

MATLAB EXPO

UAV 시스템 검증을 위한 SIL HIL 테스트 환경 개발

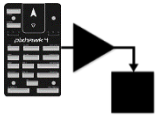
김종헌 부장, 매스웍스코리아



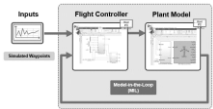
Agenda



Introduction



PX4 with Simulink



MIL, SIL and HIL Workflows



Scenario Simulation



HIL with Scenario Simulation



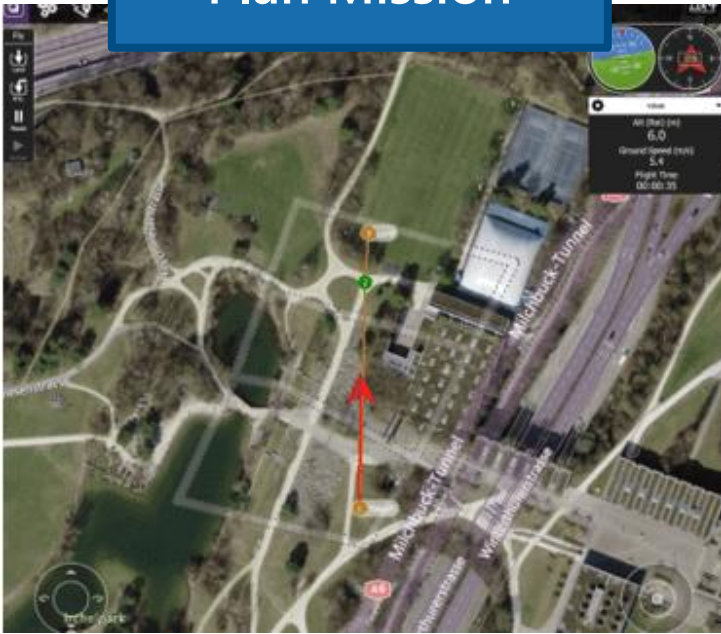
Summary and Resources

Fly a Drone Through a City Block

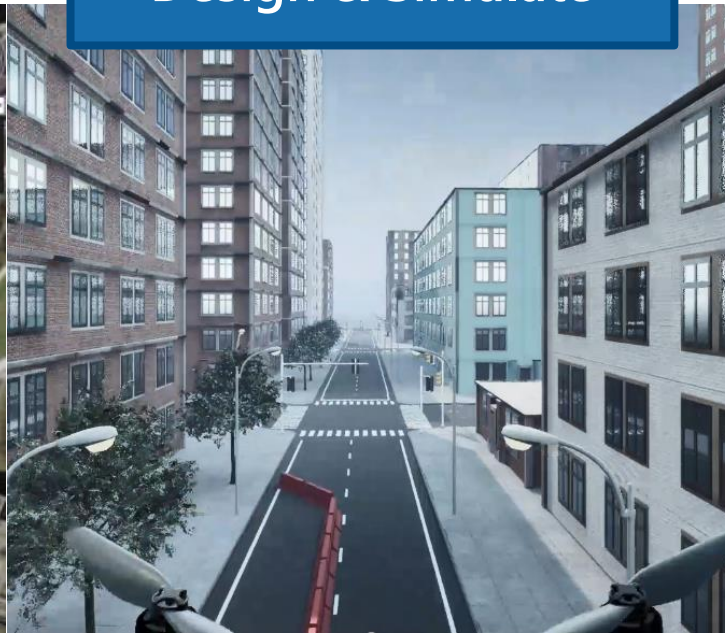


Simulation in a Virtual Scenario

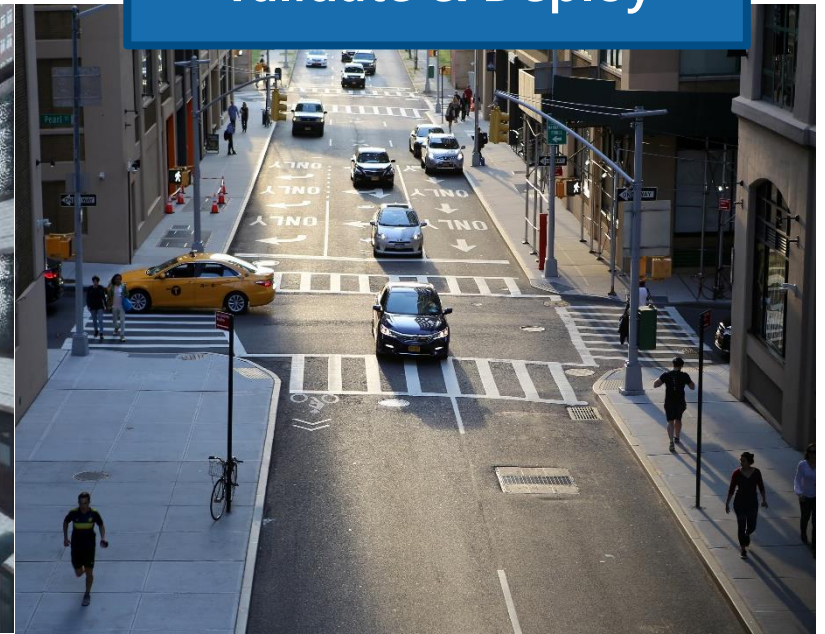
Plan Mission



Design & Simulate



Validate & Deploy

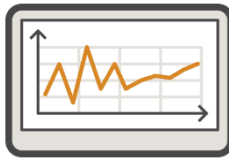


Building Blocks for UAV Simulation

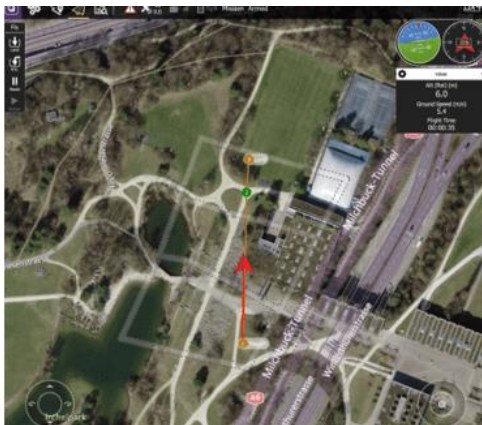
Plan Mission

Generate flight path for the mission

Simulated Waypoints



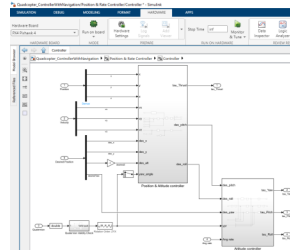
Ground Control Station



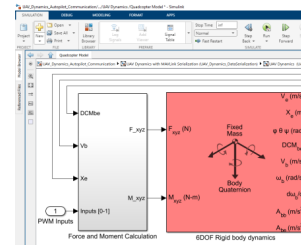
Design & Simulate

Design flight controller and simulate plant behavior in virtual scenarios

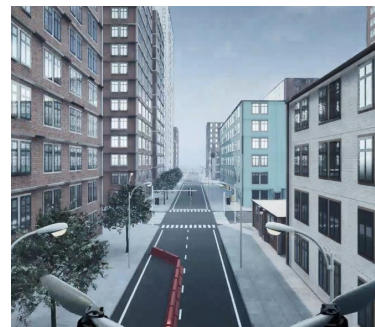
Flight Controller



Plant Model

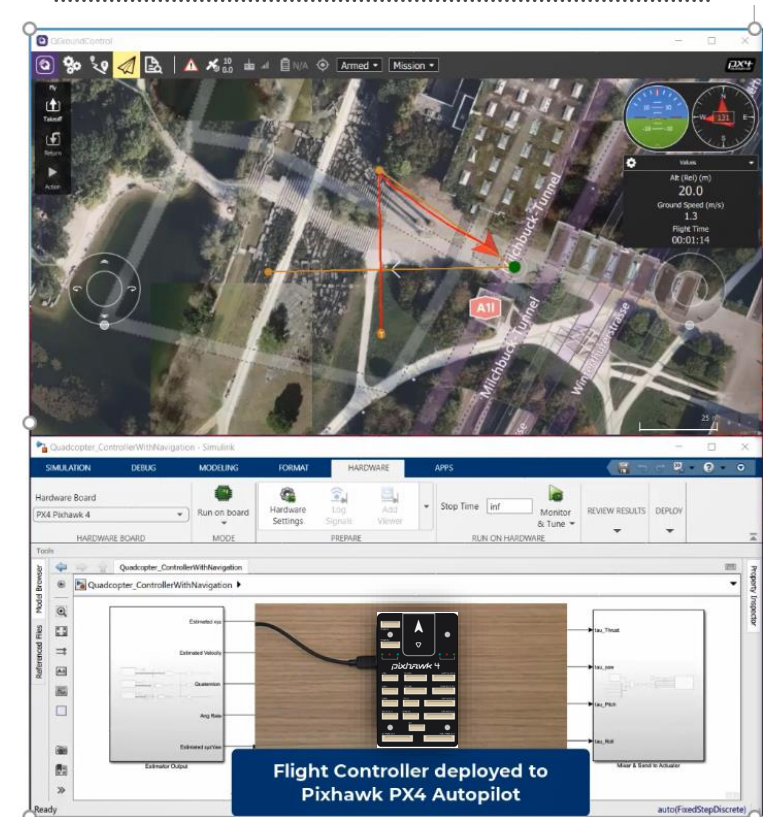


Scenario Simulation



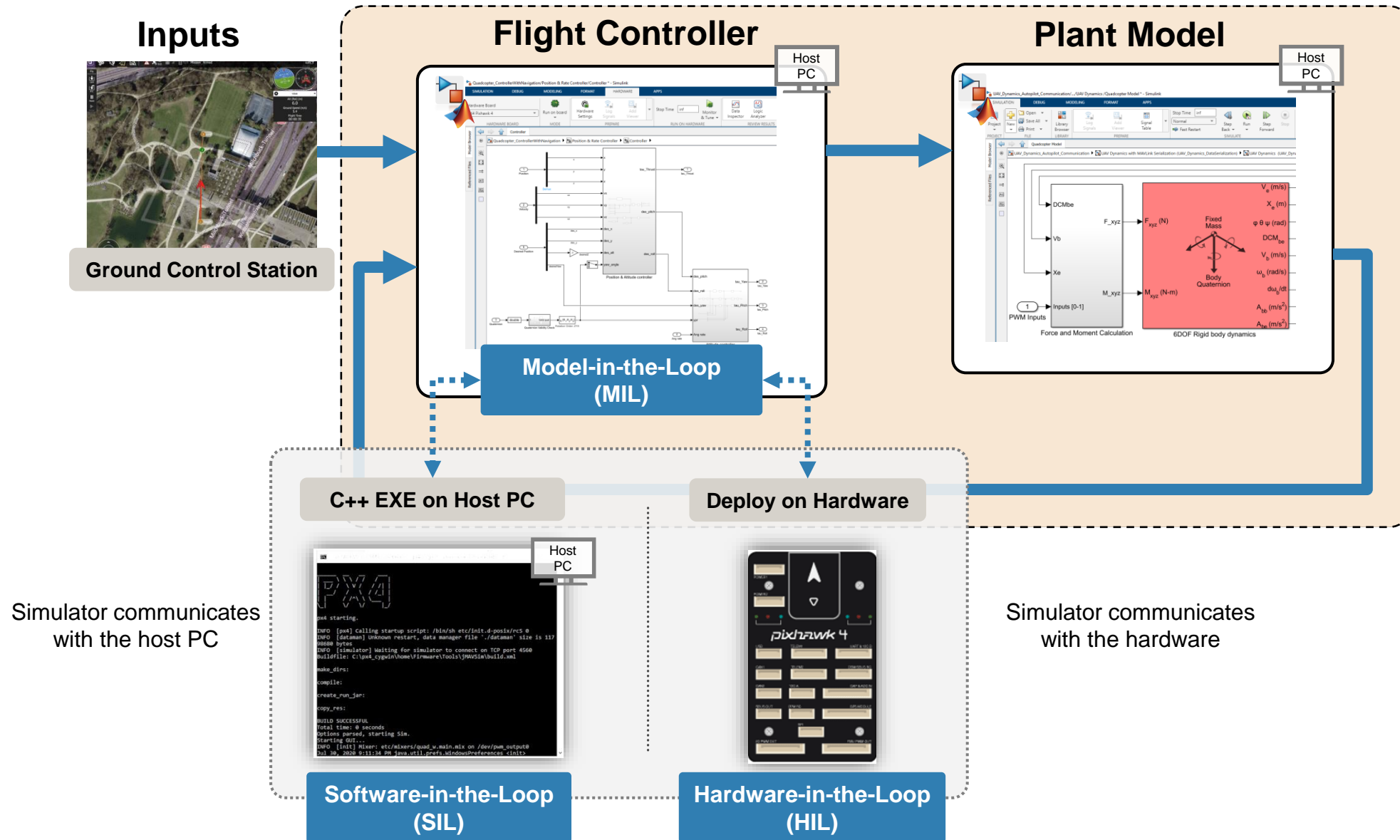
