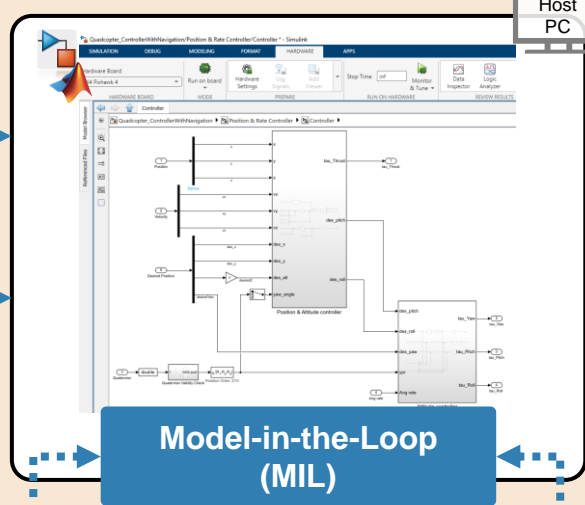
# Visualize Flight Behavior in a Virtual Scenario

## Inputs



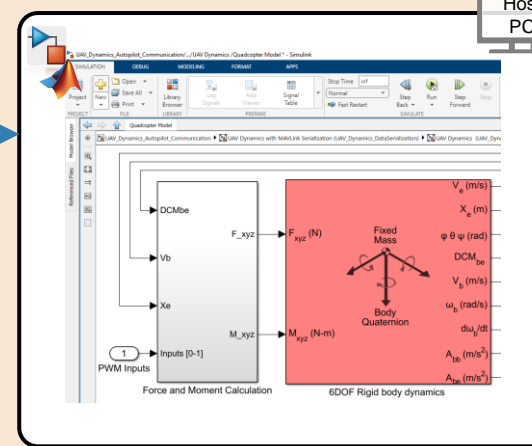
Ground Control Station

## Flight Controller



Model-in-the-Loop (MIL)

## Plant Model



## Scenario Simulation



## C++ EXE on Host PC

```

px4 starting.
INFO [px4] Calling startup script: /bin/sh etc/init.d-posix/rcs 0
INFO [dataman] unknown restart, data manager file './dataman' size is 117
INFO [simulator] waiting for simulator to connect on TCP port 4566
make_dirs:
make_dirs:
compile:
create_run_dir:
copy_res:
BUILD SUCCESSFUL
Total time: 0 seconds
Options parsed, starting Sim.
Starting Gazebo...
INFO [tilt] Mmap: etc/rover/quad_xc-main.mix on /dev/pwm_output
INFO [tilt] Mmap: etc/rover/quad_xc-main.mix on /dev/pwm_output
  
```

Software-in-the-Loop (SIL)

## Deploy on Hardware

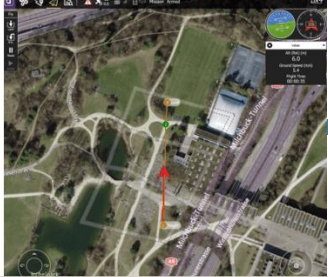


Hardware-in-the-Loop (HIL)



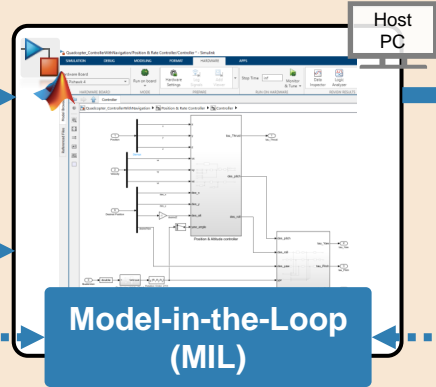
# Design Autonomy Algorithms with UAV Simulation Workflow

## Inputs

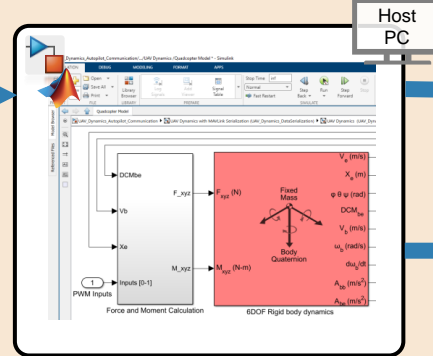


Ground Control Station

## Flight Controller



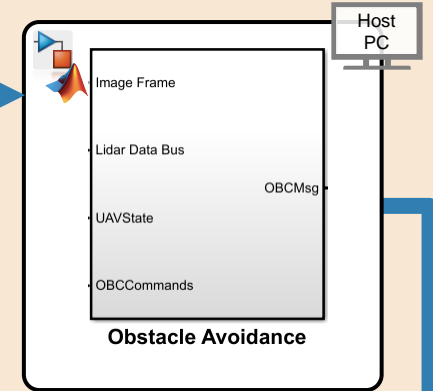
## Plant Model



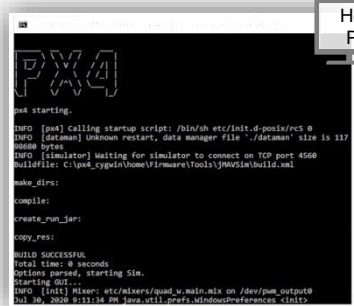
## Scenario Simulation



## Onboard Autonomy



## C++ EXE on Host PC



## Software-in-the-Loop

## Deploy on Hardware



## Hardware-in-the-Loop

## Deploy on Hardware



NVIDIA® Jetson™

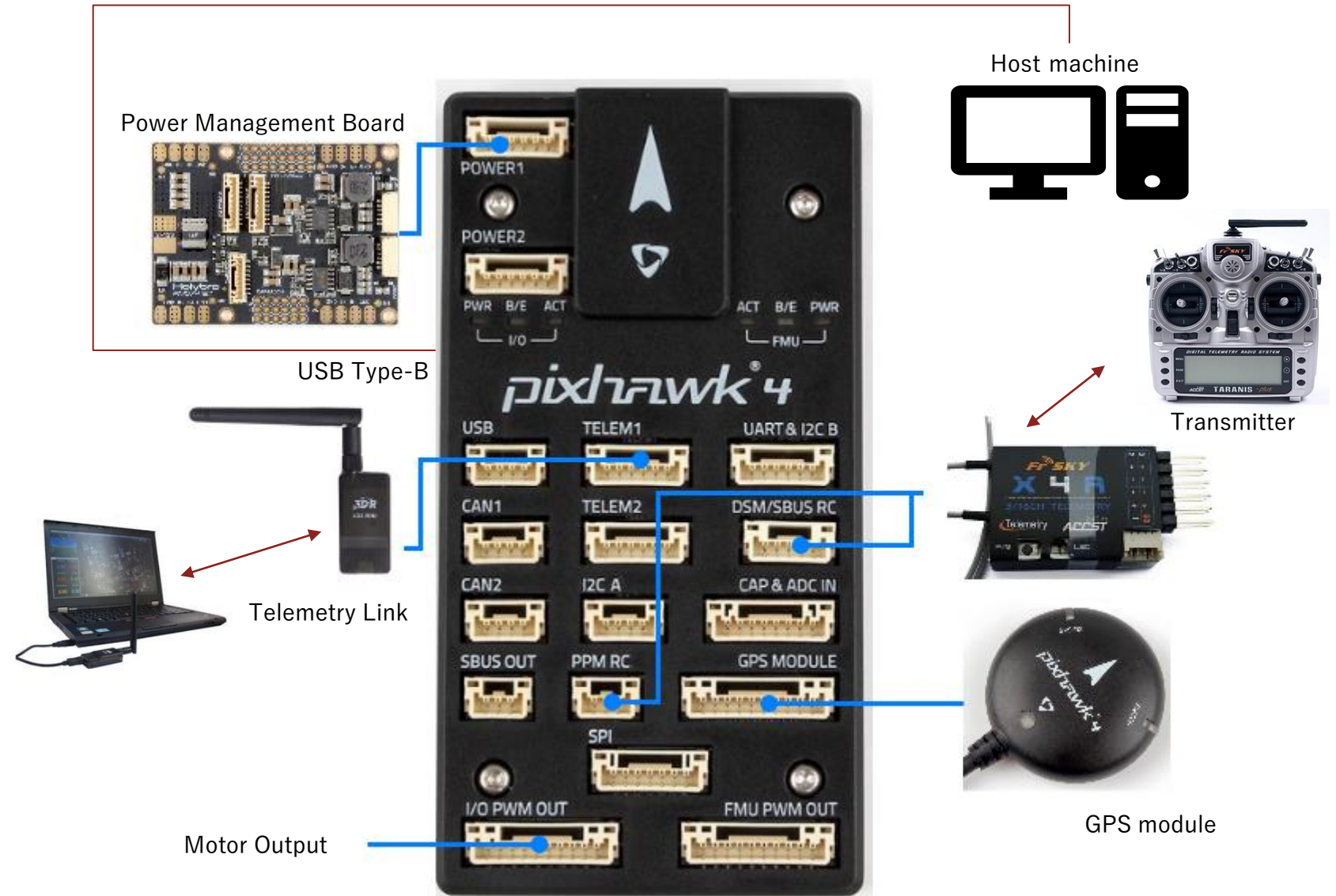
# What is Pixhawk<sup>®</sup>

## On-board sensors:

- Accel/Gyro: ICM-20689
- Accel/Gyro: BMI055 or ICM20602
- Magnetometer: IST8310
- Barometer: MS5611

## Interfaces:

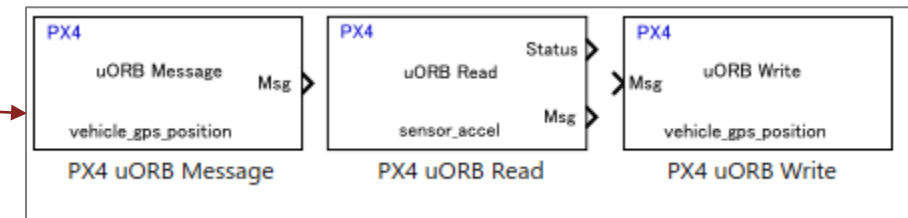
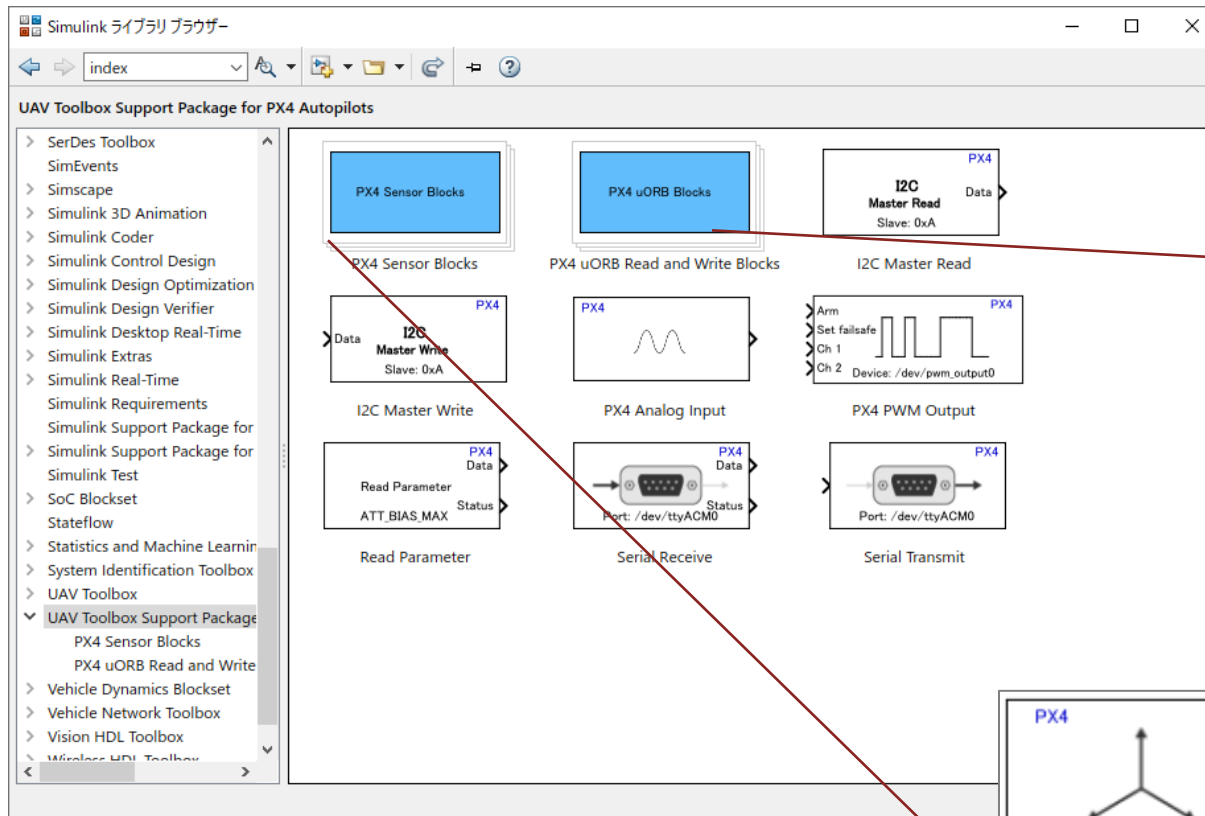
- 8-16 PWM outputs
- 3 dedicated PWM
- Dedicated R/C
- 5 serial ports
- 3 I2C ports
- 4 SPI buses
- 2 CANBuses