Validate & Deploy

Deploy flight controller and autonomy algorithms to the platform

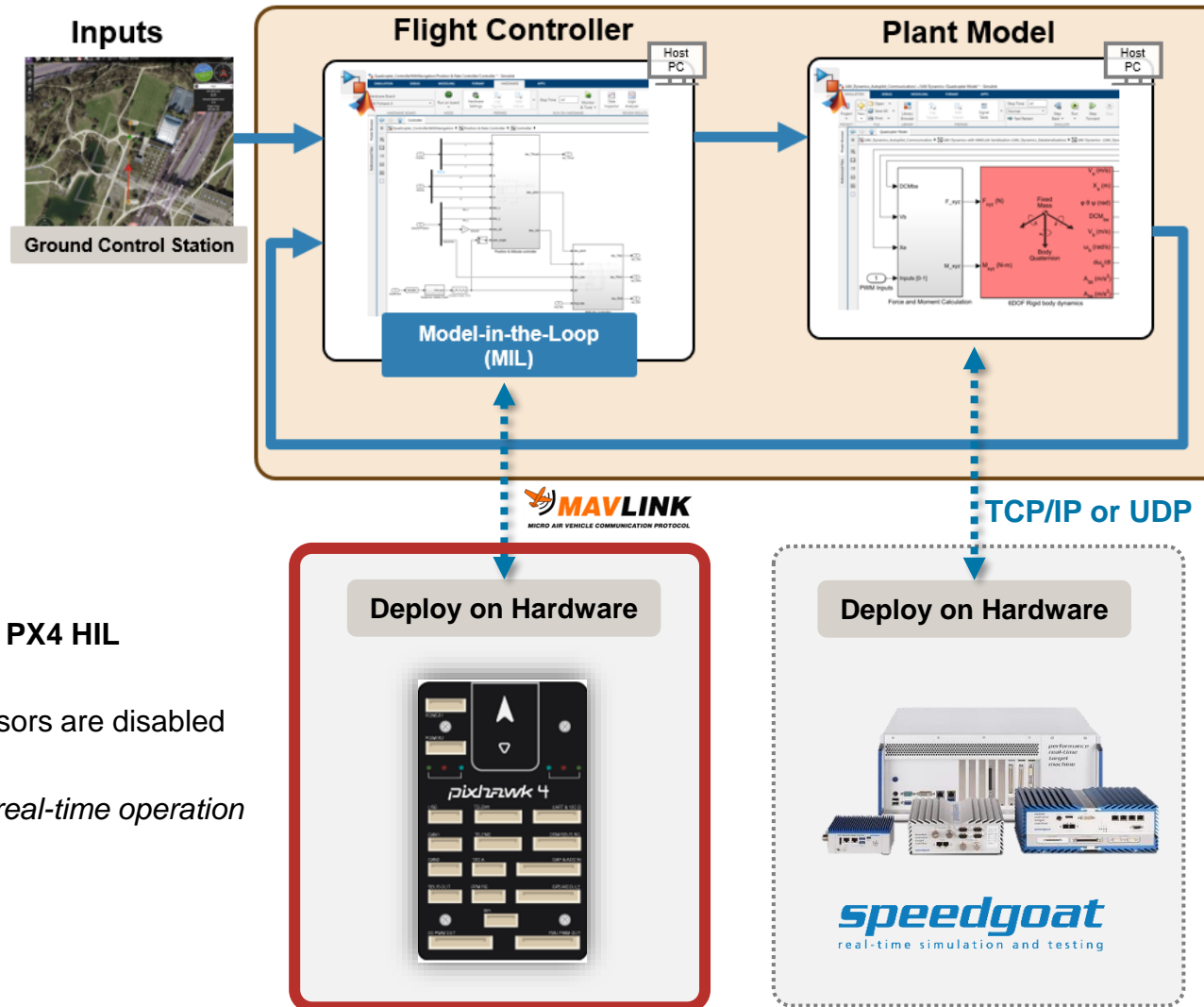


Flight Controller deployed to Pixhawk PX4 Autopilot

MIL, SIL and HIL Workflows for UAV Simulation



HIL with Flight Controller Deployed on PX4

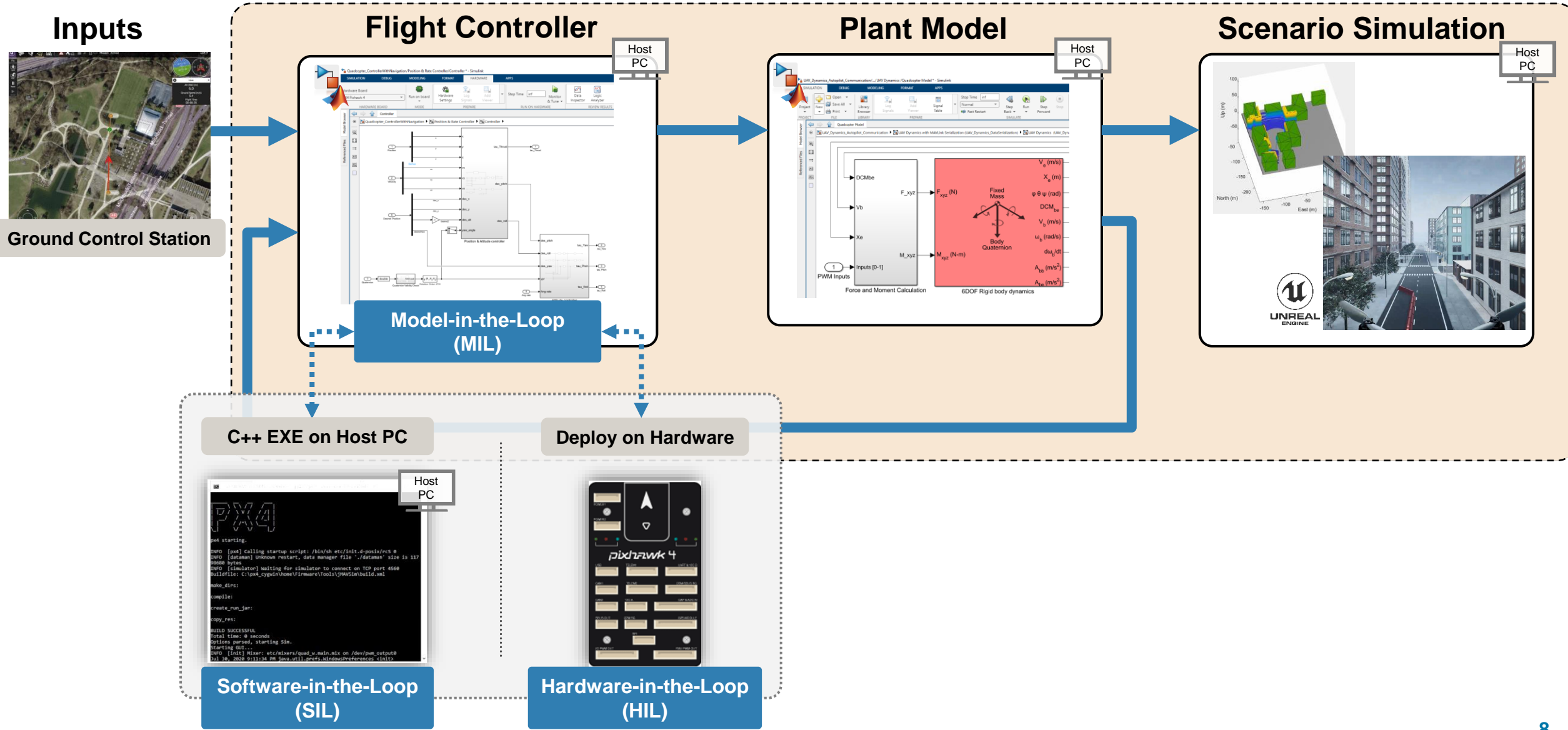


- PX4 HIL**
- PX4 sensors are disabled
 - *Pseudo real-time operation*

Focus of this talk

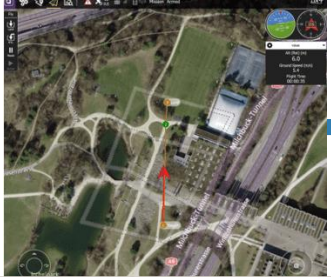
- Full HIL Workflow**
- Communicates with actuators, sensors and the drone peripherals
 - *Real-time operation*

Visualize Flight Behavior in a Virtual Scenario



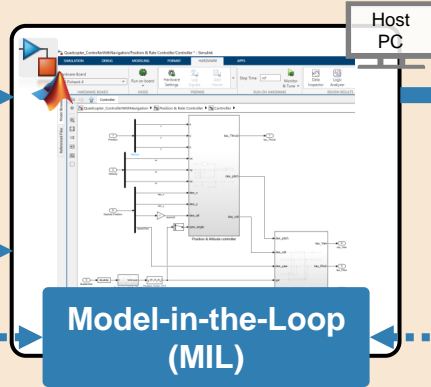
Design Autonomy Algorithms with UAV Simulation Workflow

Inputs

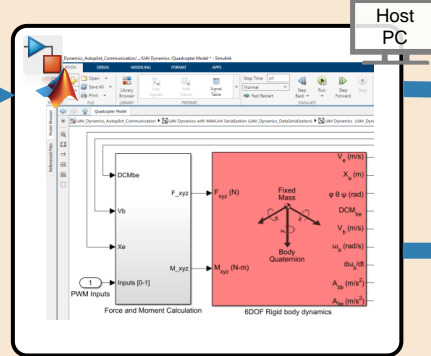


Ground Control Station

Flight Controller



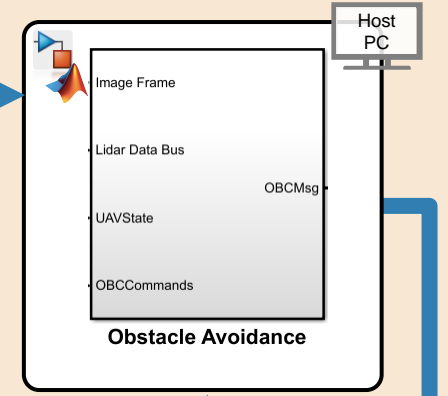
Plant Model



Scenario Simulation



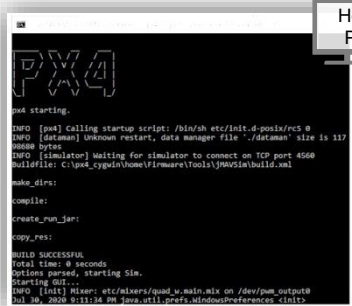
Onboard Autonomy



C++ EXE on Host PC

Deploy on Hardware

Deploy on Hardware



Software-in-the-Loop



Hardware-in-the-Loop



NVIDIA® Jetson™

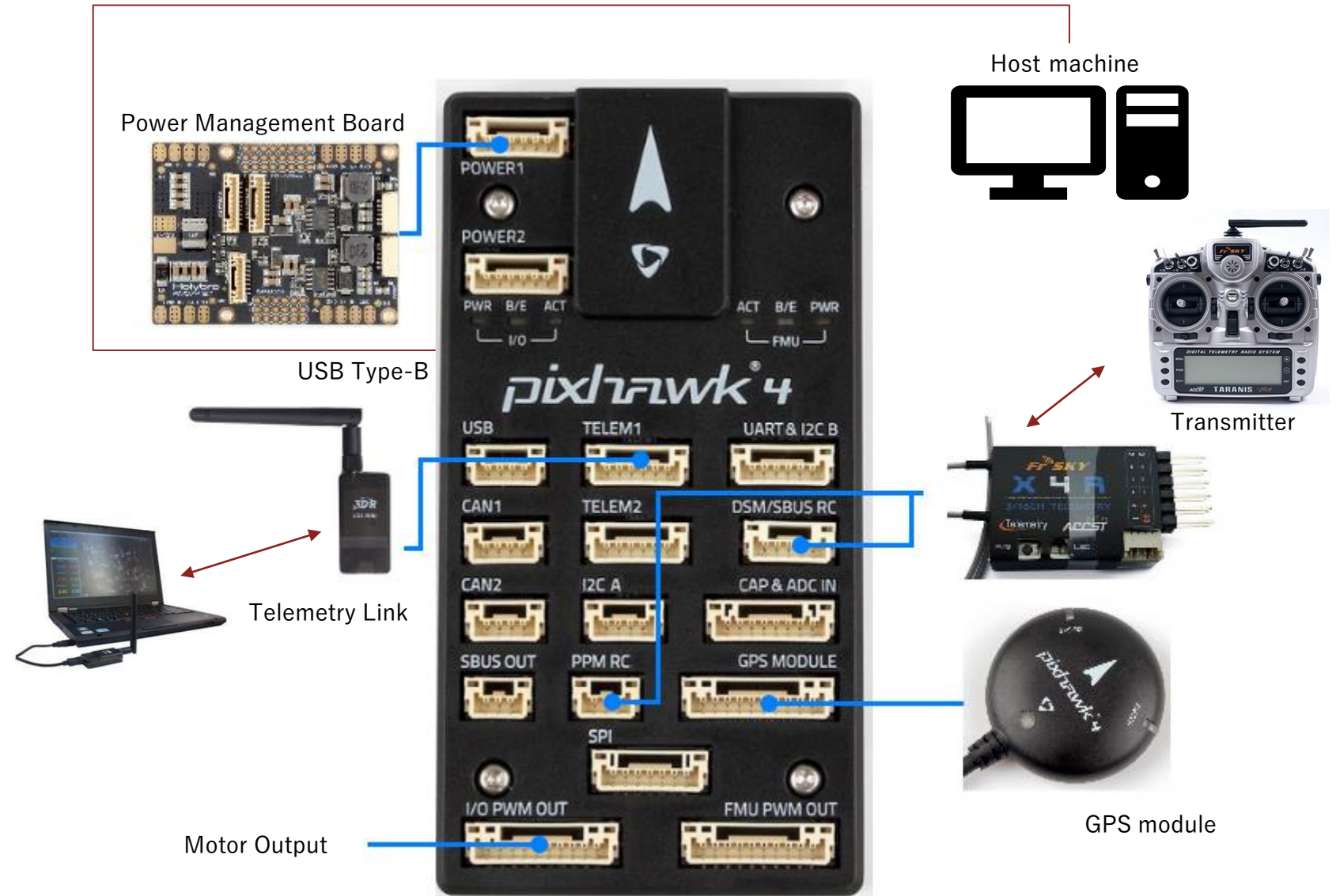
What is Pixhawk[®]

On-board sensors:

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

Interfaces:

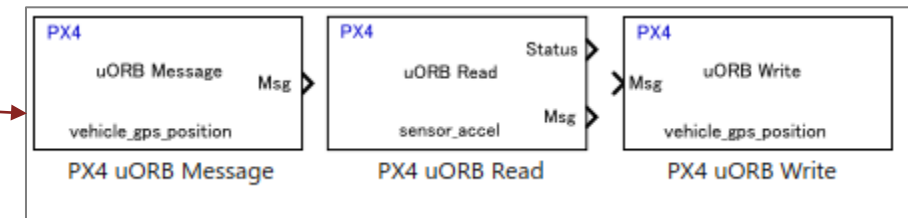
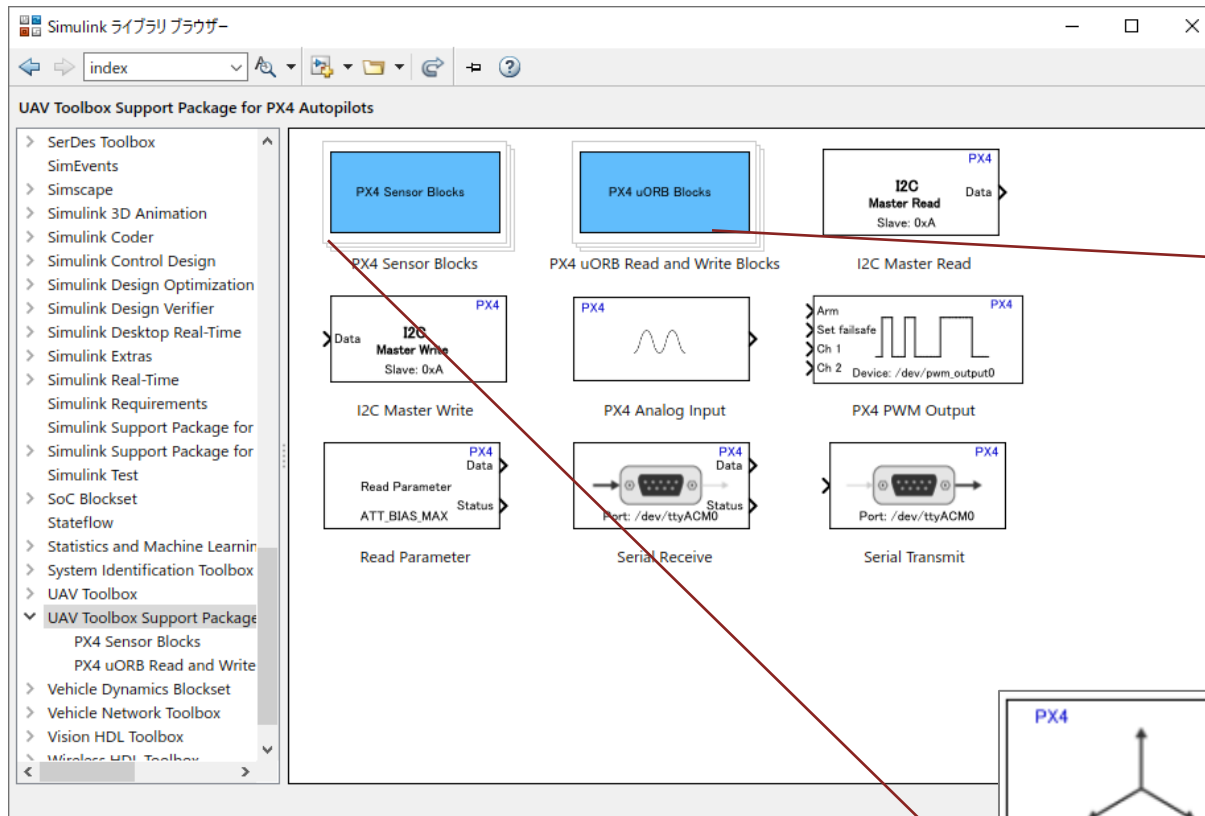
- 8-16 PWM outputs
- 3 dedicated PWM
- Dedicated R/C
- 5 serial ports
- 3 I2C ports
- 4 SPI buses
- 2 CANBuses



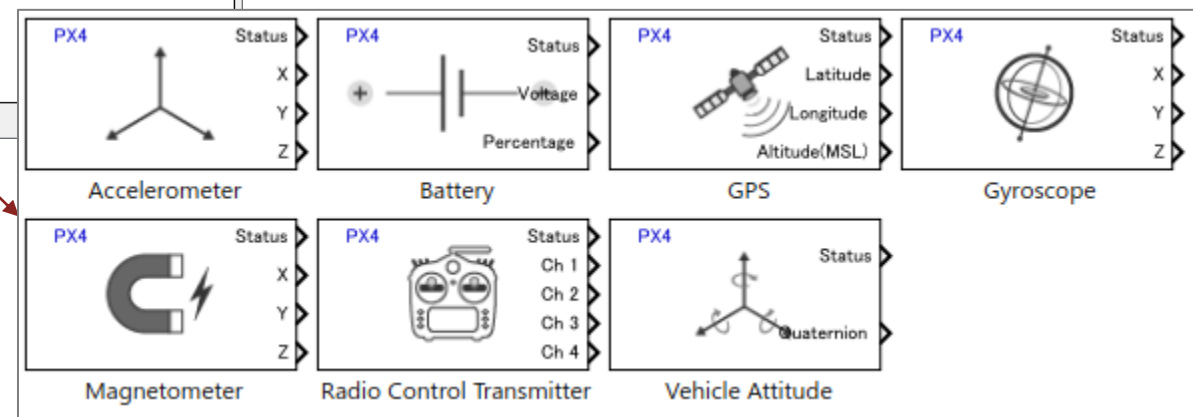
https://docs.px4.io/en/assembly/quick_start_pixhawk4.html

UAV Toolbox Support Package for PX4 Autopilots

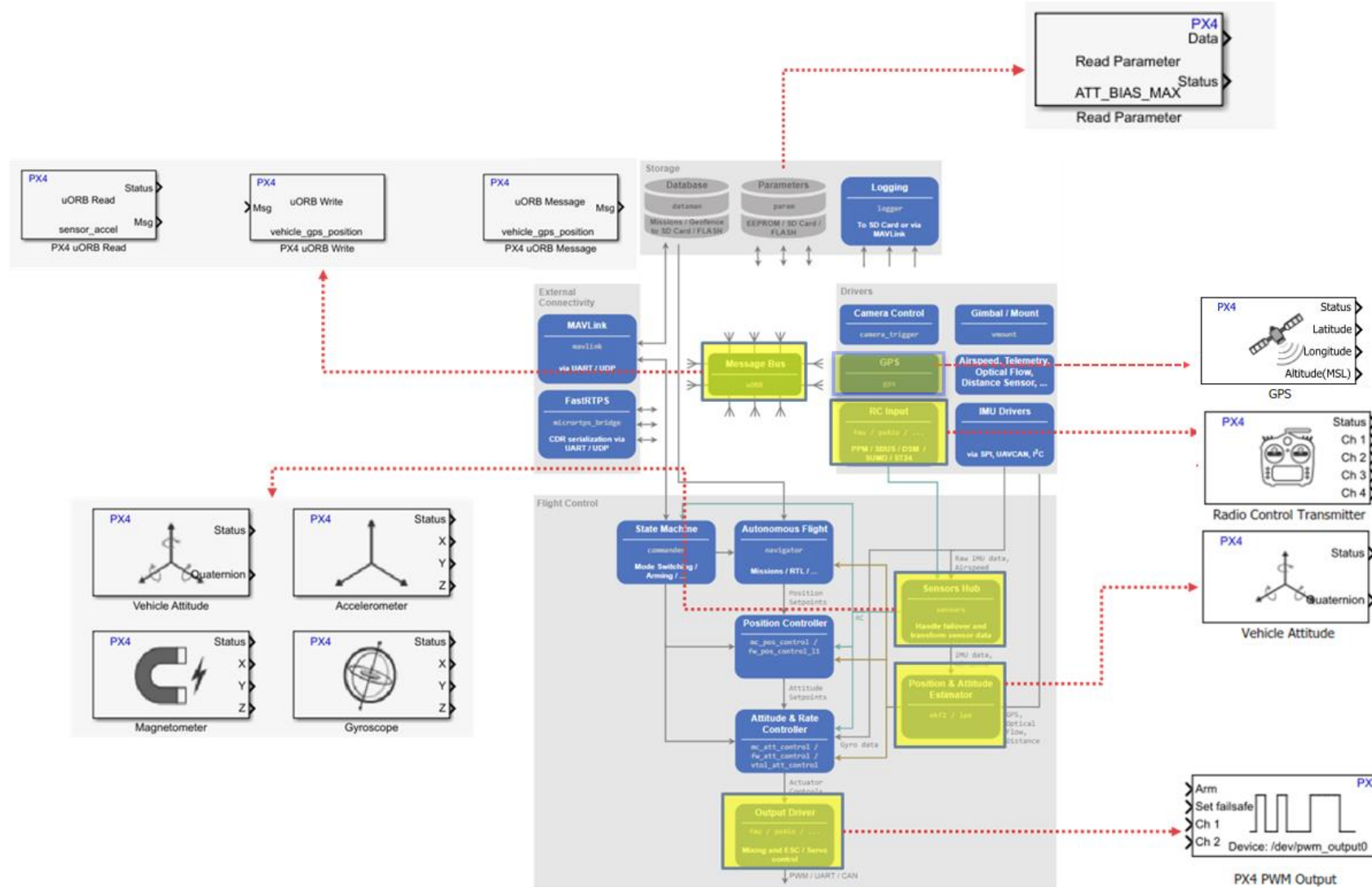
Simulink Block Library



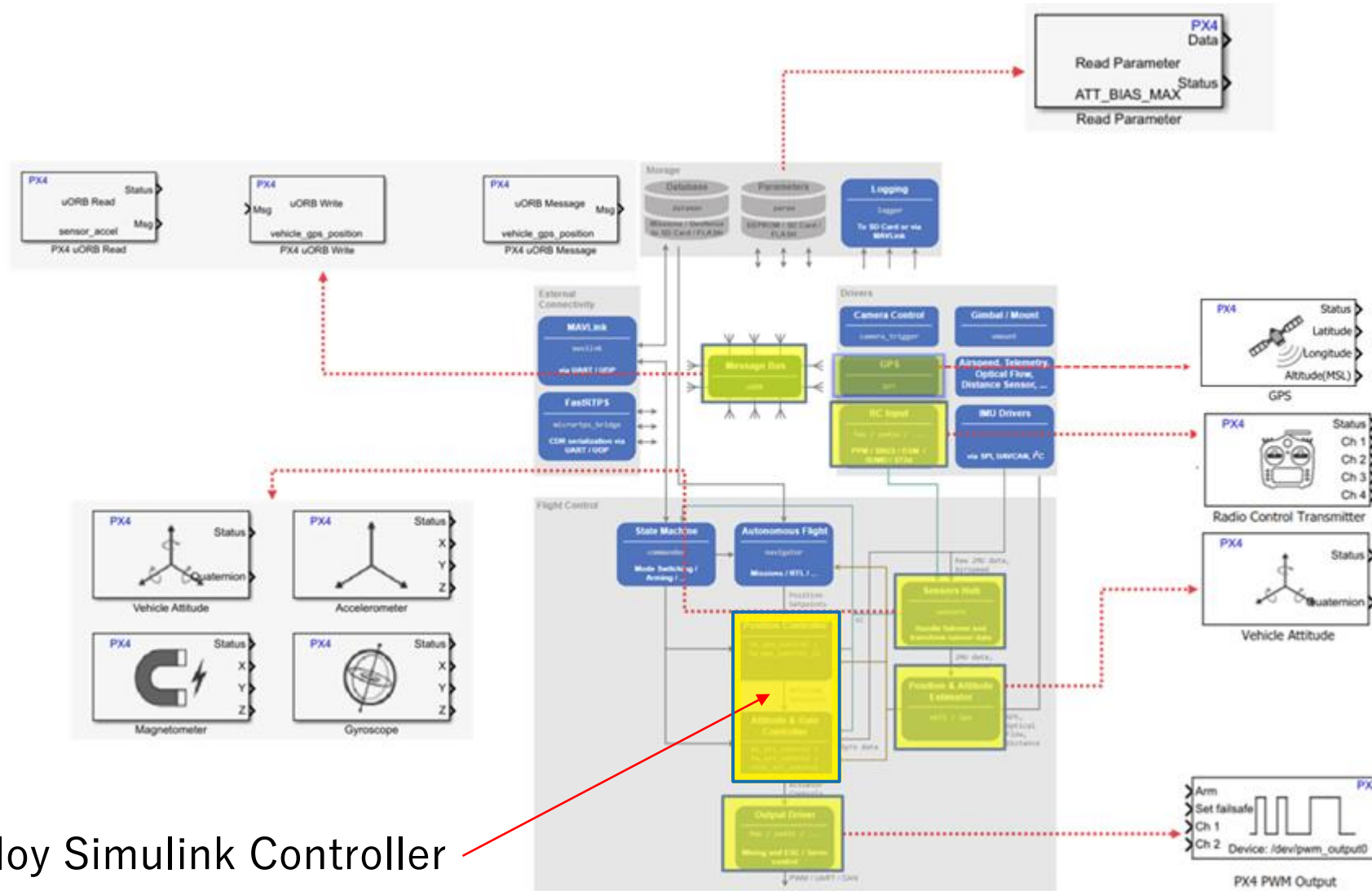
uORB: Asynchronous pub/sub messaging API (middleware)