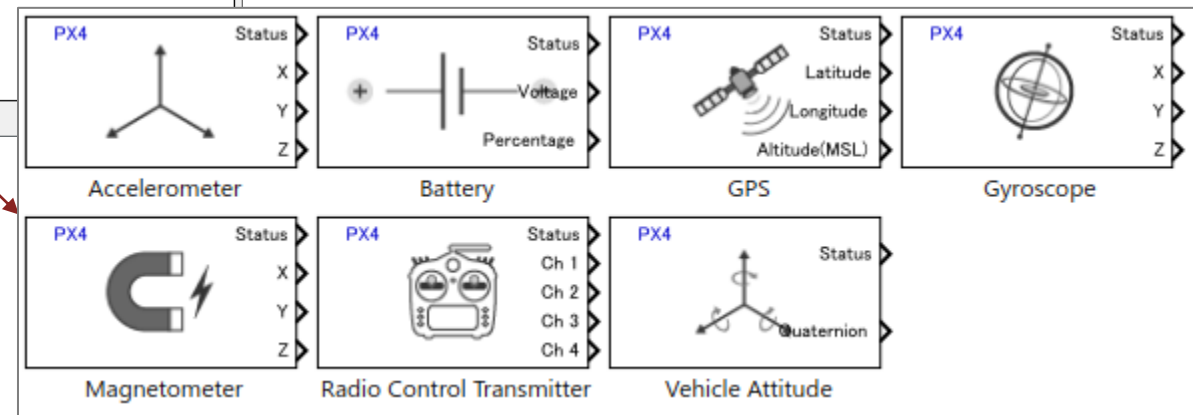
[https://docs.px4.io/en/assembly/quick\\_start\\_pixhawk4.html](https://docs.px4.io/en/assembly/quick_start_pixhawk4.html)

# UAV Toolbox Support Package for PX4 Autopilots

## Simulink Block Library

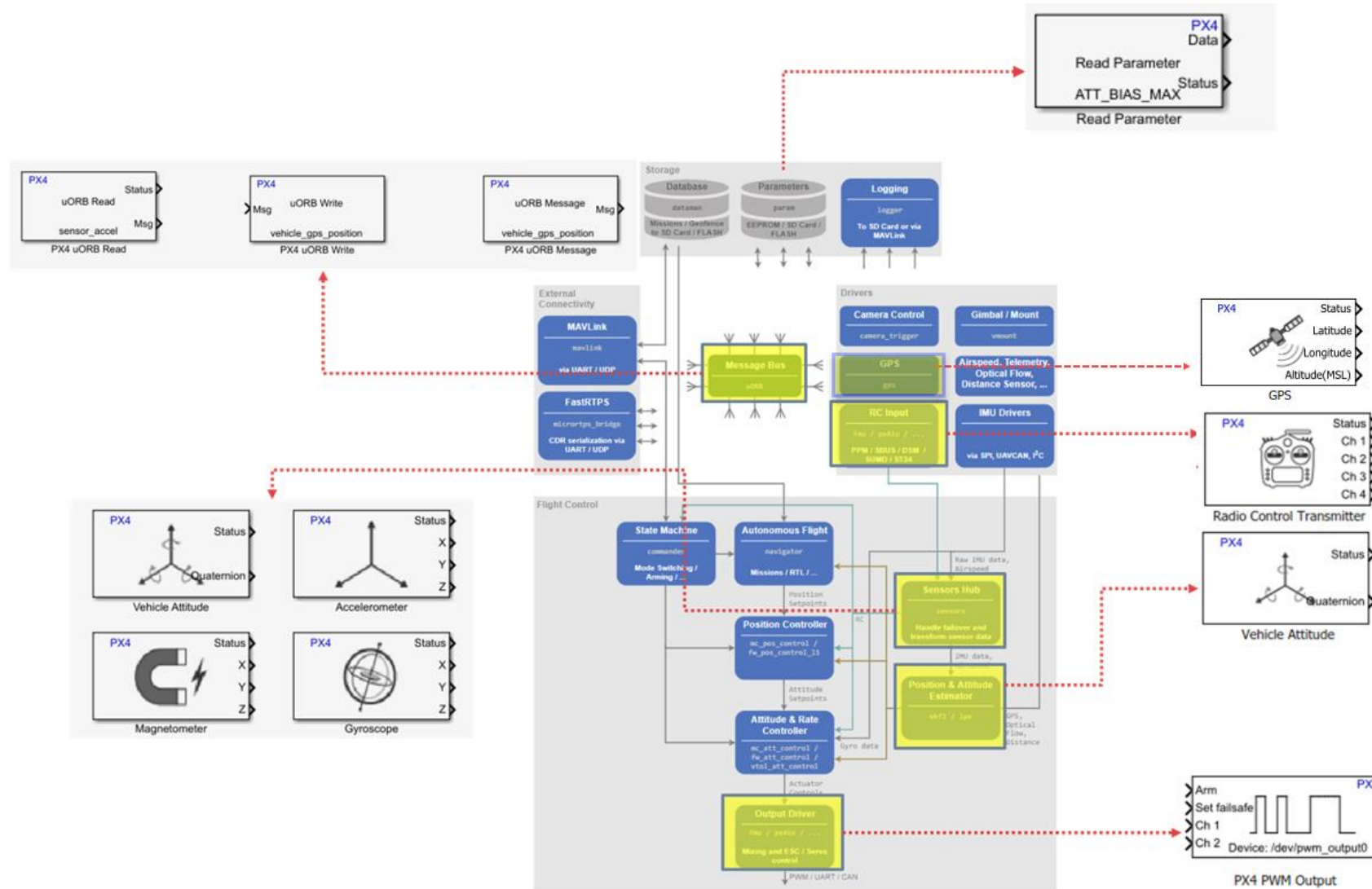


uORB: Asynchronous pub/sub messaging API (middleware)

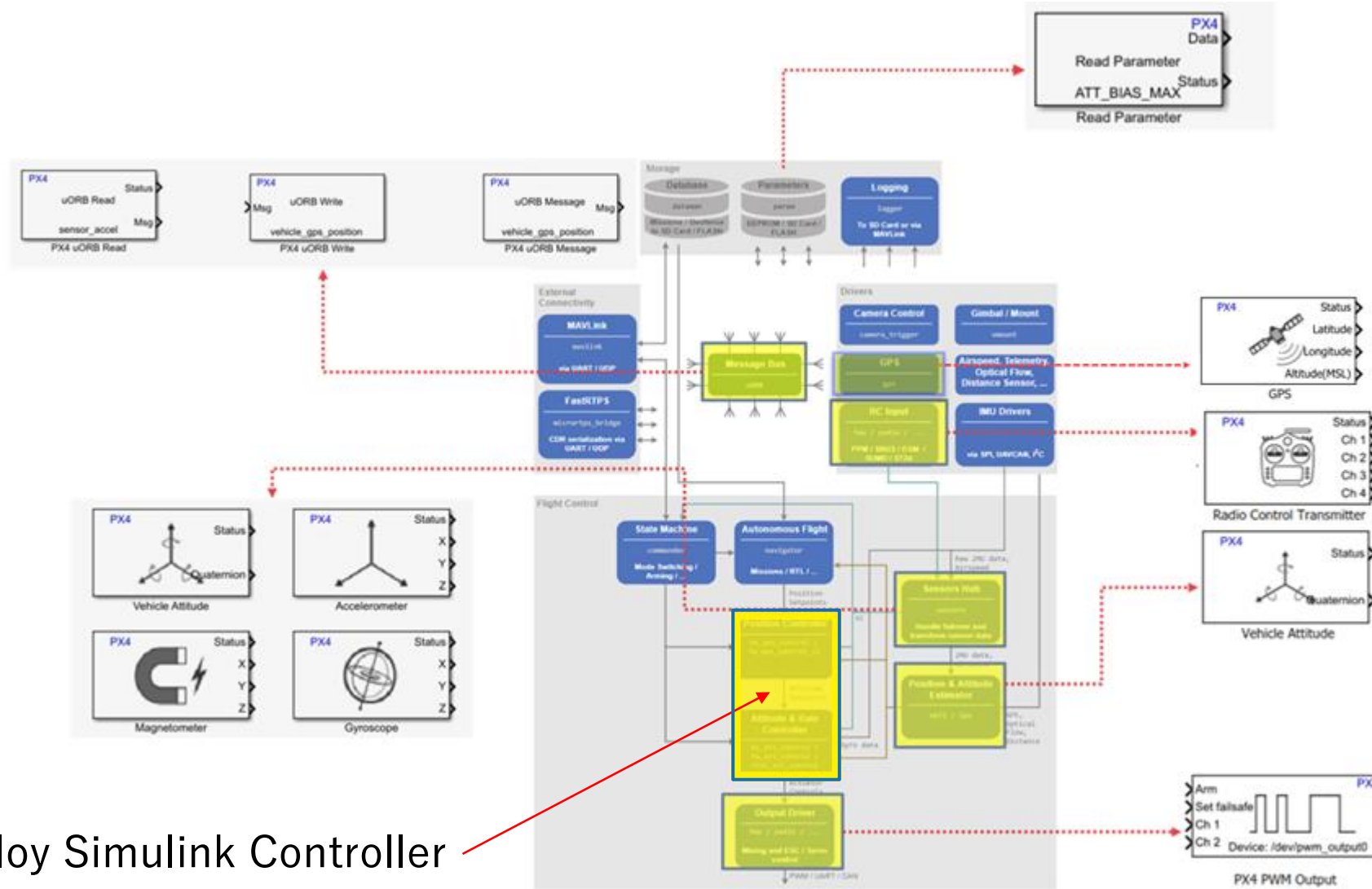




# PX4 Autopilots Support Package Relationship to PX4 Architecture



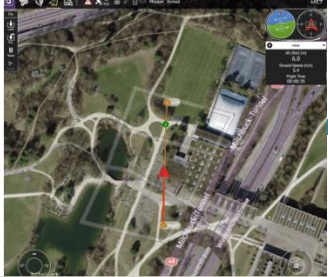
# PX4 Autopilots Support Package Relationship to PX4 Architecture