PX4 Autopilots Support Package Relationship to PX4 Architecture



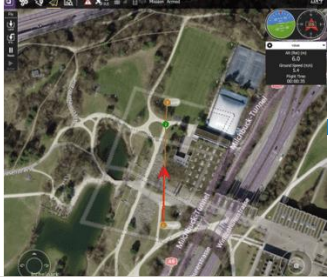
PX4 Autopilots Support Package Relationship to PX4 Architecture



Deploy Simulink Controller

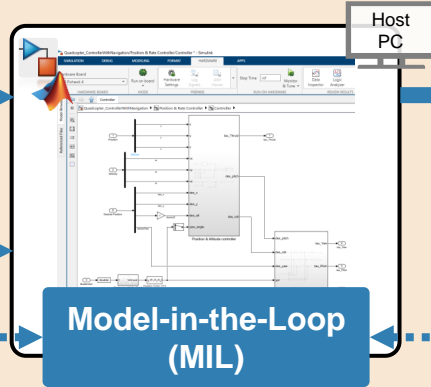
UAV Simulation Workflow with PX4 and Simulink

Inputs

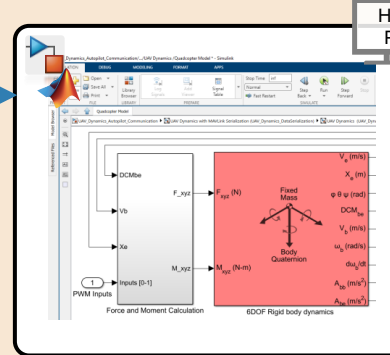


Ground Control Station

Flight Controller



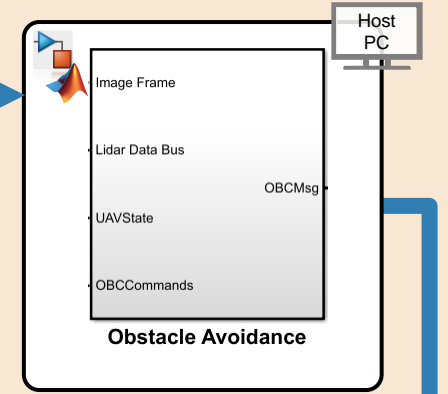
Plant Model



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, 2024 9:11:34 AM java.util.prefs.WindowsPreferences.cinit
    
```

Host PC

Software-in-the-Loop

Deploy on Hardware



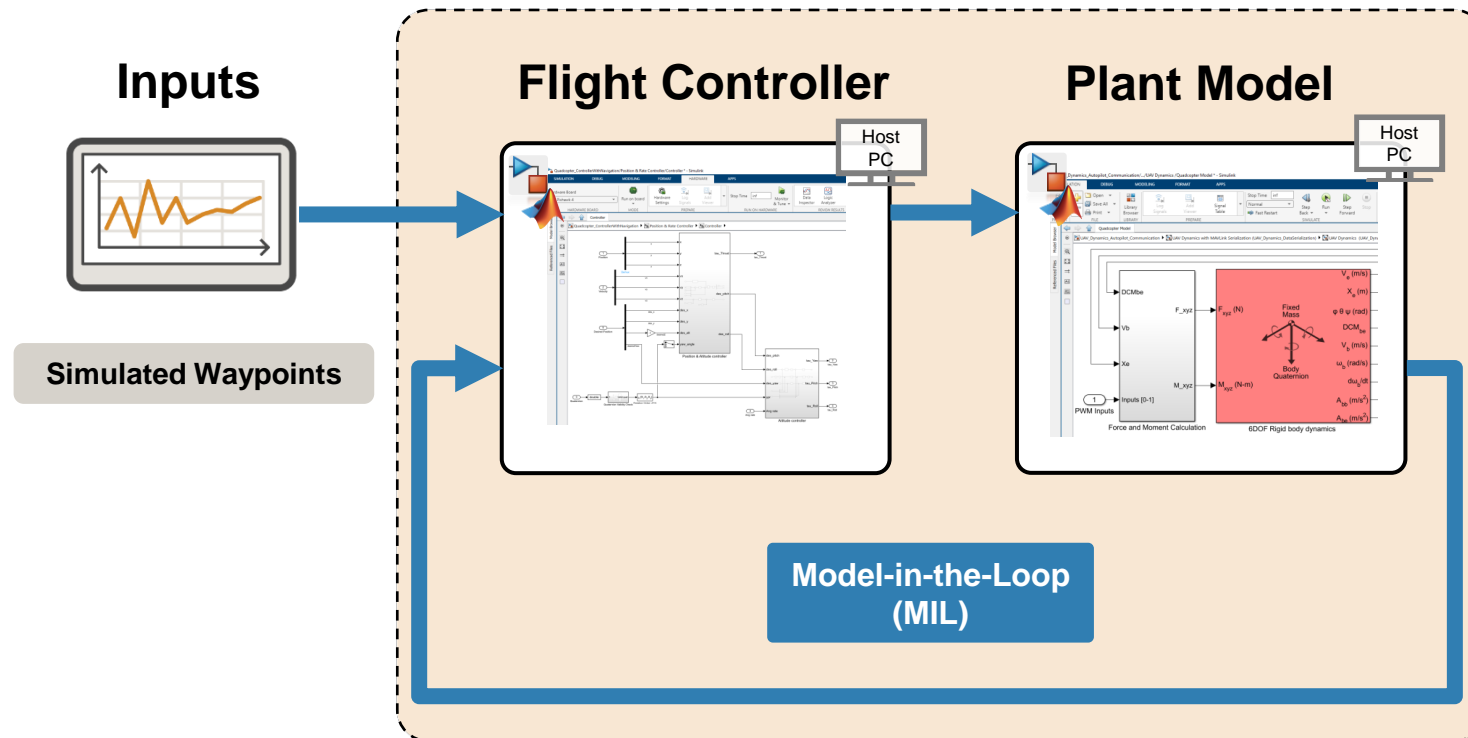
Hardware-in-the-Loop

Deploy on Hardware

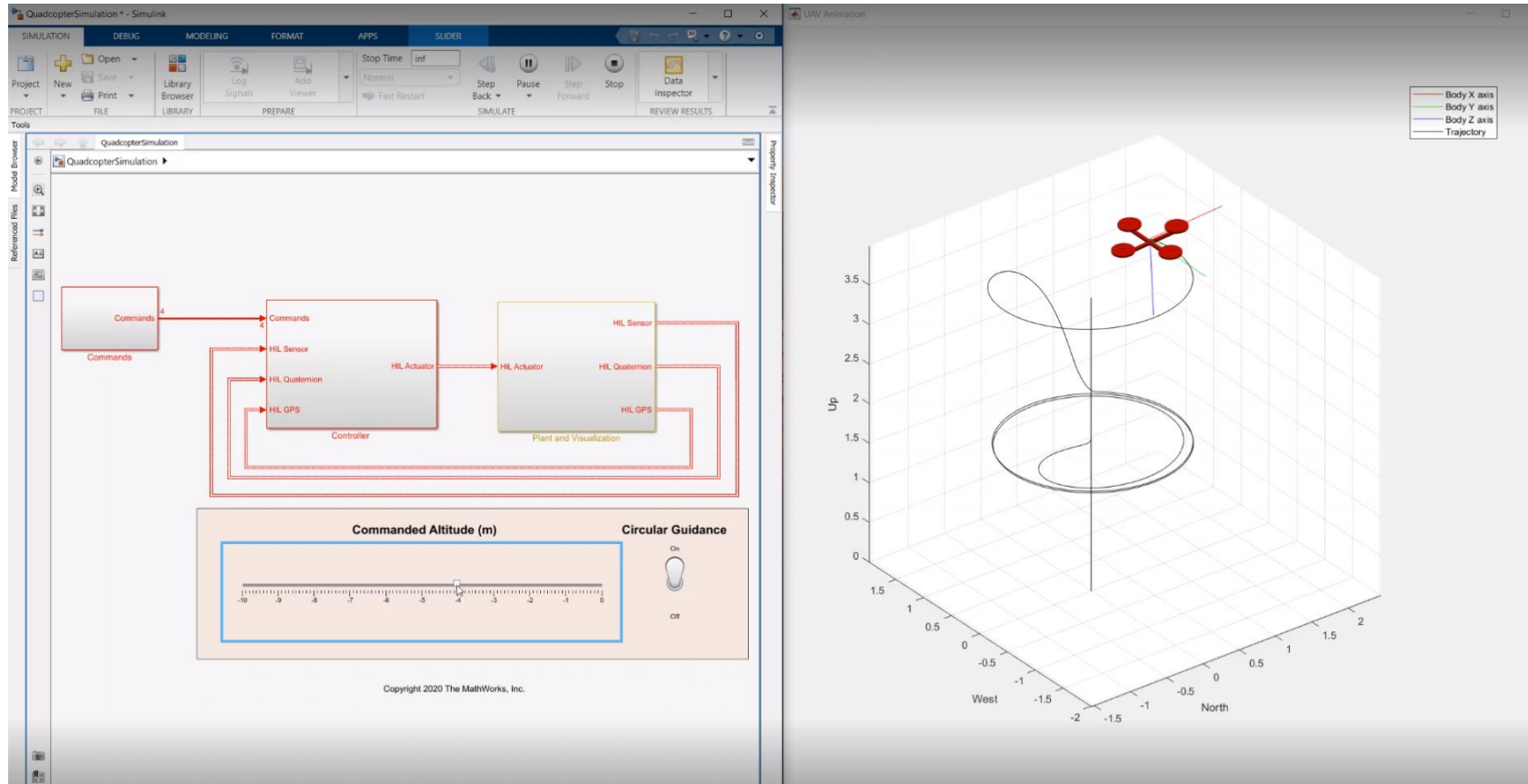


NVIDIA Jetson

Model In the Loop



Quadcopter Simulation in Simulink

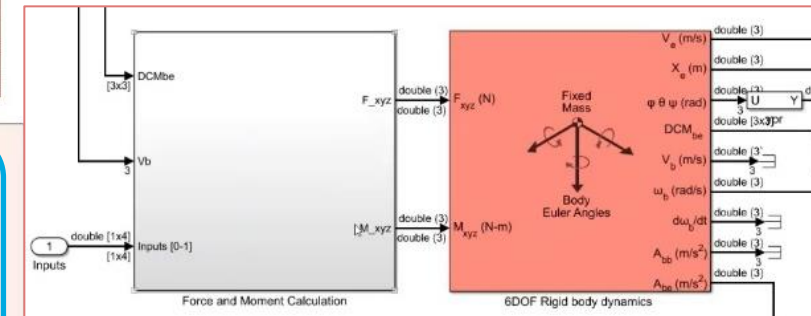
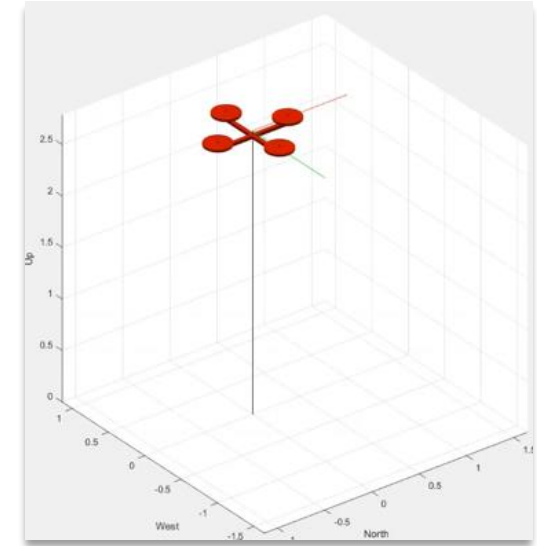
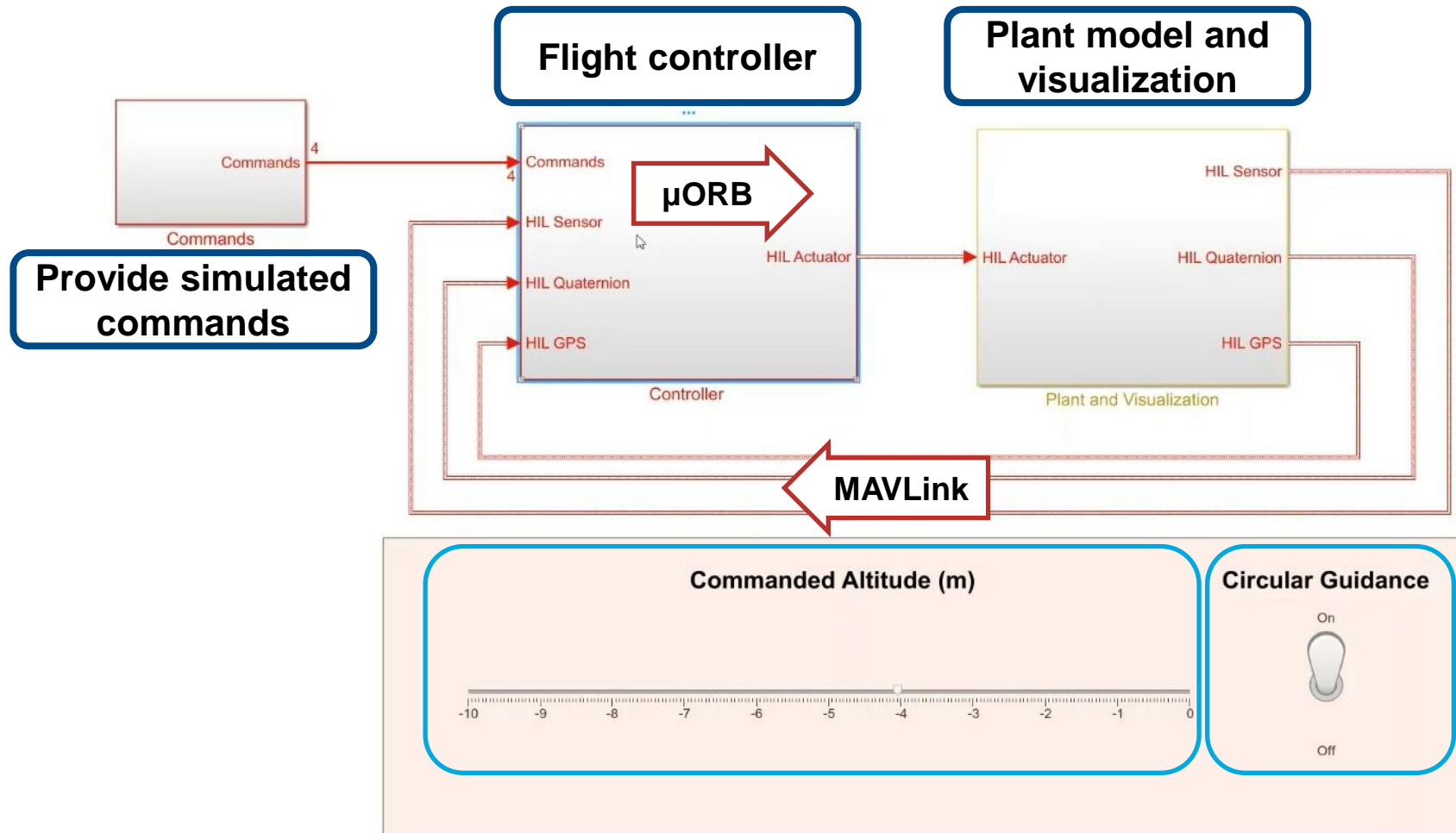


Monitor and Tune PX4 Host Target Flight Controller with Simulink-Based Plant Model

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



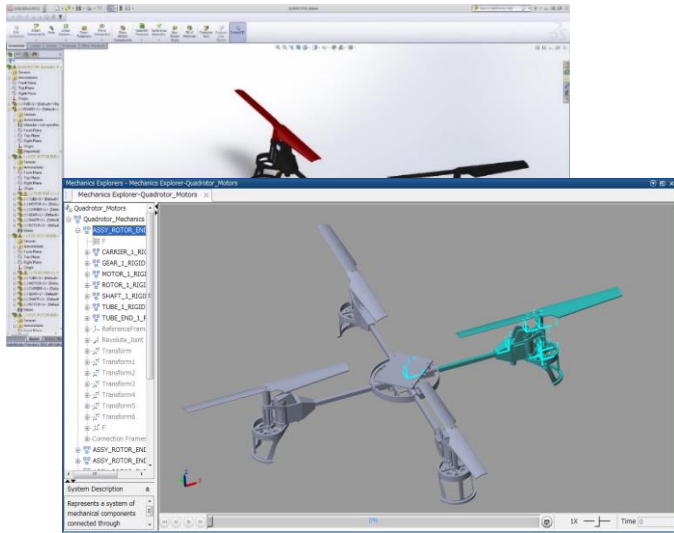
Quadcopter Simulation in Simulink

The image displays two windows from a Simulink simulation environment. The left window, titled "QuadcopterSimulation", shows a block diagram of the control system. It includes a "Commands" input block, a "Controller" block containing "HIL Sensor", "HIL Quaternion", and "HIL GPS" sub-blocks, an "HIL Actuator" block, and a "Plant and Visualization" block containing "HIL Sensor", "HIL Quaternion", and "HIL 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" at 92% completion with a time of T=2.608.

The right window, titled "UAV Animation", shows a 3D visualization of a quadcopter in flight. 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 3D plot has axes labeled "Up", "West", and "North". The "Up" axis ranges from 0 to 2.5, "West" from -1 to 1, and "North" from -1 to 1. The quadcopter is positioned at approximately (0, 0, 2.5) in the coordinate system.

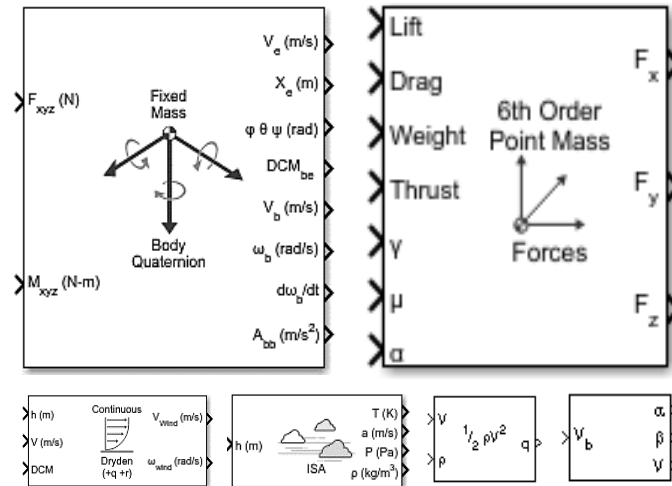
Full Quadcopter Simulation

Simulink Plant Modelling



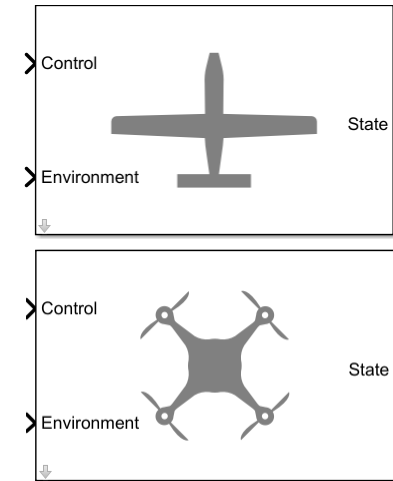
Physical Modeling

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



Vehicle Dynamics

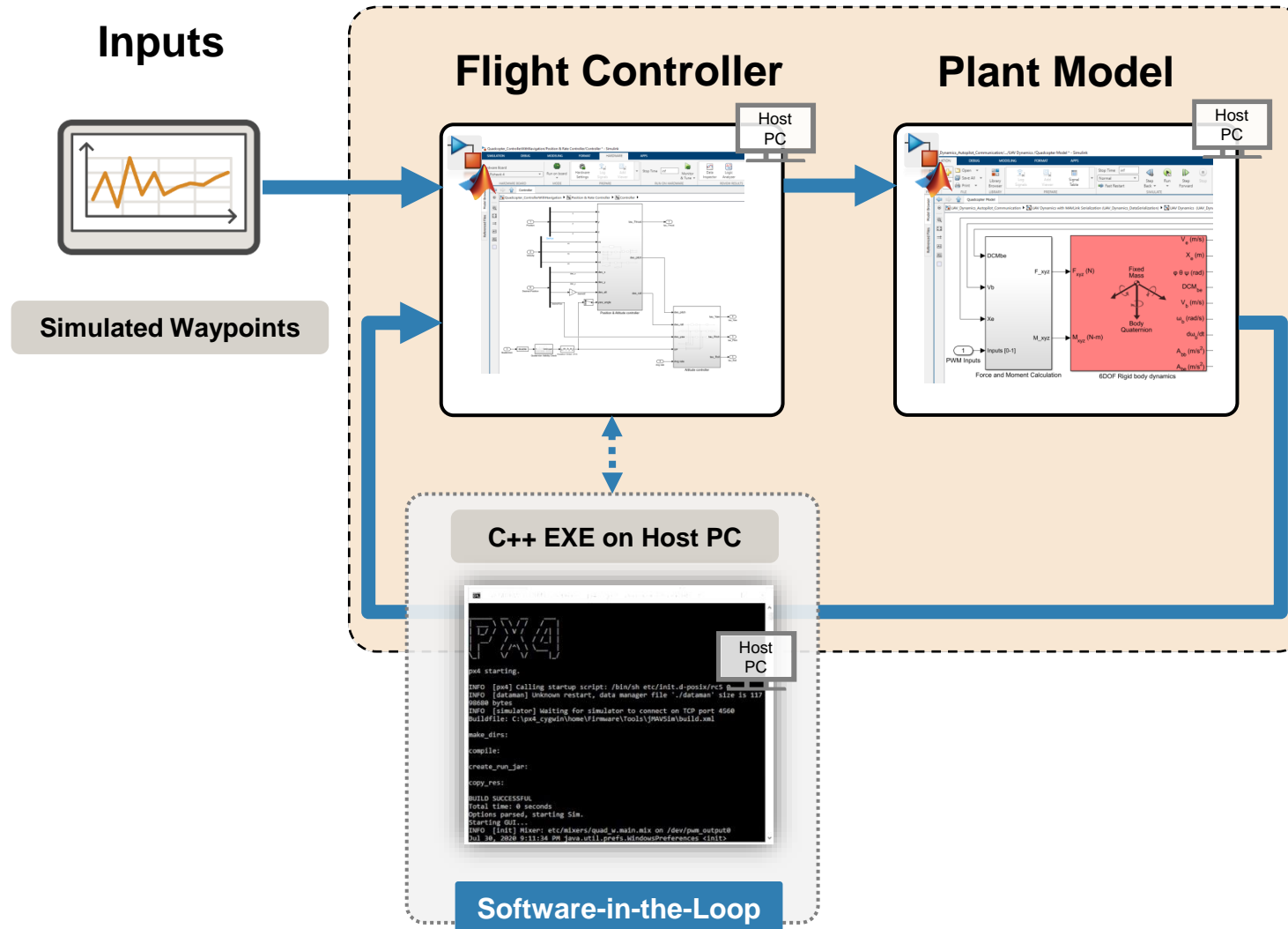
Model aerodynamics, propulsion, and motion of aircraft and spacecraft



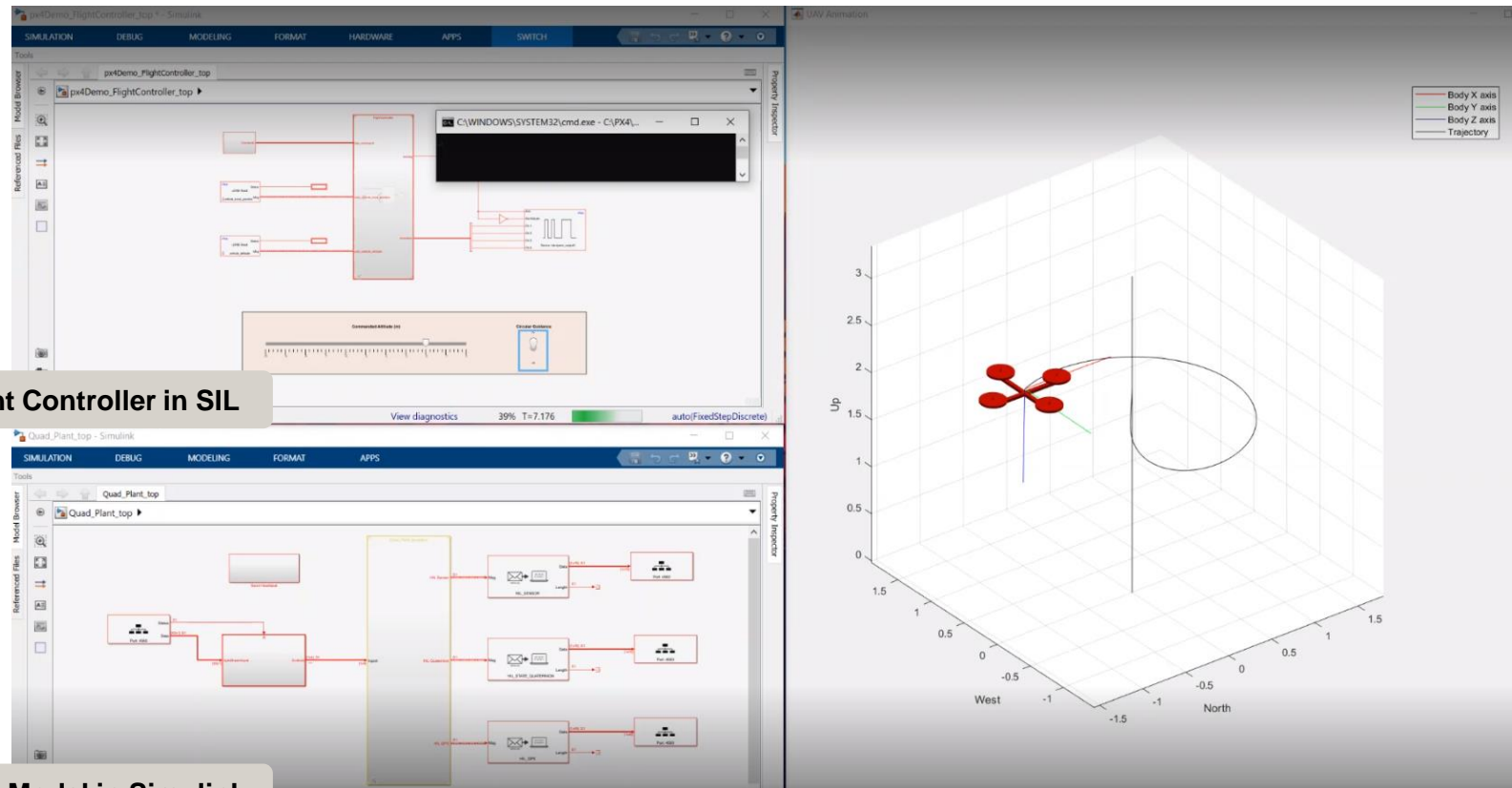
Guidance Model