Deploy Simulink Controller

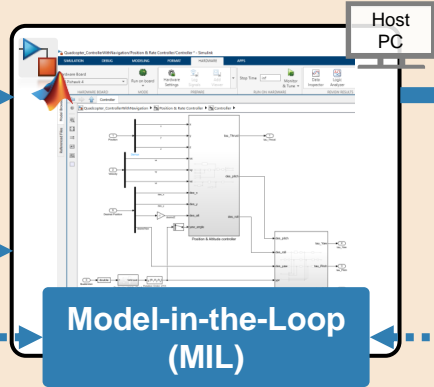
# UAV Simulation Workflow with PX4 and Simulink

## Inputs

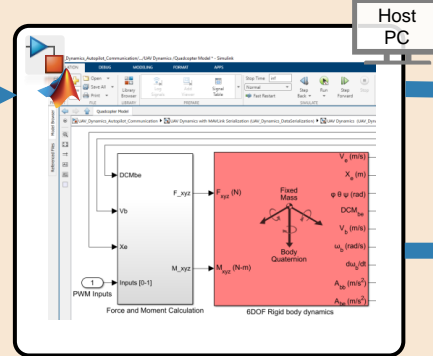


Ground Control Station

## Flight Controller



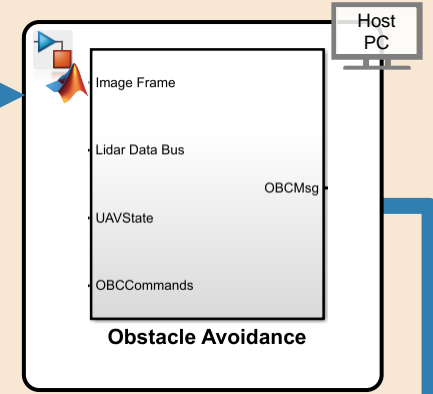
## Plant Model



## Scenario Simulation



## Onboard Autonomy



### C++ EXE on Host PC

```

PX4
-----
pxd starting.
INFO [px4] calling startup script: /bin/sh etc/init.d-px4/rcs 0
INFO [dataman] Unknown restart, data manager file './dataman' size is 117
INFO [simulator] Waiting for simulator to connect on TCP port 4560
make_dirs:
compile:
create_run_dir:
copy_res:
BUILD SUCCESSFUL
Total time: 0 seconds
Waiting for simulator, starting Sim.
Starting QRT...
INFO [Info] Hwmon: rtc/at91rm9200/rtc.y_min.nix on /dev/pwm_out0@0
Jul 19, 2015 01:11:34 PM java.util.PrivilegedActionImpl: cinit
  
```

### Software-in-the-Loop

### Deploy on Hardware



### Hardware-in-the-Loop

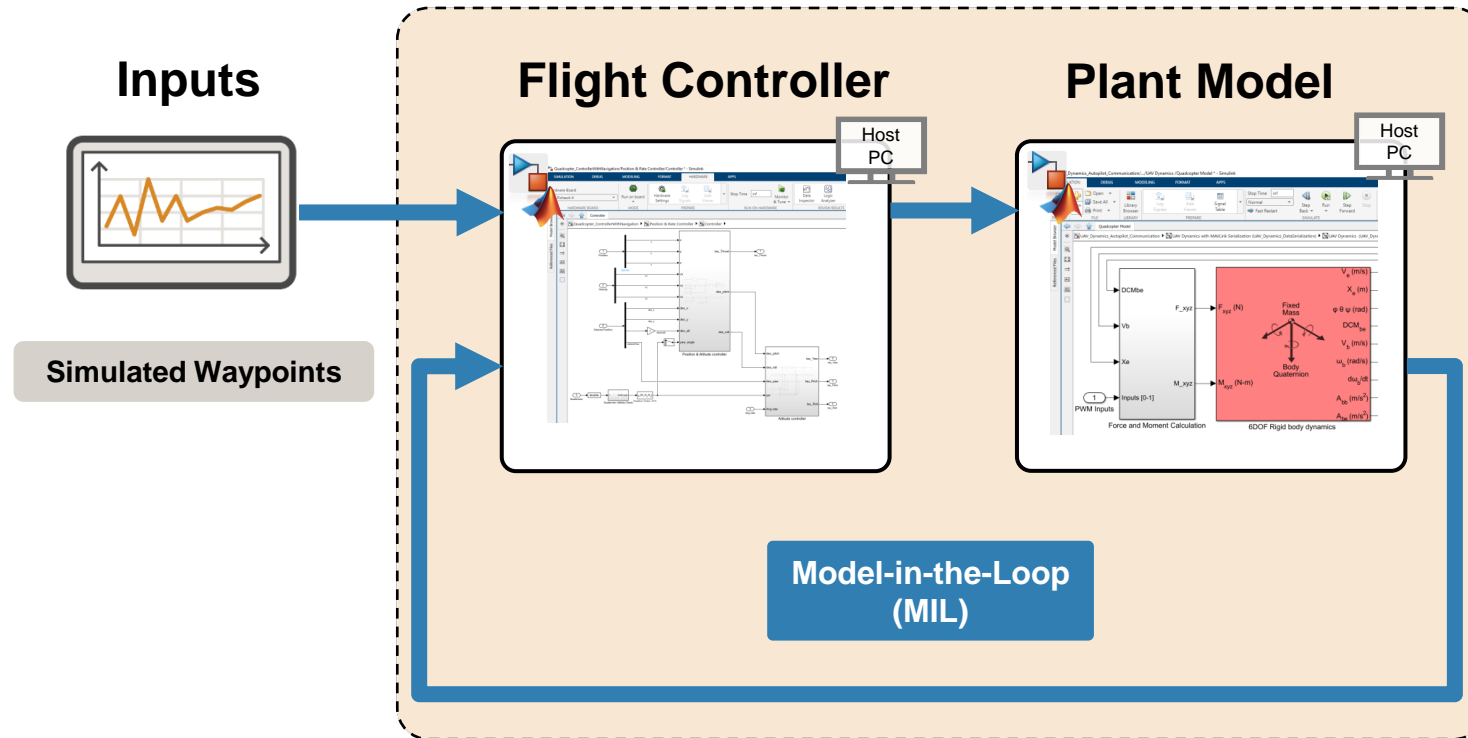
### Deploy on Hardware



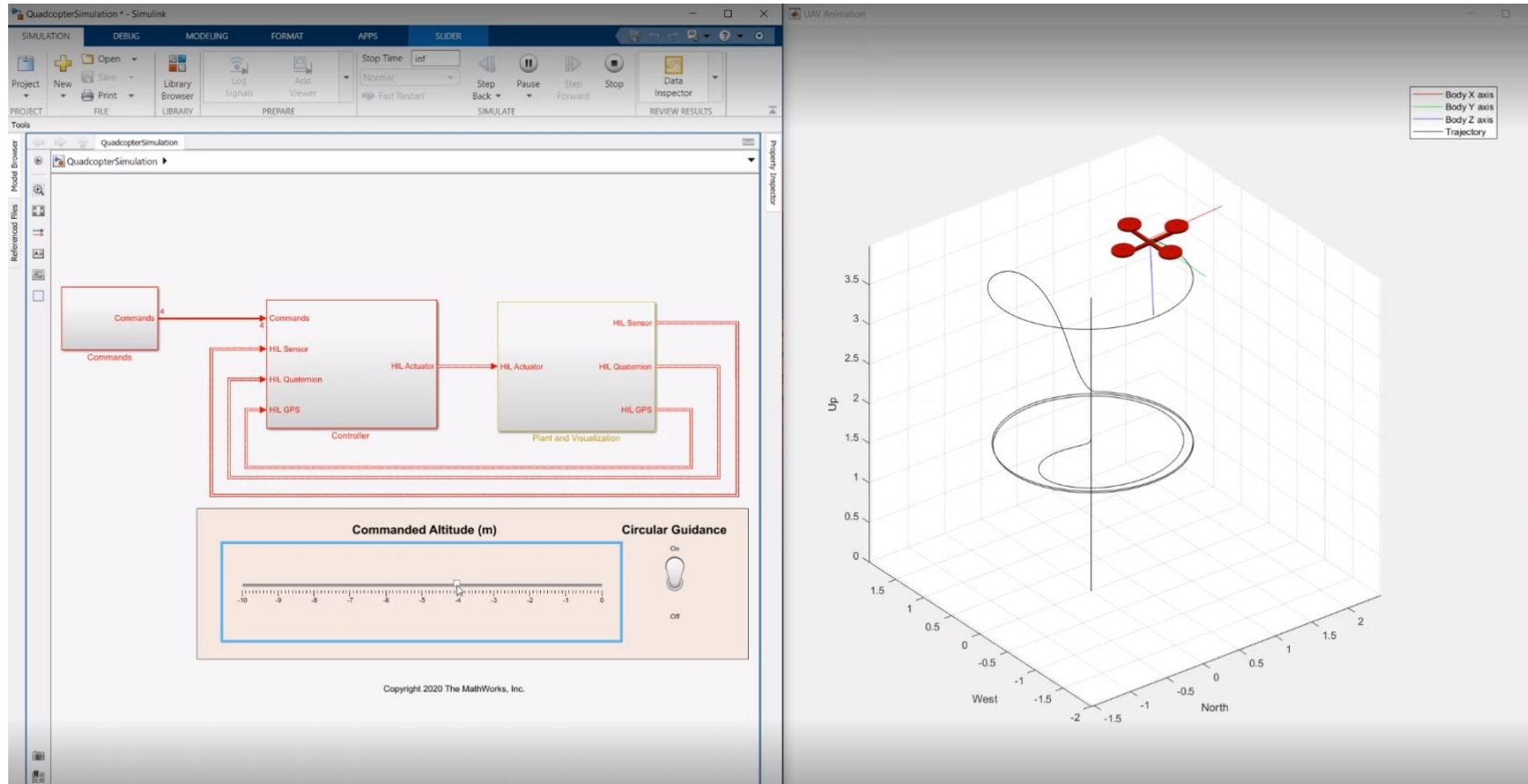
NVIDIA Jetson



# Model In the Loop



# Quadcopter Simulation in Simulink



**Monitor and Tune PX4 Host Target Flight Controller with Simulink-Based Plant Model**

Use the UAV Toolbox Support Package for PX4 Autopilots to verify the controller design using PX4 Host Target versus the simulator

[Shipping example in UAV Toolbox](#)

# Quadcopter Simulation in Simulink

The image displays a Simulink simulation environment for a quadcopter. The left window, titled "QuadcopterSimulation - Simulink", shows a block diagram of the control system. It includes a "Commands" input block, a "Controller" block containing "HL Sensor", "HL Quaternion", and "HL GPS" sub-blocks, an "HL Actuator" block, and a "Plant and Visualization" block containing "HL Sensor", "HL Quaternion", and "HL GPS" sub-blocks. Below the diagram is a control panel with a "Commanded Altitude (m)" slider ranging from -10 to 0 and a "Circular Guidance" toggle switch currently set to "On". The status bar at the bottom indicates "Running" with 92% completion and a time of T=2.808.

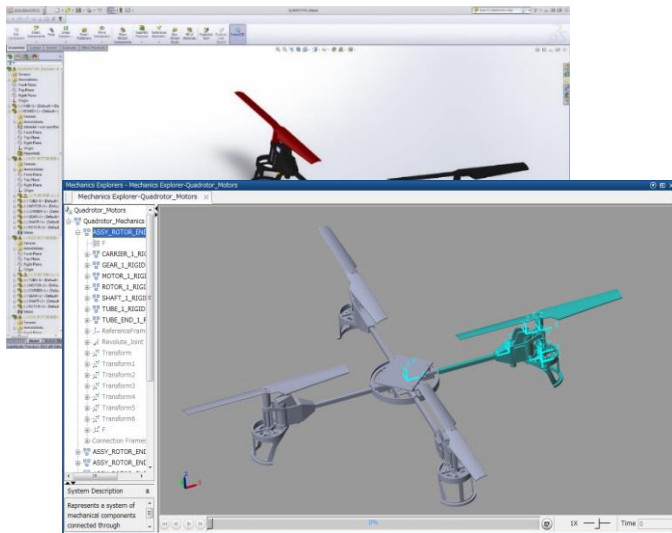
The right window, titled "UAV Animation", shows a 3D perspective view of the quadcopter. The quadcopter is a red model with four rotors. A legend in the top right corner identifies the visual elements: "Body X axis" (red line), "Body Y axis" (green line), "Body Z axis" (blue line), and "Trajectory" (black line). The axes are labeled "Up", "West", and "North". The vertical axis ranges from 0 to 2.5, while the horizontal axes range from -1.5 to 1.5.