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 two Simulink model windows and a 3D plot. The top window, titled 'px4Demo_flightController_top', shows a 'Flight Controller' model with a 'µORB Reader' block and a 'px4 PWM output' block highlighted in red. The bottom window, titled 'Quad_Plant_top', shows a 'Drone Plant Model' with a 'udp reader to host target' block and a 'udp writer to host target' block highlighted in red. To the right, a 3D plot shows a quadcopter model with axes labeled 'Up', 'West', and 'North'. A legend indicates 'Body X axis' (red), 'Body Y axis' (green), 'Body Z axis' (blue), and 'Trajectory' (black).

Flight Controller

Drone Plant Model

Flight Controller Software in the loop (SIL)

Video included with expo session content package

SIL with PX4 HSP and Simulink Plant

Video included with expo session content package

SIL with PX4 HSP and Simulink Plant

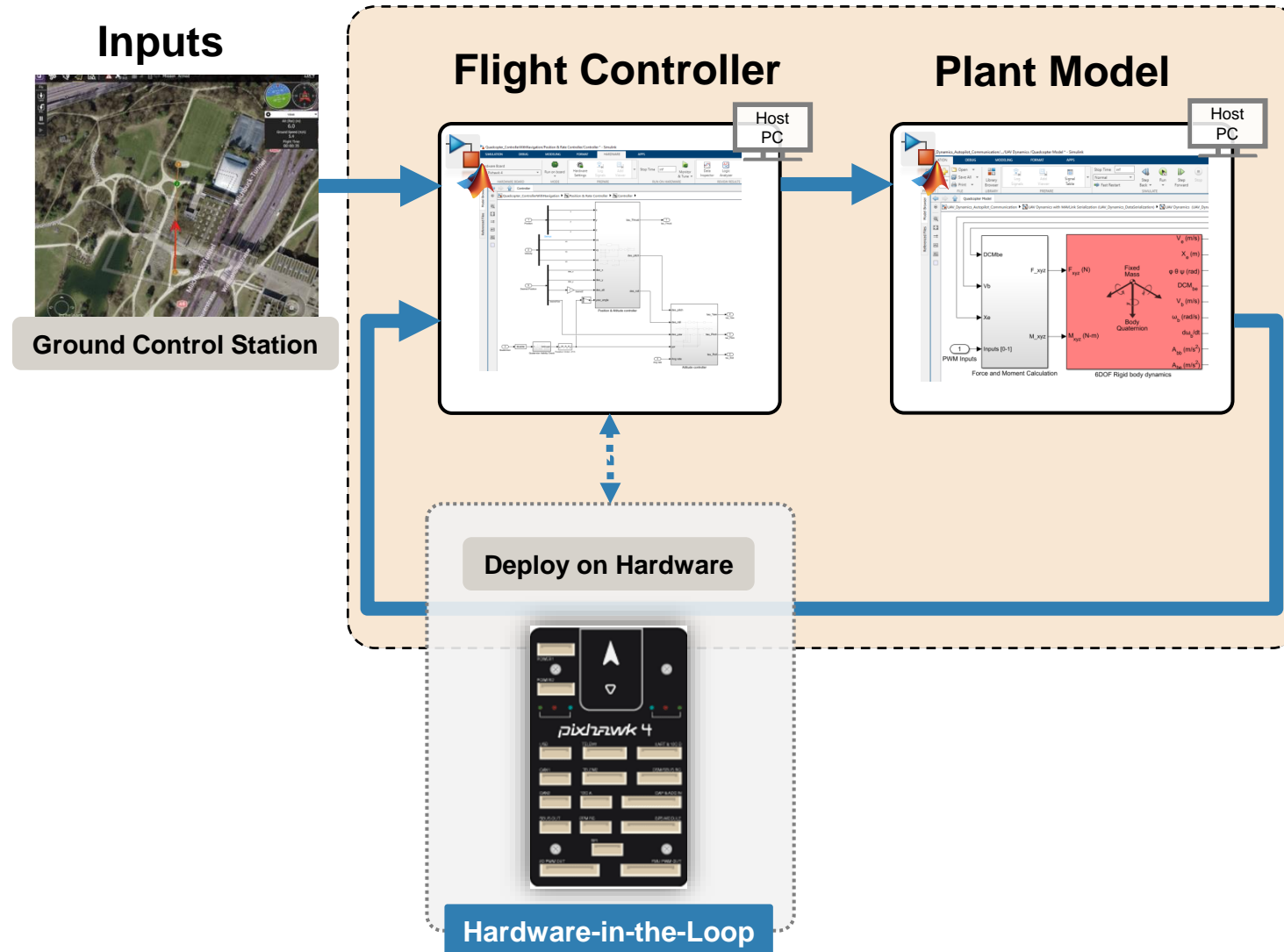
Flight Controller

Drone Plant Model

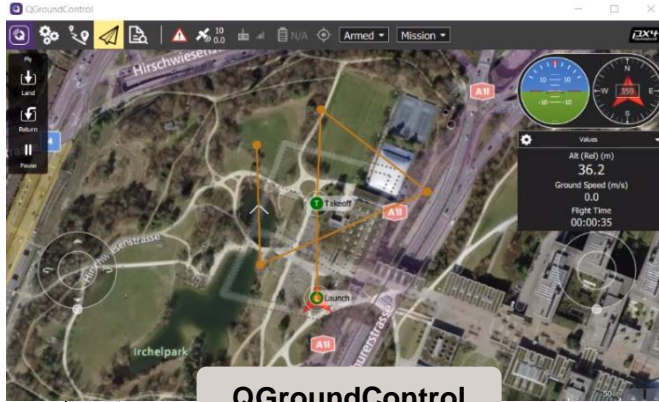
Flight Controller Software in the loop (SIL)

Video included with expo session content package

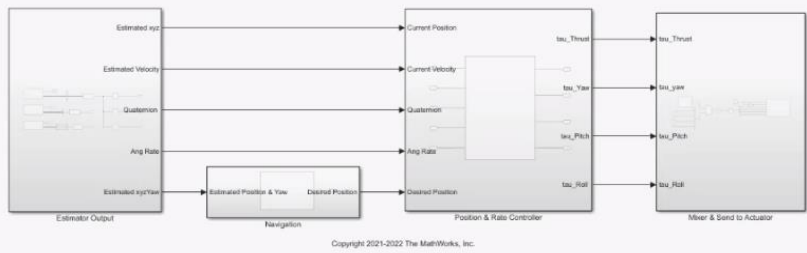
Hardware-in-the-Loop (HIL)



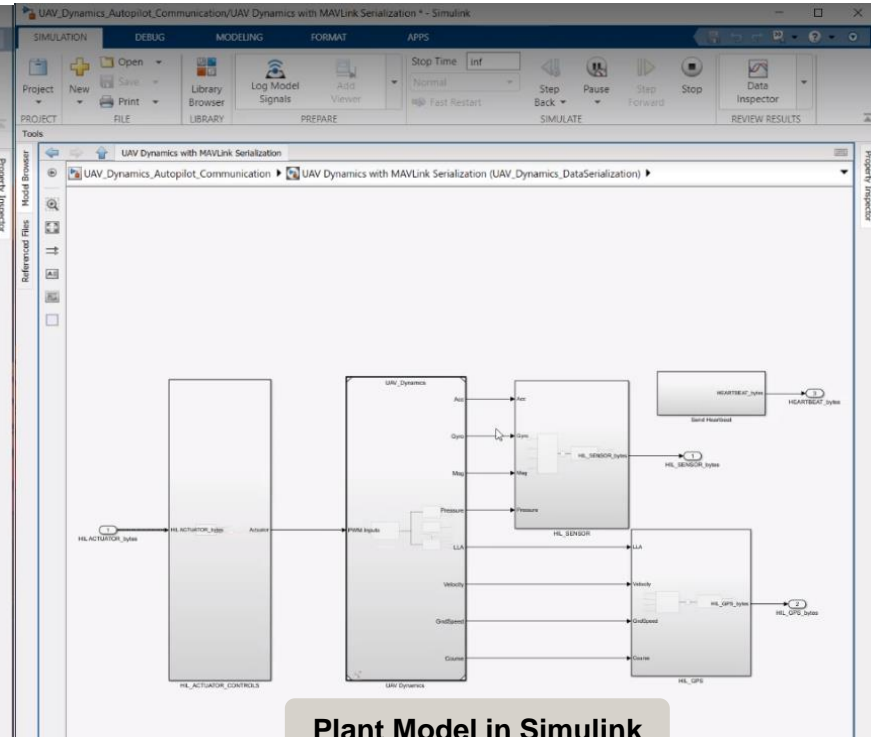
HIL with PX4 HSP and Simulink Plant



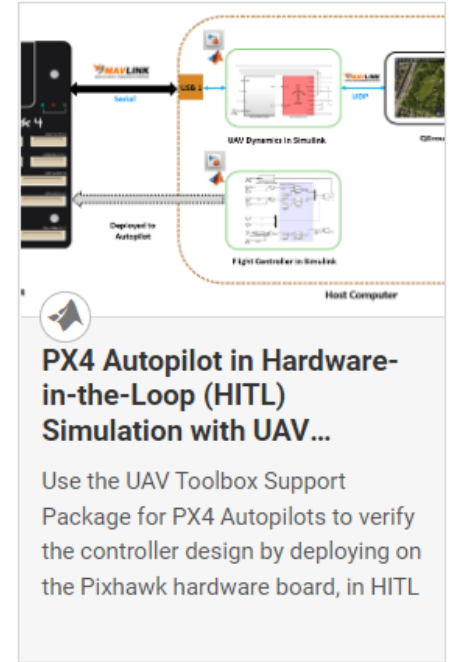
QGroundControl



Deploy on Hardware



Plant Model in Simulink



PX4 Autopilot in Hardware-in-the-Loop (HIL) Simulation with UAV...

Use the UAV Toolbox Support Package for PX4 Autopilots to verify the controller design by deploying on the Pixhawk hardware board, in HIL

[Shipping example in UAV Toolbox](#)

HIL with PX4 HSP and Simulink Plant

QGroundControl for Planning Mission

One or more vehicle components require setup prior to flight.

System ID	Airframe type	Yaw	Throttle	Flight Mode 2	Channel 18
HIL Quadcopter X	Vehicle	1.10.2dev	0.0.0	Flight Mode 3	Manual
	Firmware Version			Flight Mode 4	Position
	Custom Fw. Ver.			Flight Mode 5	Unassigned
				Flight Mode 6	Unassigned