**Full Quadcopter Simulation**

Video included with session content package

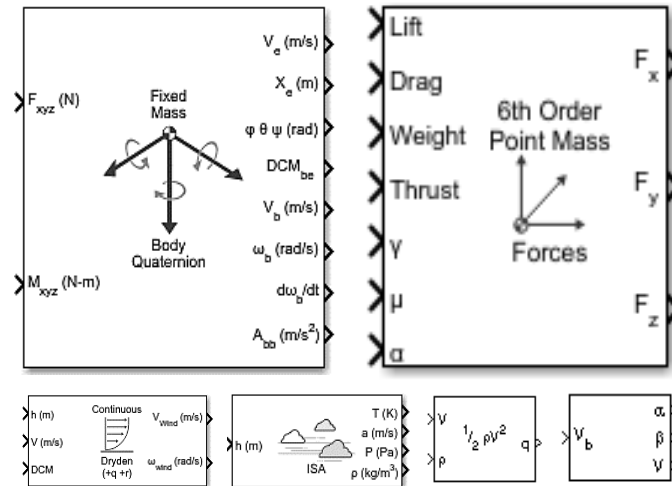


# Simulink Plant Modelling



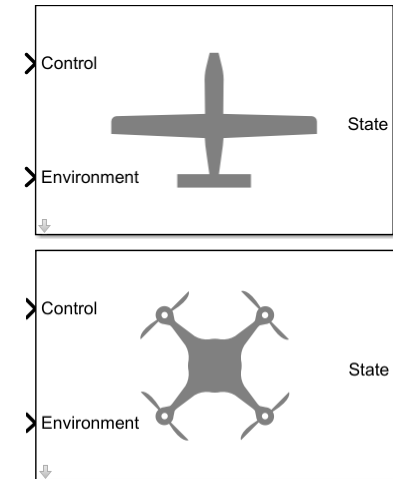
## Physical Modeling

Model construction techniques and best practices, domain-specific modeling, physical units



## Vehicle Dynamics

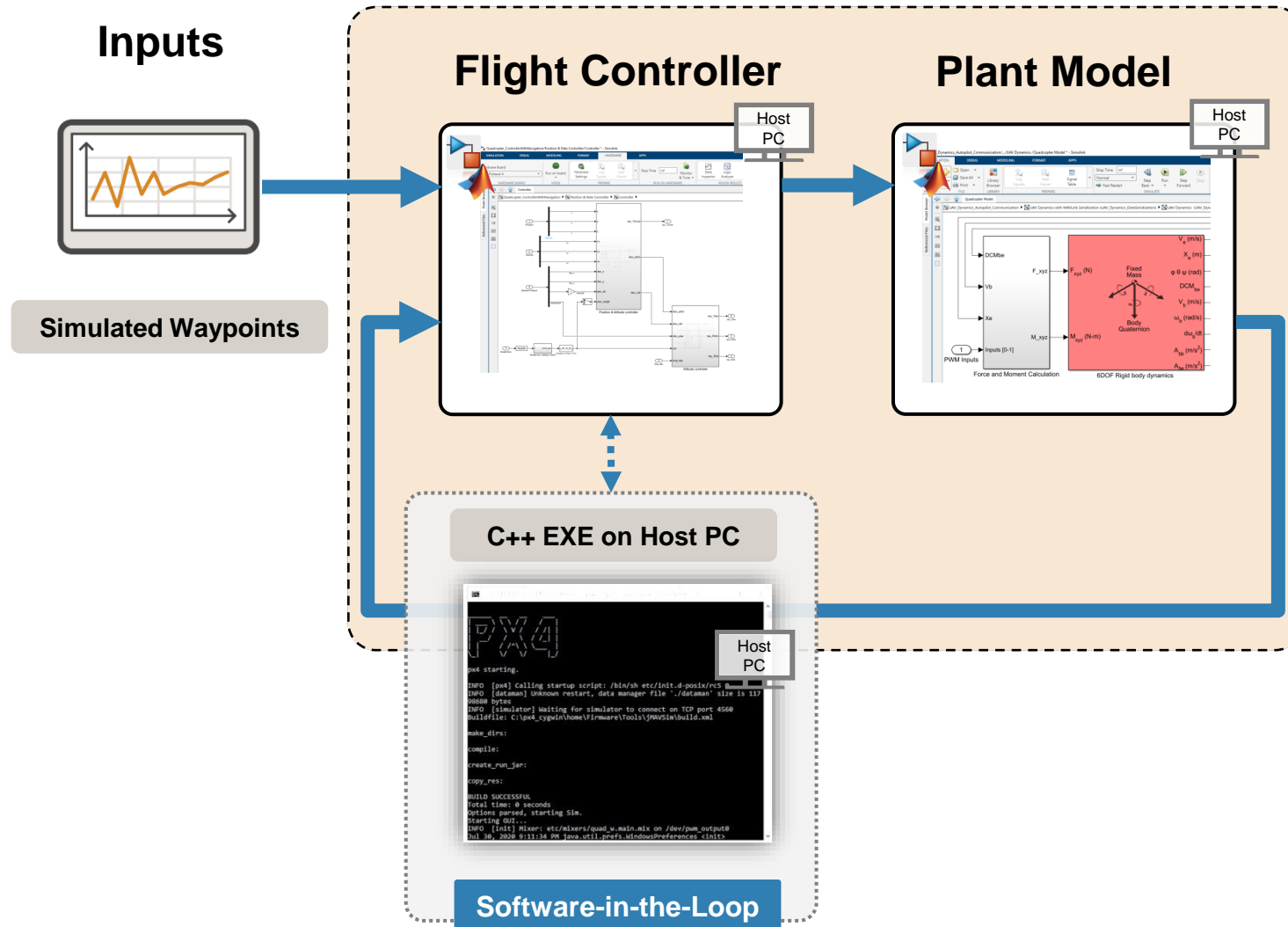
Model aerodynamics, propulsion, and motion of aircraft and spacecraft



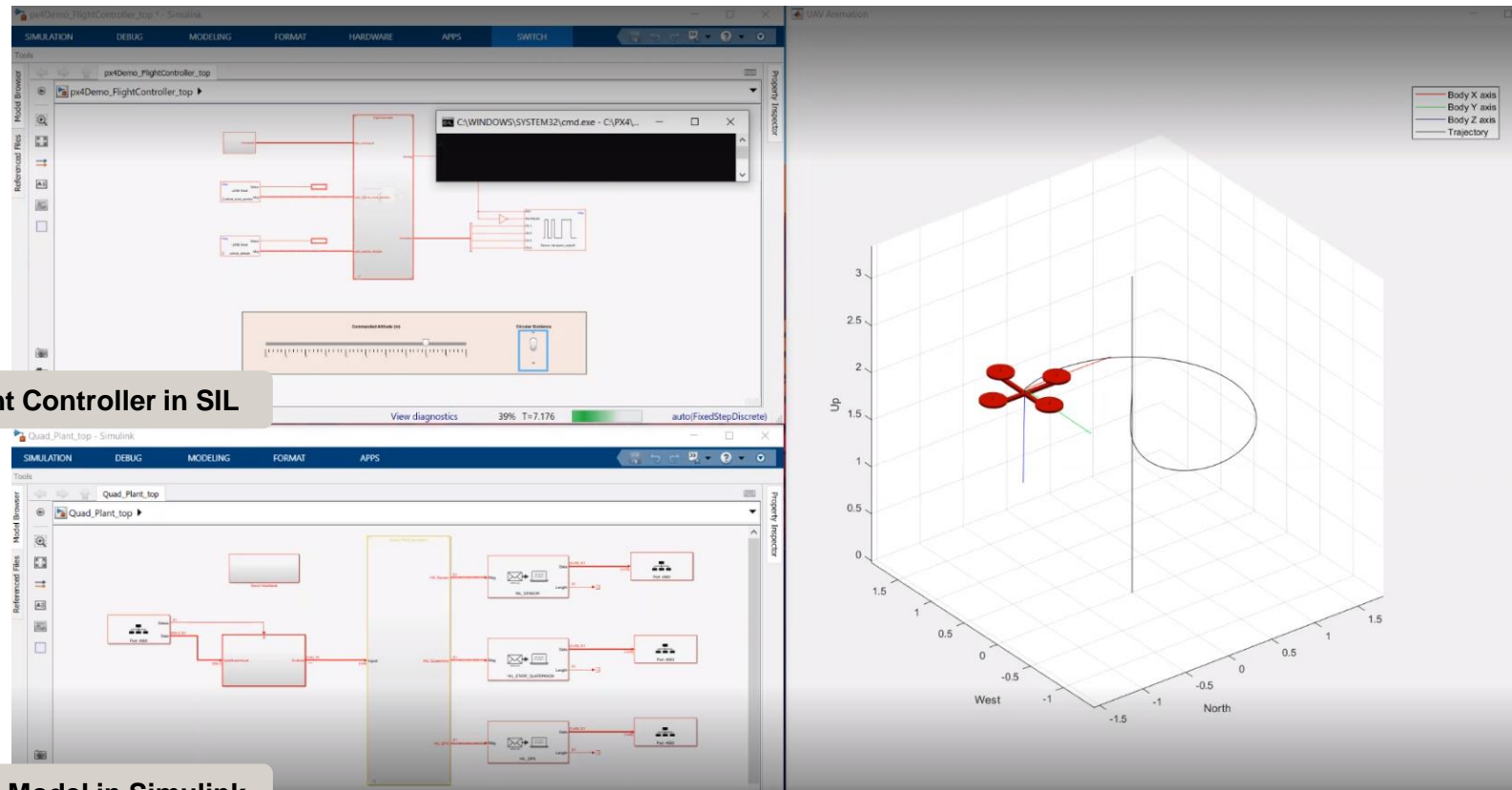
## Guidance Model

Reduced-order model for UAV

# Software-in-the-Loop (SIL)



# SIL with PX4 HSP and Simulink Plant



**Flight Controller in SIL**

**Plant Model in Simulink**

**Monitor and Tune PX4 Host Target Flight Controller with Simulink-Based Plant Model**

Use the UAV Toolbox Support Package for PX4 Autopilots to verify the controller design using PX4 Host Target versus the simulator

[Shipping example in UAV Toolbox](#)  
(See Task 2 in the example)

# SIL with PX4 HSP and Simulink Plant

The image displays a Simulink environment with three windows:

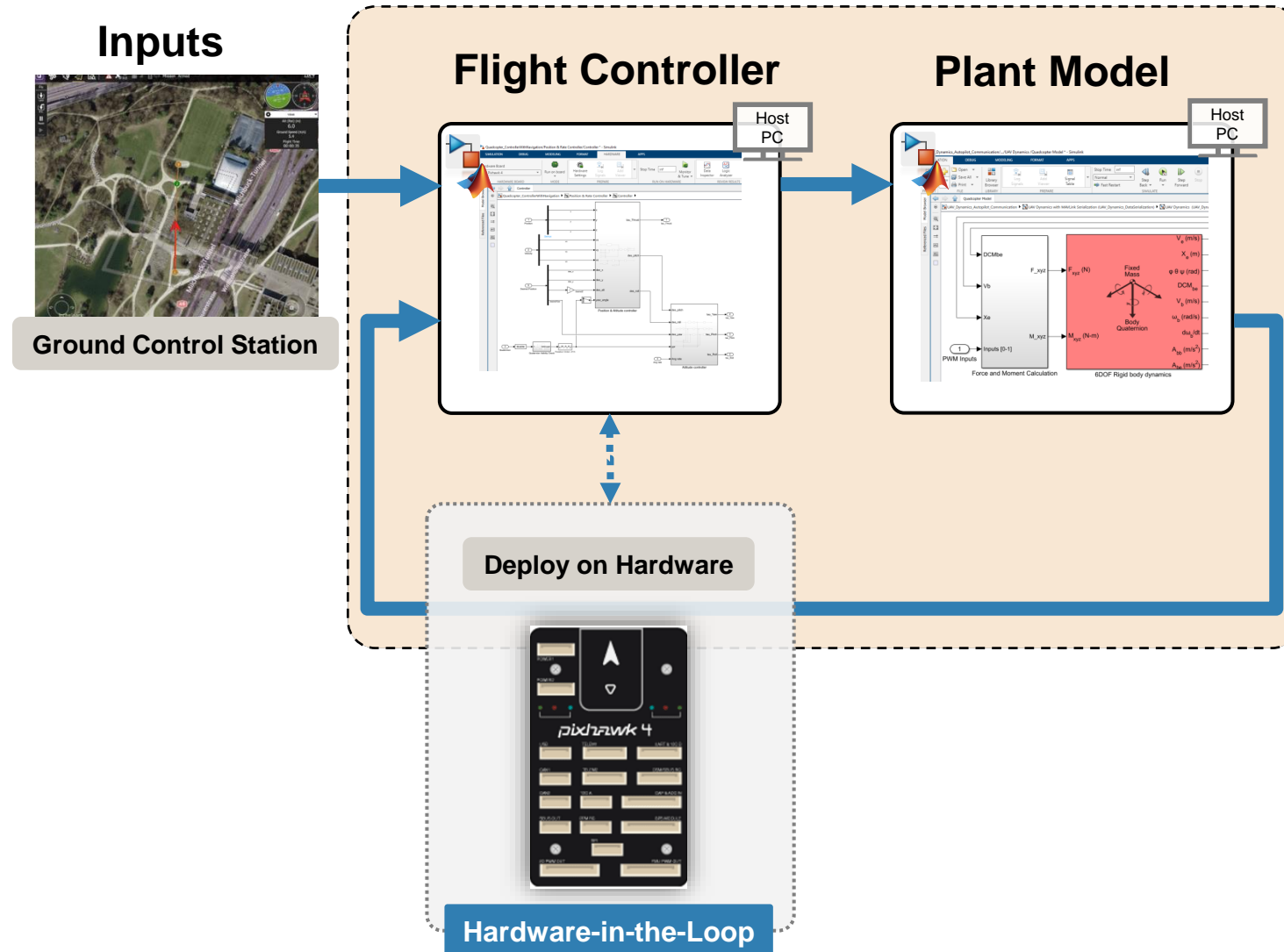
- px4Demo\_FlightController\_top - Simulink:** Shows a control system model with various blocks and a scope. The status bar indicates "Running the model on 'PX4 Host Target'..." with a progress of 39% and T=0.352.
- Quad\_Plant\_top - Simulink:** Shows a more complex model with multiple interconnected blocks. The status bar indicates "Running: pacing active. Unable to pace at specified rate" with a progress of 50% and T=0.736.
- UAV Animation:** A 3D plot showing a quadcopter model in a coordinate system with axes labeled "Up", "West", and "North". A legend identifies the "Body X axis", "Body Y axis", "Body Z axis", and "Trajectory".

**Flight Controller Software in the loop (SIL)**

Video included with session content package



# Hardware-in-the-Loop (HIL)



# HIL with PX4 HSP and Simulink Plant

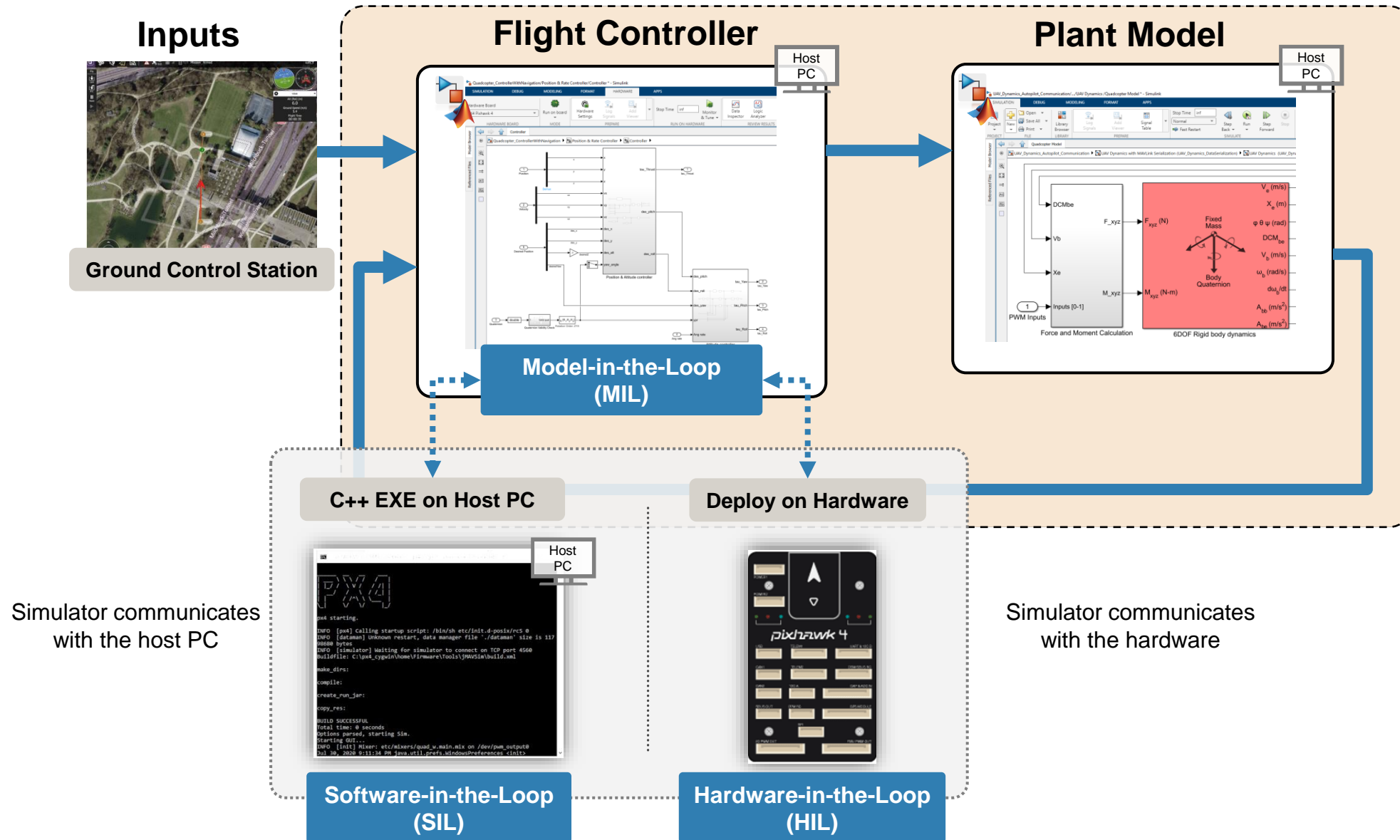
The image displays two software windows side-by-side. The left window is QGroundControl, showing a top-down view of a flight path over a map with a 'Start Mission' dialog box. The right window is Simulink, showing a block diagram of the UAV Dynamics with MAVLink Serialization model. The diagram includes blocks for 'UAV Dynamics', 'HIL\_SENSOR', 'HIL\_GPS', and 'Send Heartbeat'. A table of numerical values is visible in the Simulink workspace:

Variable	Value
Acc	0.00081 0.00189 -9.81
Gyro	0.00032 0.00415 -0.12e-05
Mag	21.5 -1.16 43.1
Pressure	9.56e04
LLA	47.4 -0.55 4.88
Velocity	-0.00214 -0.0118 -0.0704
GrndSpeed	0.012
Course	2.68

A blue callout box at the bottom center of the Simulink window contains the text: **Flight Controller Hardware in the loop (HIL)**. The status bar at the bottom of the Simulink window shows '100%' zoom, 'T=84.700', and 'ode4'.

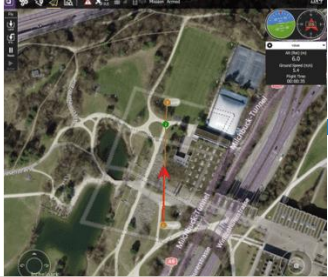
Video included with session content package

# UAV Simulation Workflow with PX4 and Simulink



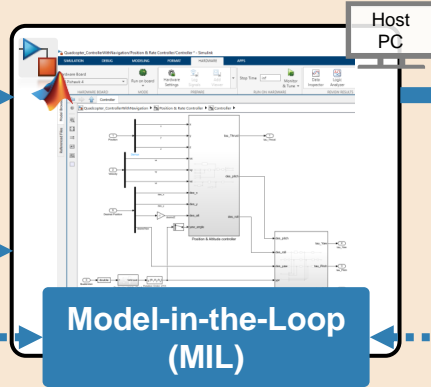
# UAV Simulation Workflow with PX4 and Simulink

## Inputs

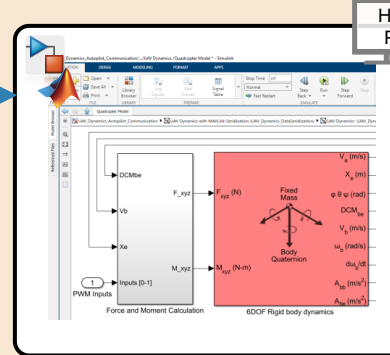


Ground Control Station

## Flight Controller



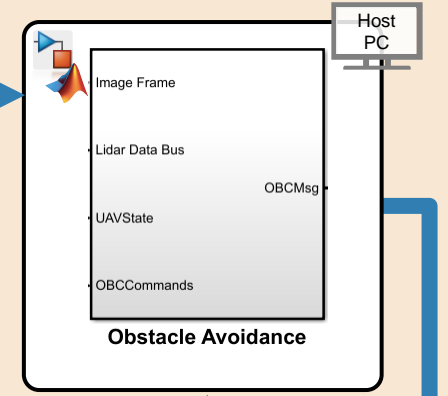
## Plant Model



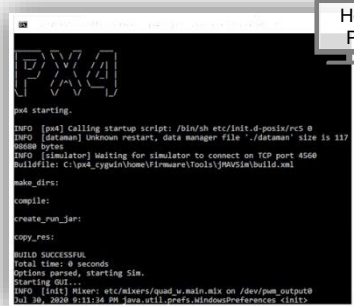
## Scenario Simulation



## Onboard Autonomy



### C++ EXE on Host PC



Software-in-the-Loop

### Deploy on Hardware



Hardware-in-the-Loop

### Deploy on Hardware



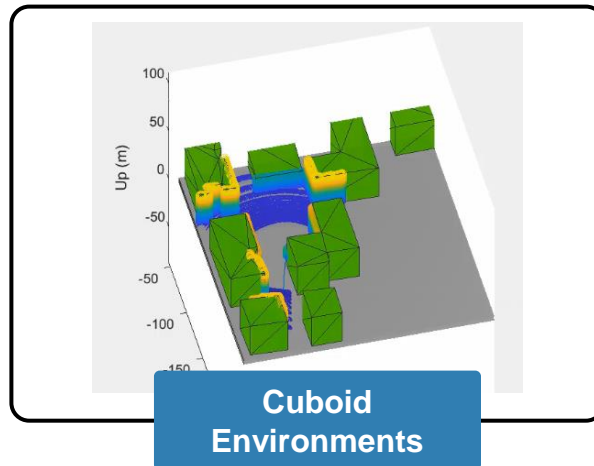
NVIDIA Jetson



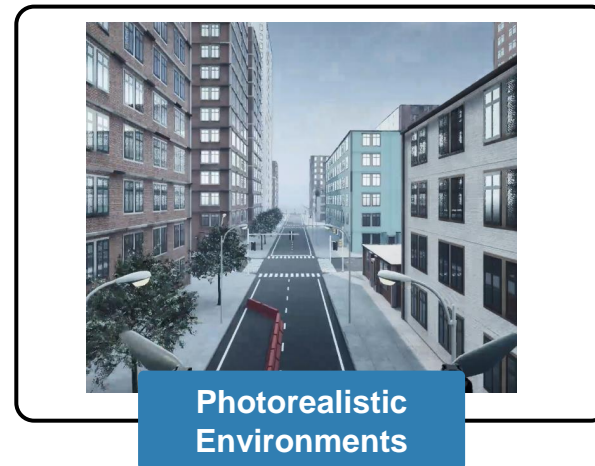
# Closed-loop autonomy simulation



## Scenario Simulation



Cuboid  
Environments



Photorealistic  
Environments

# Create environments and simulate sensor readings

## *UAV Scenario Designer*

DESIGNER | TRAJECTORY

New Open Save Import Scenario Import Terrain Latitude(deg) 40.7046 Longitude(deg) -74.016 Altitude 0

Cylinder Quadrotor GPS Default Layout Run Update Rate(s) 10 Stop Time (s) Inf Export Scenario

FILE IMPORT REFERENCE LOCATION SCENE OBJECT PLATFORM SENSORS DEFAULT LAYOUT SIMULATE EXPORT

**Property Panel**  
**Platform**  
 Name: Platform  
 Reference Frame: NED  
 Start Time: 0  
 Elevation Control: Snap To Ground Elevation  
**Geometry**  
**Body Properties**  
 Position(m): X: 500, Y: 400, Z: 50.0161

**Scene Browser**  
 Platforms: Platform  
 Objects: CustomObject, CustomObject1, CustomObject2, CustomObject3, CustomObject4, CustomObject5, CustomObject6

**UAVScenarioCanvas**  
 Y North (m) vs X East (m) plot showing a trajectory path over a city map.

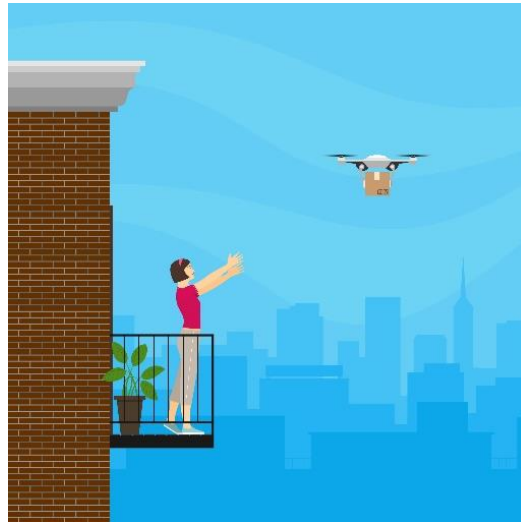
Altitude (m) vs Time (s) plot showing a constant altitude of 52 meters.

**Trajectory Table**

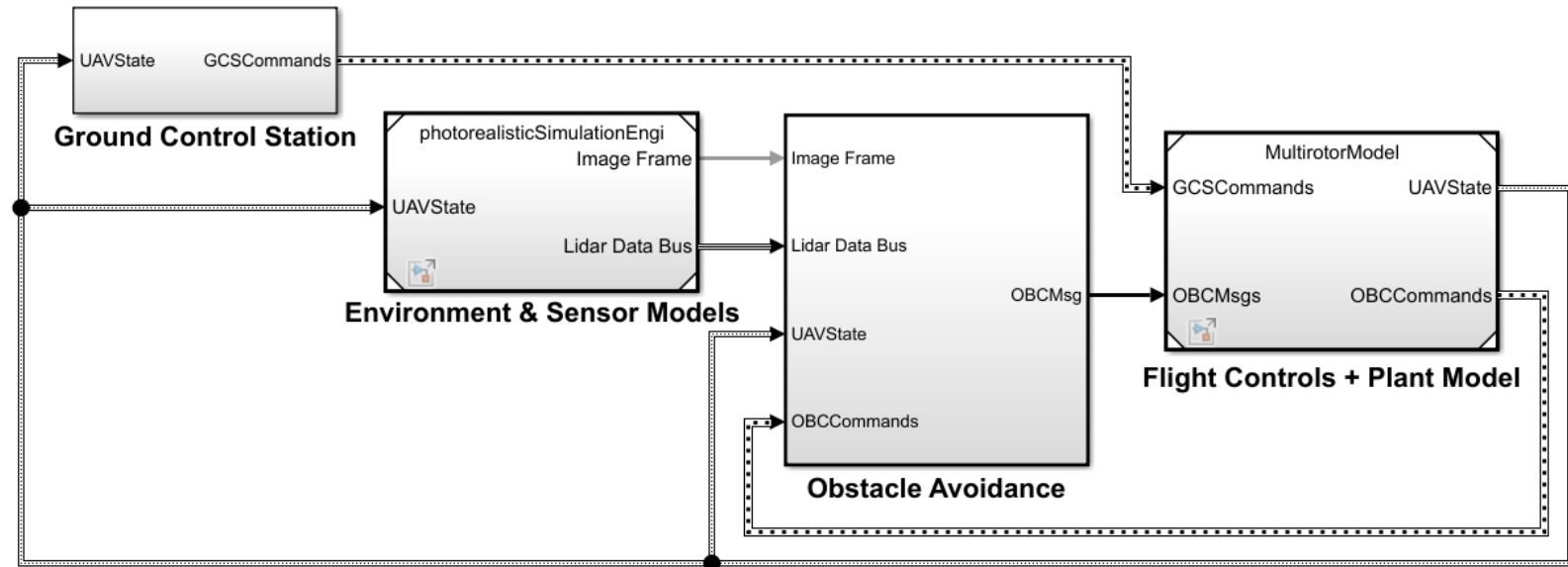
	Time	X	Y	Z	Course	Group
1	0	-583.0000	-133.0000	-52.0500	42.9300	
2	18.4260	-262.0000	16.0000	-52.0500	-11.5900	
3	25.9700	-137.0000	-63.0000	-52.0500	-51.3600	
4	36.5420	-27.0000	-243.0000	-52.0500	-48.5400	