MAULink Bridge Source (COM8) → Data → From_AutoPilot (Signal) → Input Signal Conditioning → UAV Dynamics with MAVLink Serialization (HL_ACTUATOR_bytes, HL_SENSOR_bytes, HL_GPS_bytes, HEARTBEAT_bytes) → Output Signal Conditioning → MAULink Bridge Sink (COM8)



Flight Controller deployed to Pixhawk PX4 Autopilot

Plant Model running in Simulink

Video included with expo session content package

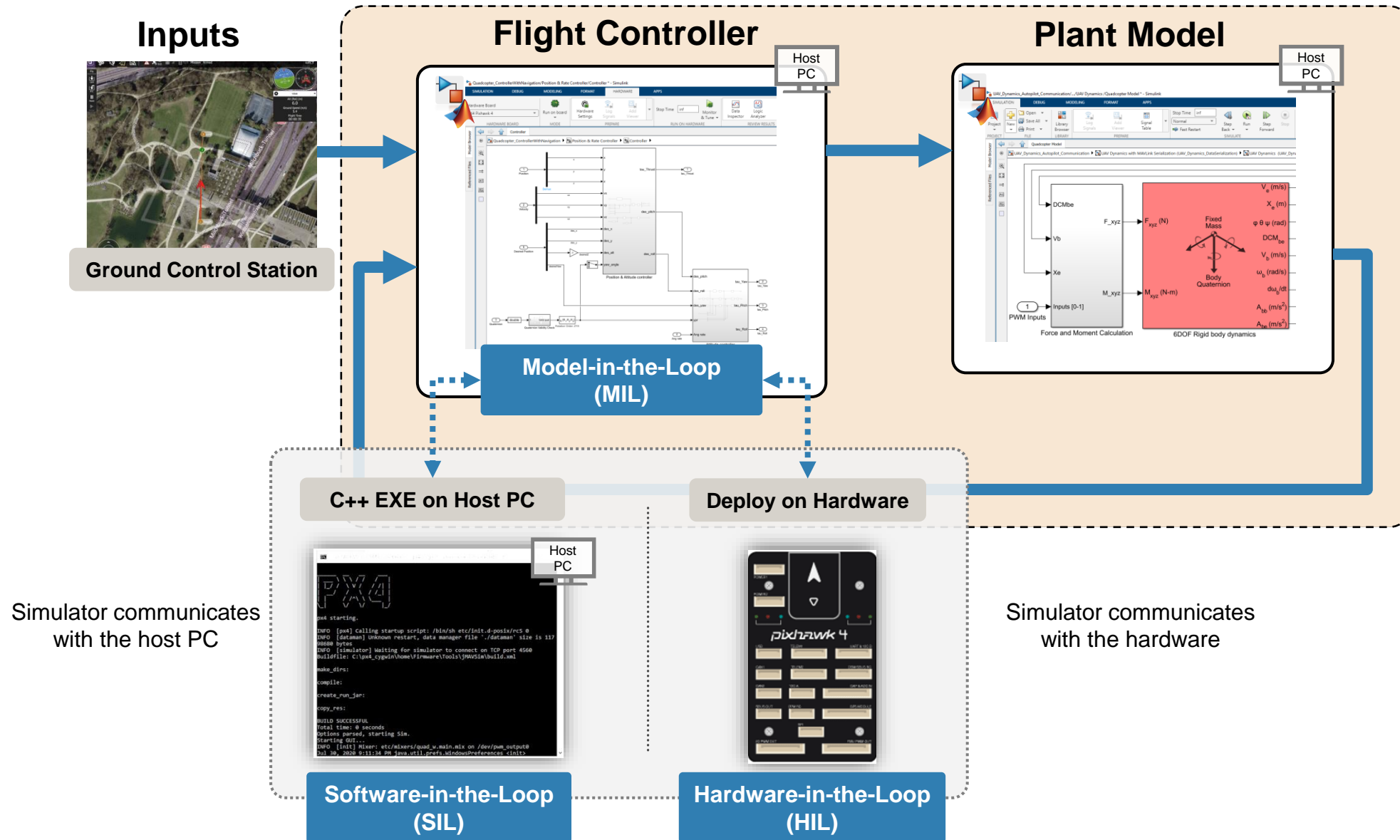
HIL with PX4 HSP and Simulink Plant

The image displays two software windows side-by-side. The left window is QGroundControl, showing a 3D map of a flight area with a 'Launch' point and a 'Mission' menu. The right window is Simulink, showing a block diagram of a plant model. The diagram includes a 'MAULink Bridge Source' block connected to a 'From_AutoPilot' block, which feeds into a 'UAV_Dynamics' block. The 'UAV_Dynamics' block has three outputs: 'HL_ACTUATOR_bytes', 'HL_GPS_bytes', and 'HEARTBEAT_bytes', which are connected to a 'To_AutoPilot' block. The 'To_AutoPilot' block is connected to a 'MAULink Bridge Sink' block. A blue callout box at the bottom of the Simulink window reads 'Plant Model running in Simulink'.

Below the QGroundControl window, there is a Simulink window titled 'Quadcopter_ControllerWithNavigation'. It shows a hardware board set to 'PX4 Pixhawk 4' and a block diagram of the controller. A blue callout box at the bottom of this window reads 'Flight Controller deployed to Pixhawk PX4 Autopilot'.

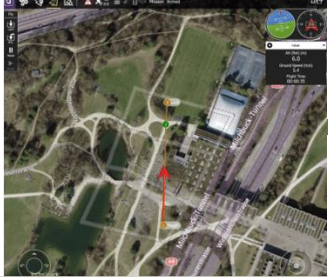
Video included with expo session content package

UAV Simulation Workflow with PX4 and Simulink



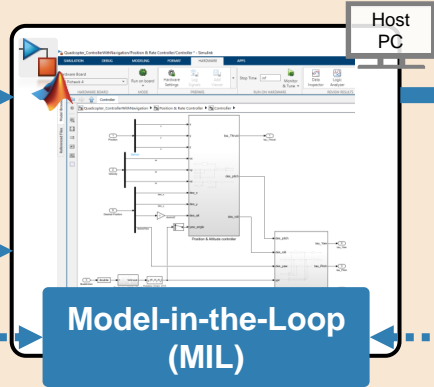
UAV Simulation Workflow with PX4 and Simulink

Inputs

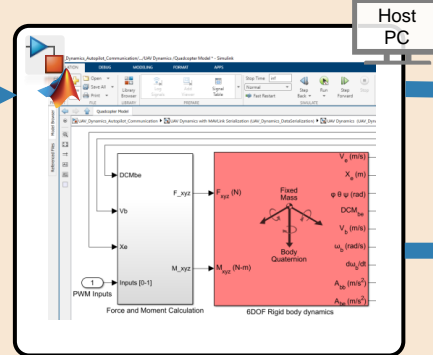


Ground Control Station

Flight Controller



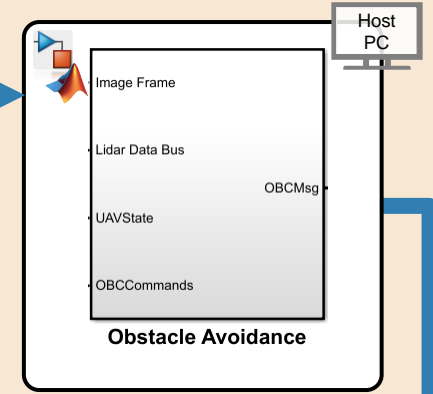
Plant Model



Scenario Simulation



Onboard Autonomy



C++ EXE on Host PC