**UAVScenarioView**  
 3D visualization of the UAV trajectory over a city environment.

# Integrate environments into full-system simulation

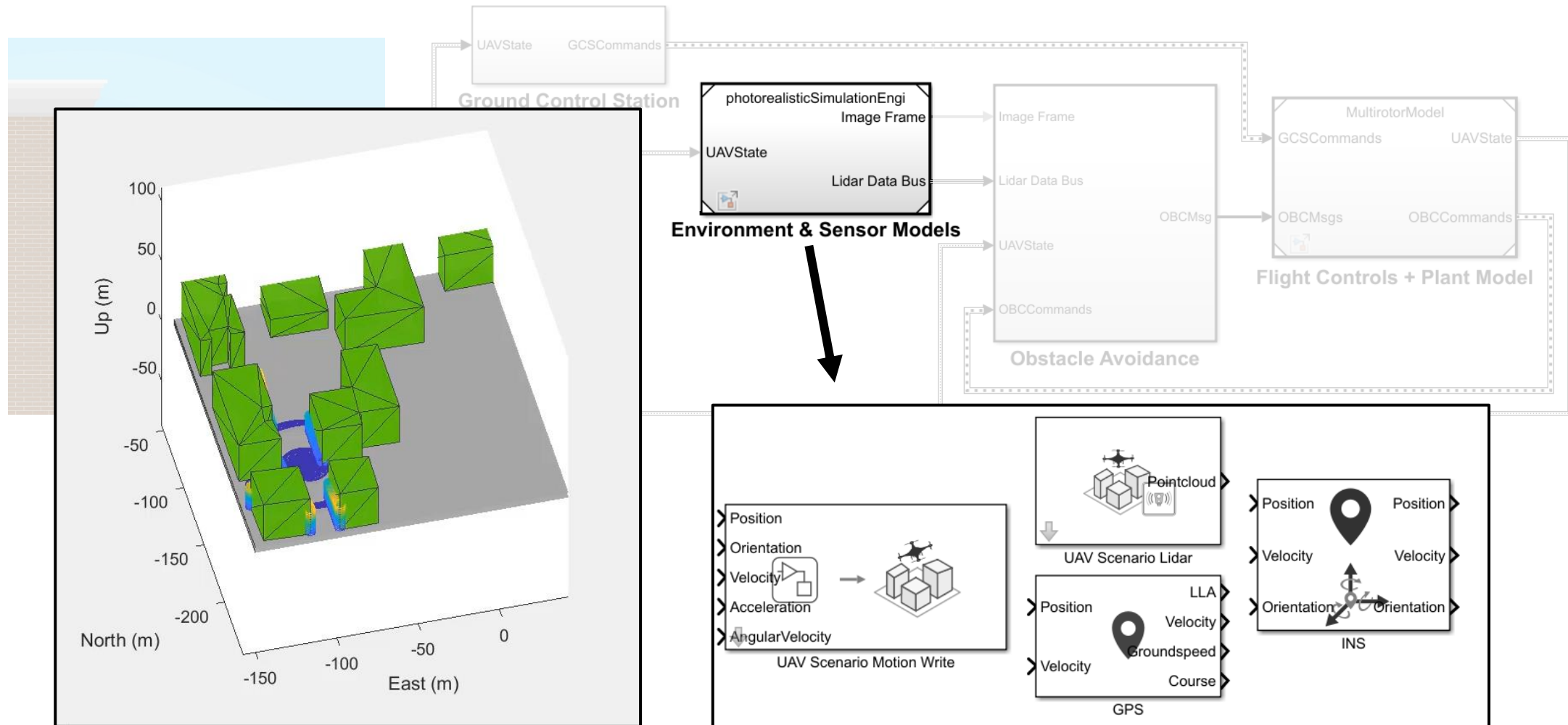


**UAV Package Delivery Example**



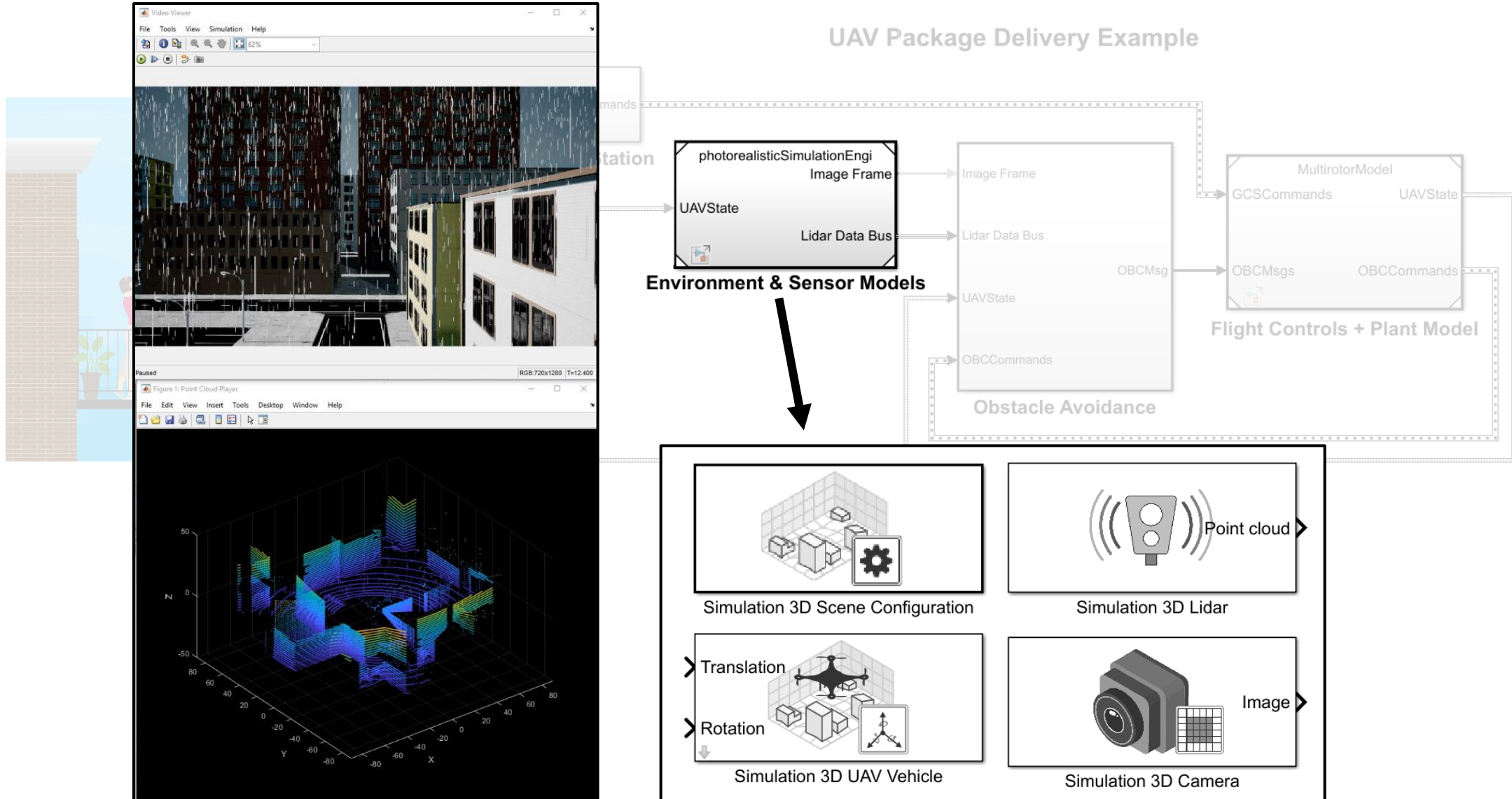
# Integrate environments into full-system simulation

## UAV Package Delivery Example



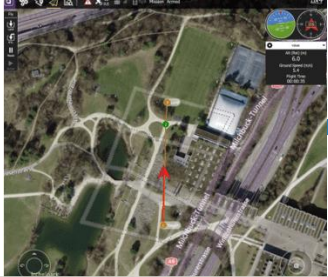


# Integrate environments into full-system simulation



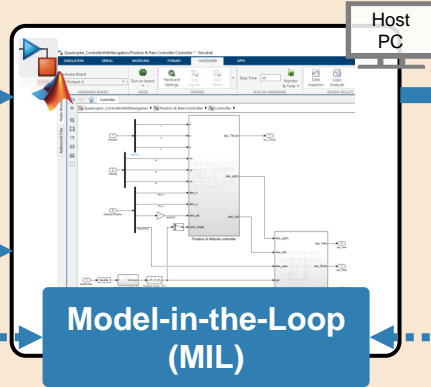
# UAV Simulation Workflow with PX4 and Simulink

## Inputs

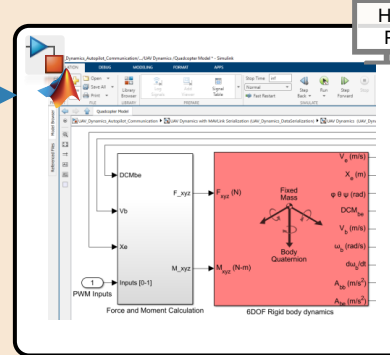


Ground Control Station

## Flight Controller



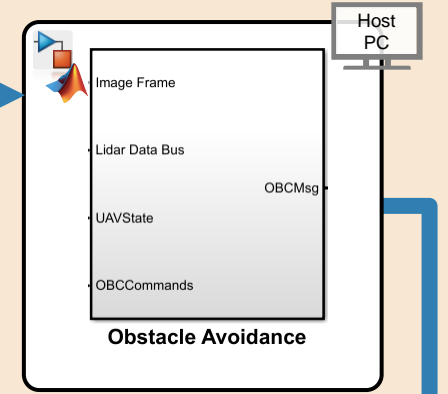
## Plant Model



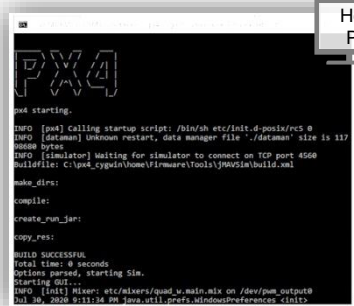
## Scenario Simulation



## Onboard Autonomy



### C++ EXE on Host PC



### Software-in-the-Loop

### Deploy on Hardware



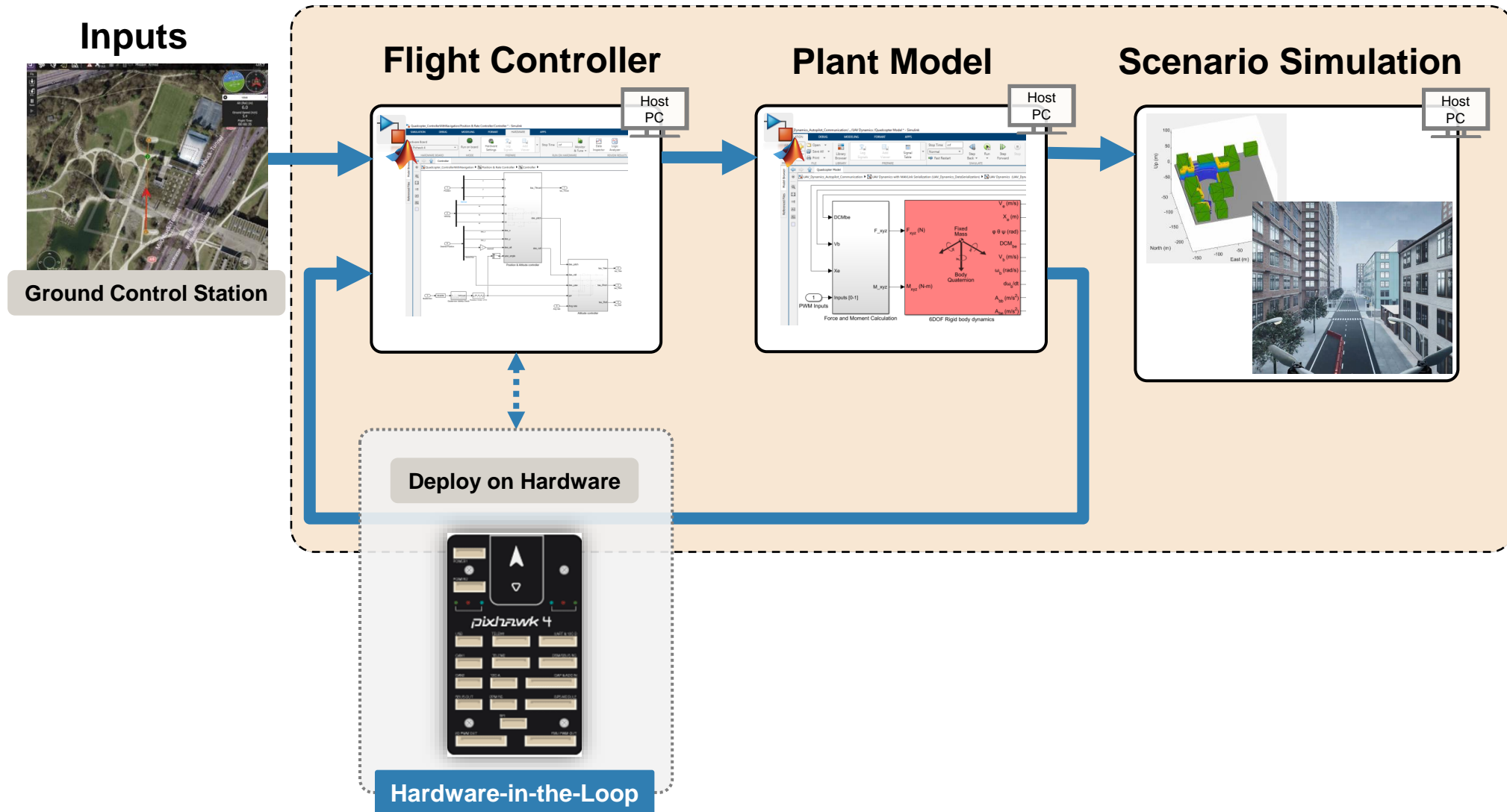
### Hardware-in-the-Loop

### Deploy on Hardware

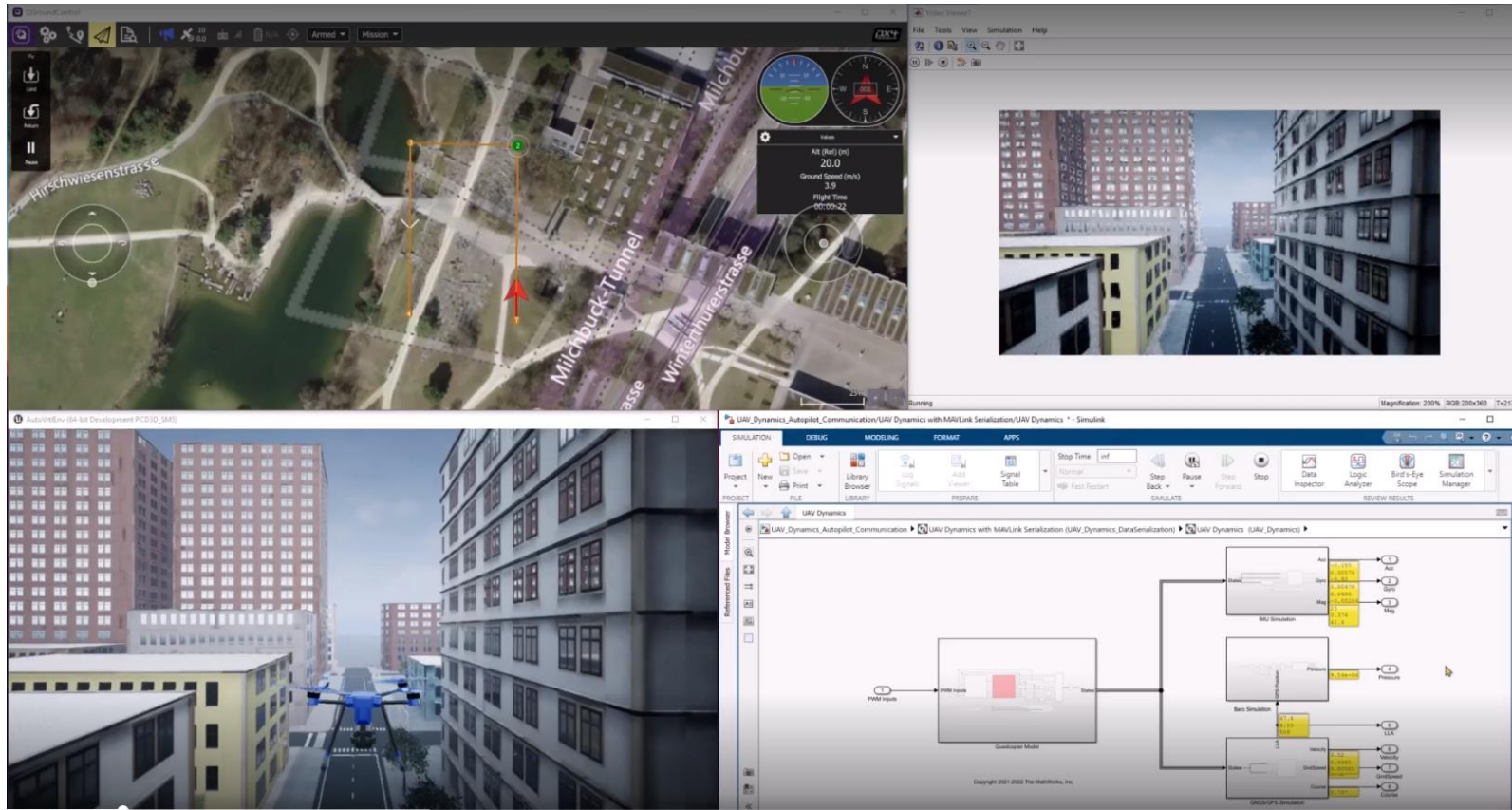



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# HIL with Scenario Visualization



# HIL with Scenario Visualization

**Scenario Simulation and Flight Visualization with PX4 Hardware-in-the-Loop...**

Demonstrates 3D scenario Simulation and Flight visualization with PX4 Hardware-in-the-Loop (HITL) and UAV Dynamics contained

[Shipping example in UAV Toolbox](#)



# HIL with Scenario Visualization

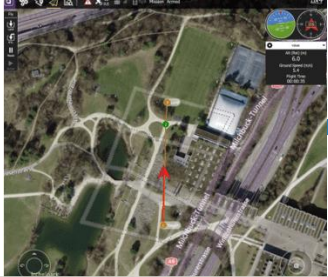
The image illustrates a Hardware-in-the-Loop (HIL) setup for UAV flight simulation. It is divided into four main visual components:

- Top-Left (QGroundControl):** A ground station interface showing a 3D map of an urban environment. A mission path is plotted in orange. A 'Start Mission' dialog box is visible, indicating the drone is ready for takeoff. A status panel on the right shows flight parameters: Alt (Rel) (m) 0.0, Ground Speed (m/s) 0.0, and Flight Time 00:00:00.
- Top-Right (Video Viewer):** A window displaying a first-person perspective view of a street scene, likely from the drone's camera or a virtual camera.
- Bottom-Left (3D Drone Model):** A 3D model of a blue quadcopter drone positioned on a street in a virtual urban environment.
- Bottom-Right (Simulink Model):** A Simulink block diagram representing the UAV's internal dynamics. It includes blocks for 'IMU Simulation', 'Baro Simulation', and 'GNSS/SPS Simulation', which are interconnected to provide sensor data to the 'UAV Dynamics' model.

**Deployed Flight Controller with Scenario Simulation**

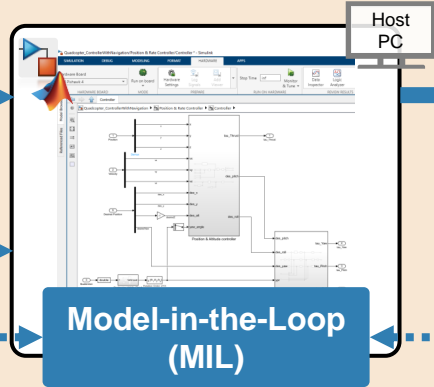
# UAV Simulation Workflow with PX4 and Simulink

## Inputs

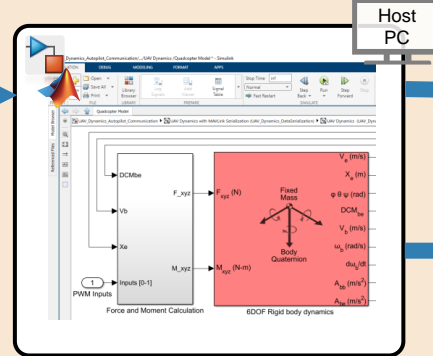


Ground Control Station

## Flight Controller



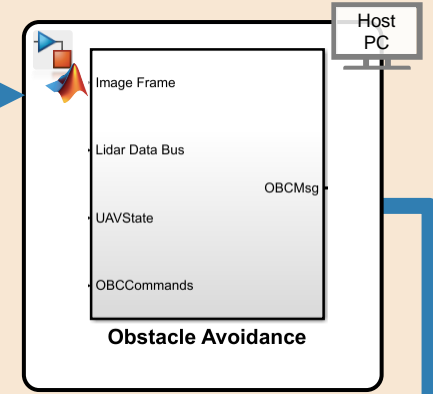
## Plant Model



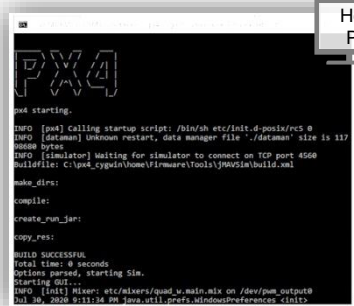
## Scenario Simulation



## Onboard Autonomy



## C++ EXE on Host PC



## Software-in-the-Loop

## Deploy on Hardware



## Hardware-in-the-Loop

## Deploy on Hardware



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# Simulate and Deploy UAV Applications with SIL and HIL Workflows

- Why SIL and HIL?
  - Ensure safety in real flights
  - Test flight behavior in simulation
- Why MATLAB & Simulink?
  - Integrate with external autopilots
  - Generate C/C++ code for onboard computers
  - Scenario simulation with MATLAB and Unreal Engine

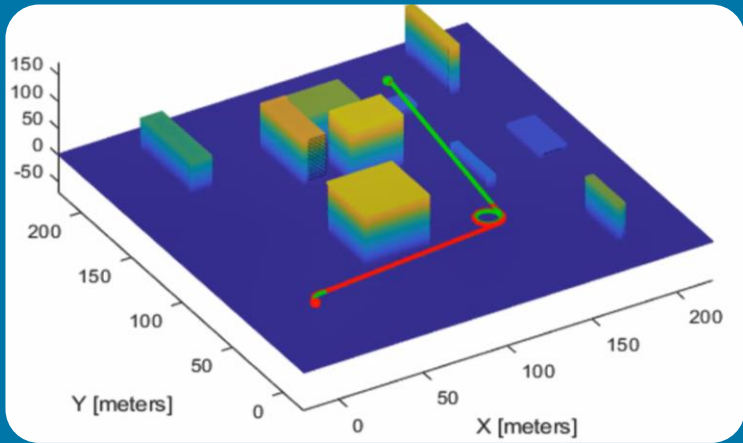


Relevant MATLAB EXPO Workshop

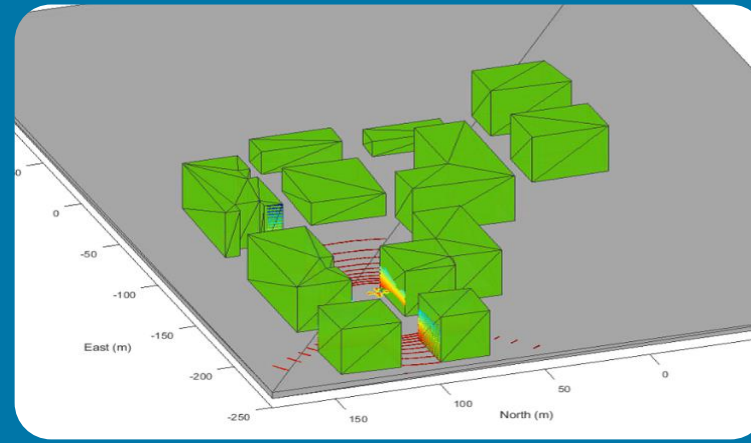


# UAV Toolbox

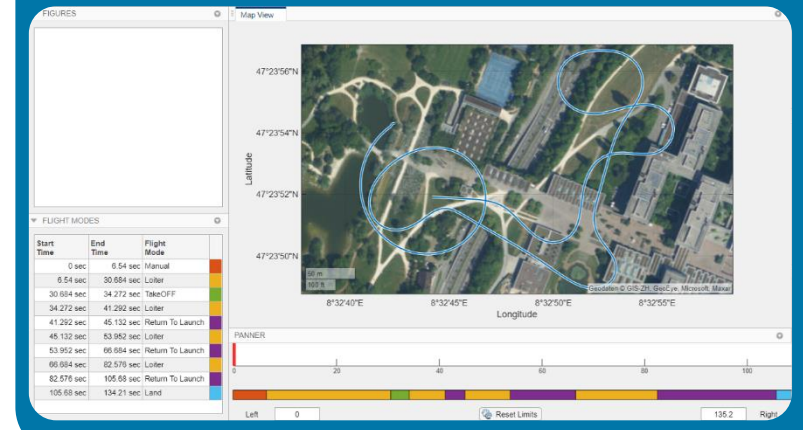
## UAV Algorithms for Planning and Control



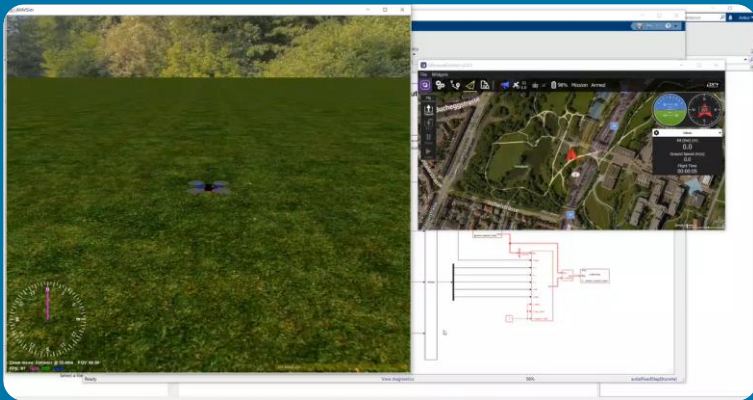
## Scenario Design & Low-Fidelity Sensor Simulation



## Flight Telemetry Data Analysis Flight Log Analyzer App



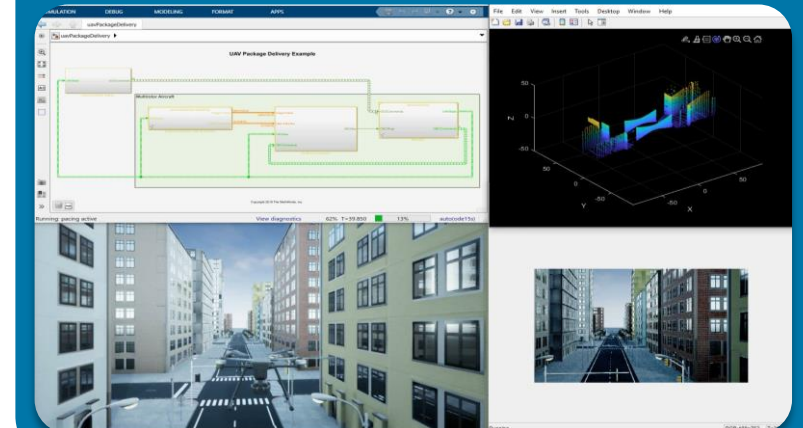
## Connectivity and Deployment with MAVLink and PX4



## Unreal Engine Co-Simulation with Sensor Models



## Reference Applications





# Resources

- Product Page
  - [www.mathworks.com/products/uav.html](http://www.mathworks.com/products/uav.html)
  
- Product Overview Video
  - <https://www.mathworks.com/videos/what-is-uav-toolbox-1600154005892.html>
  
- UAV Toolbox Support Package for PX4 Autopilots
  - [https://www.mathworks.com/help/supportpkg/px4/index.html?s\\_tid=CRUX\\_topnav](https://www.mathworks.com/help/supportpkg/px4/index.html?s_tid=CRUX_topnav)
  
- Documentation
  - [www.mathworks.com/help/uav/](http://www.mathworks.com/help/uav/)
  
- Examples
  - [www.mathworks.com/help/uav/examples.html](http://www.mathworks.com/help/uav/examples.html)



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# MATLAB EXPO

Thank you



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