```

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_jar:
copy_res:
BUILD SUCCESSFUL
Total time: 0 seconds
Waiting for simulator, starting Sim.
Starting QRT...
INFO [Info] Hicore: etc/rtosrc/pxd_qr_main.nix on /dev/pwm_out0@
Jul 19, 2024 9:11:34 AM java.util.prefs.WindowsPreferences.cinit
    
```

Host PC

Software-in-the-Loop

Deploy on Hardware



Hardware-in-the-Loop

Deploy on Hardware

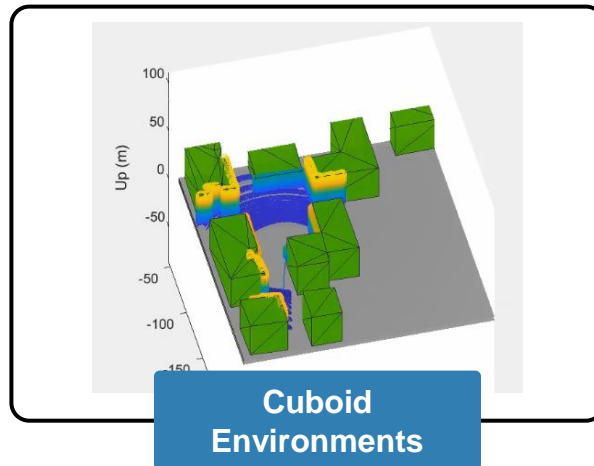


NVIDIA Jetson

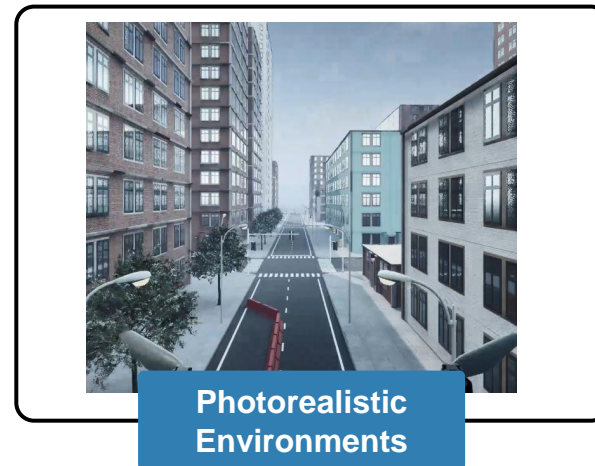
Closed-loop autonomy simulation



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: 50.0164

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

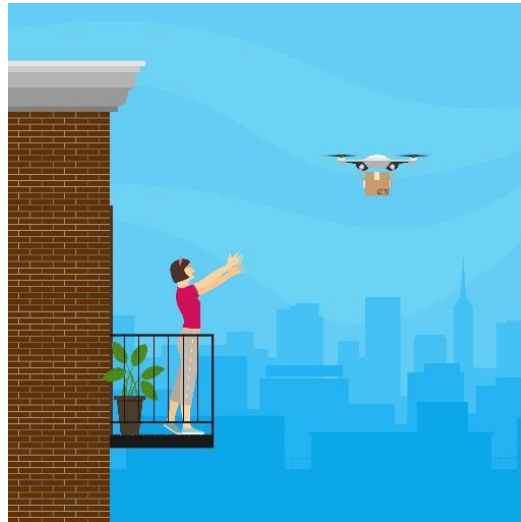
UAVScenarioCanvas
 Y North (m) vs X East (m) plot showing a trajectory over a city map. Altitude (m) vs Time (s) plot showing a constant altitude of 52m.

Trajectory Table

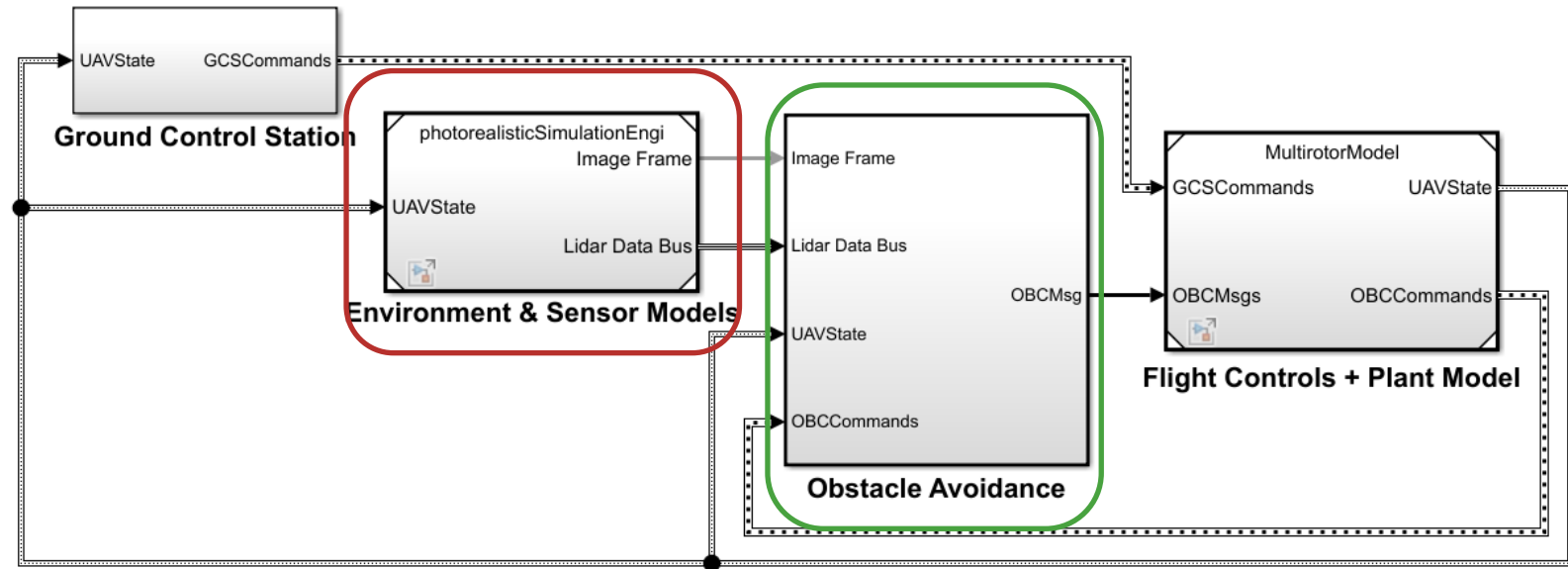
	Time	X	Y	Z	Course	Group
1	0	-583.0000	-133.0000	-52.0500	42.9300	
2	18.4260	-262.0000	16.0000	-52.0500	-11.5900	
3	25.9700	-137.0000	-63.0000	-52.0500	-51.3600	
4	36.5420	-27.0000	-243.0000	-52.0500	-48.5400	

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

Integrate environments into full-system simulation

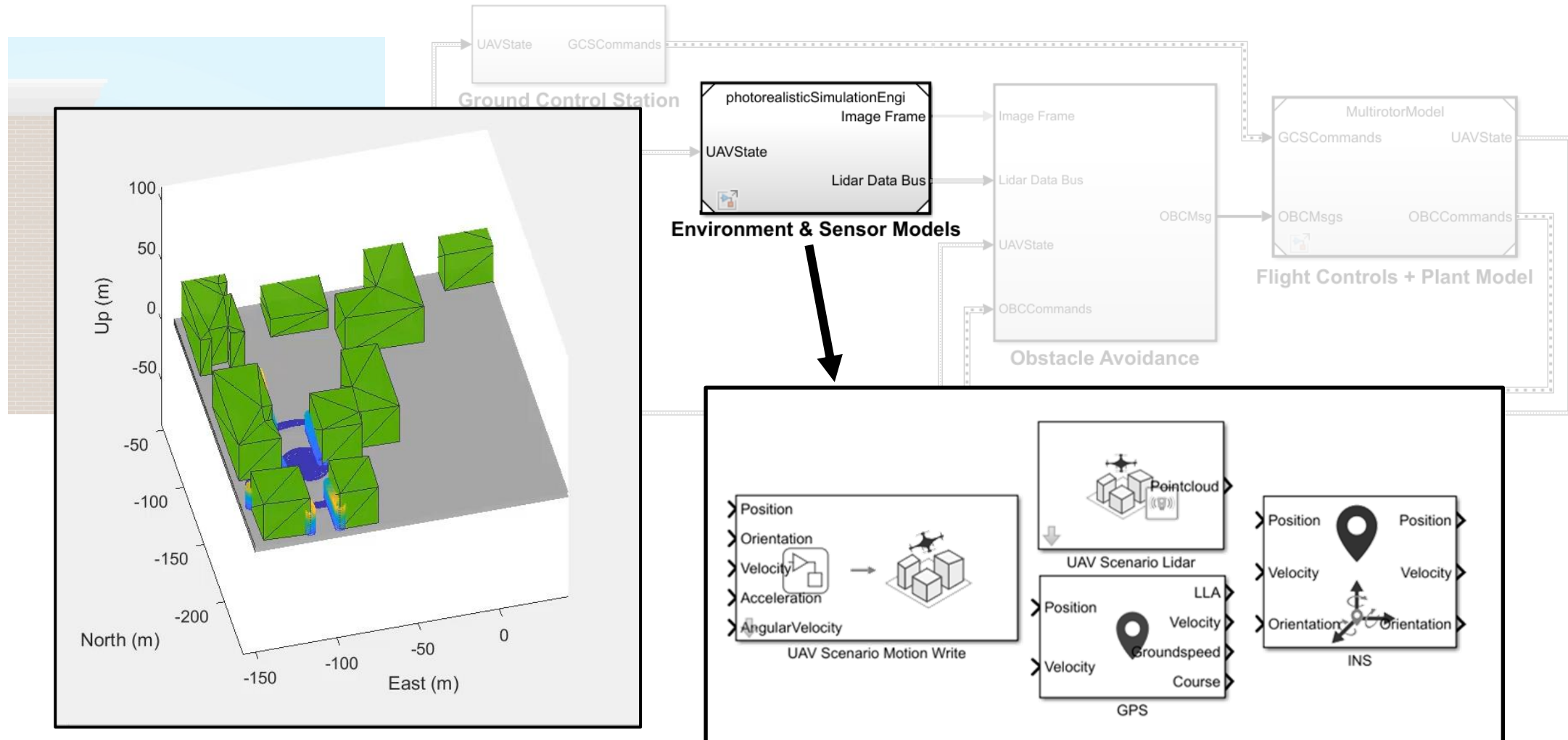


UAV Package Delivery Example

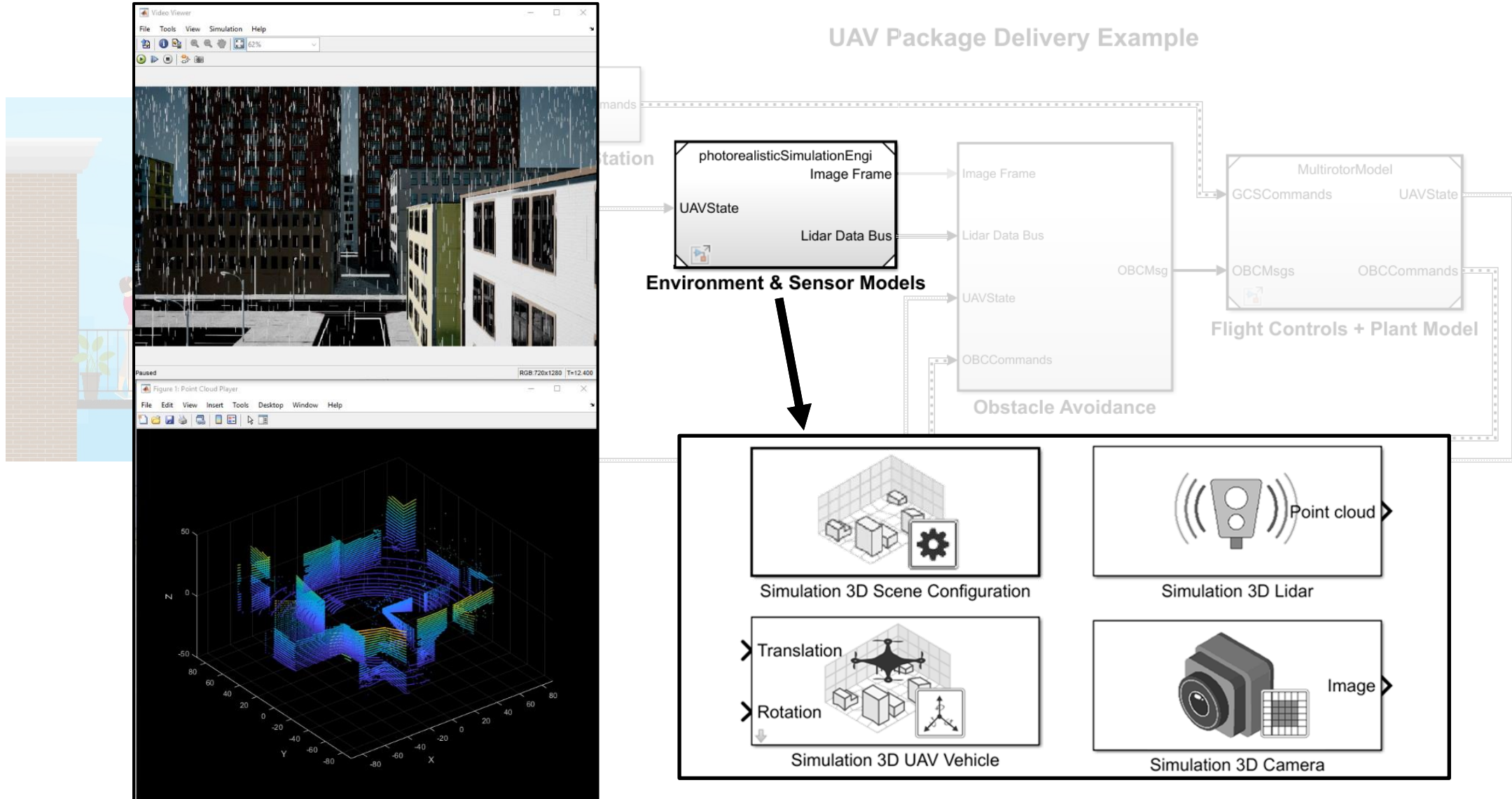


Integrate environments into full-system simulation

UAV Package Delivery Example

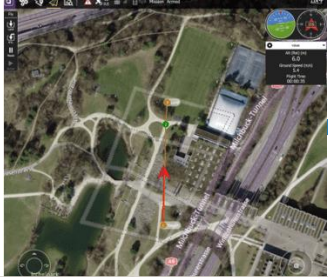


Integrate environments into full-system simulation



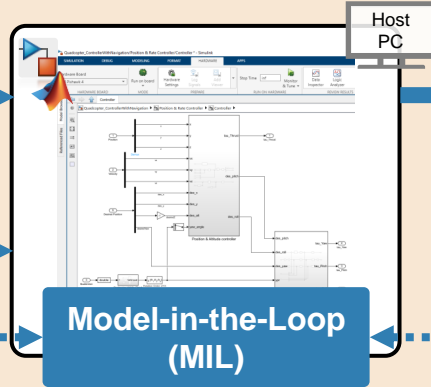
UAV Simulation Workflow with PX4 and Simulink

Inputs

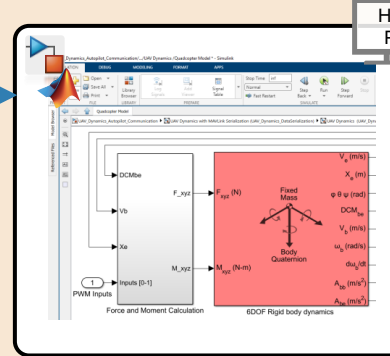


Ground Control Station

Flight Controller



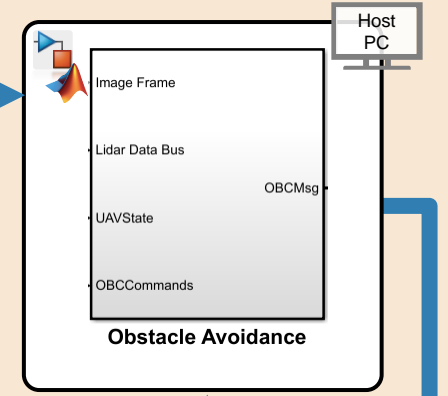
Plant Model



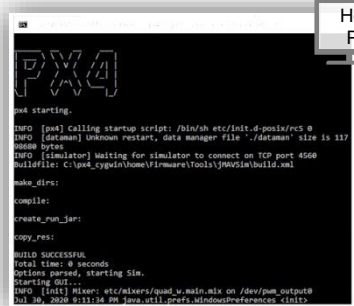
Scenario Simulation



Onboard Autonomy



C++ EXE on Host PC



Software-in-the-Loop

Deploy on Hardware



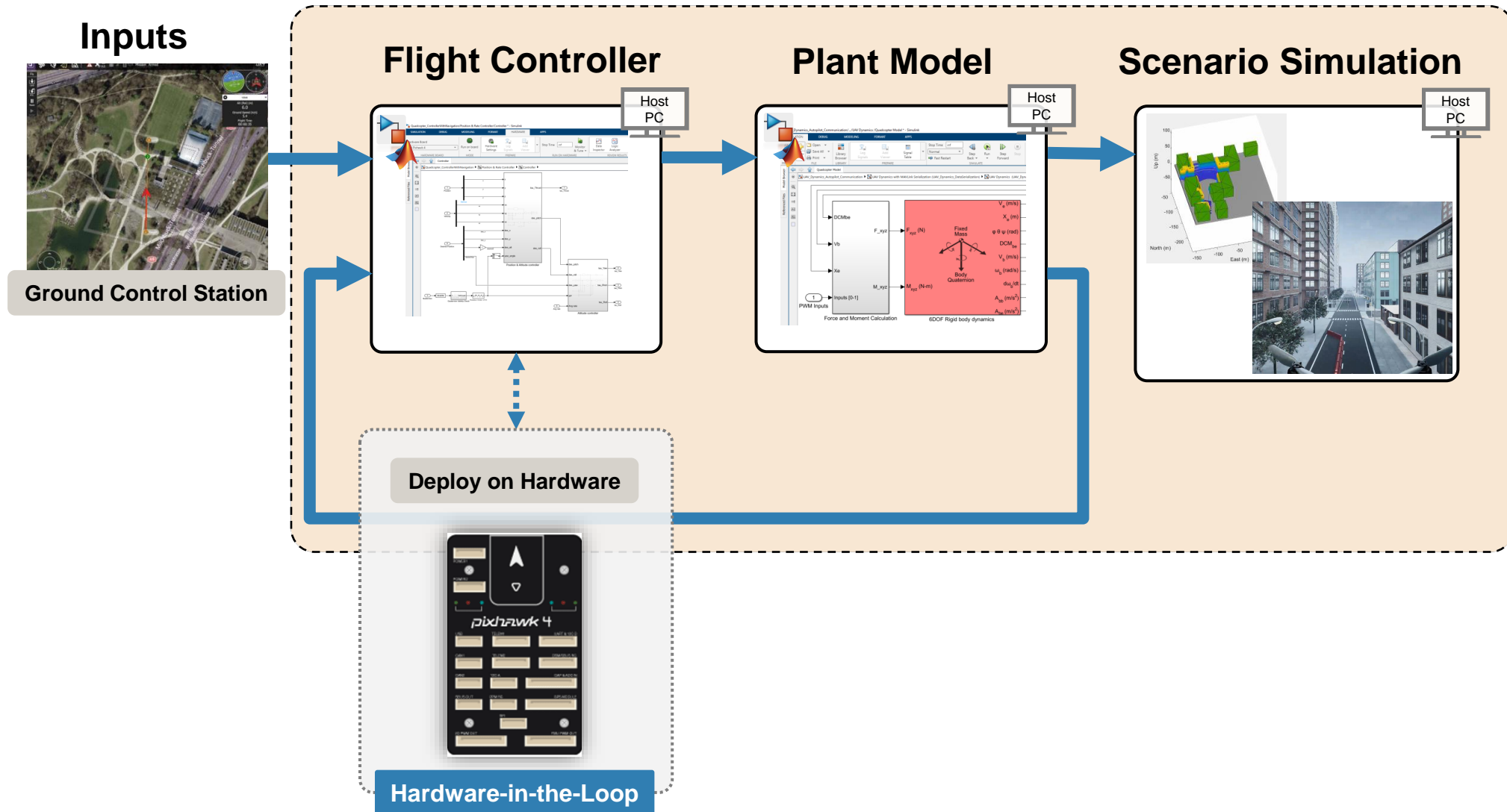
Hardware-in-the-Loop

Deploy on Hardware

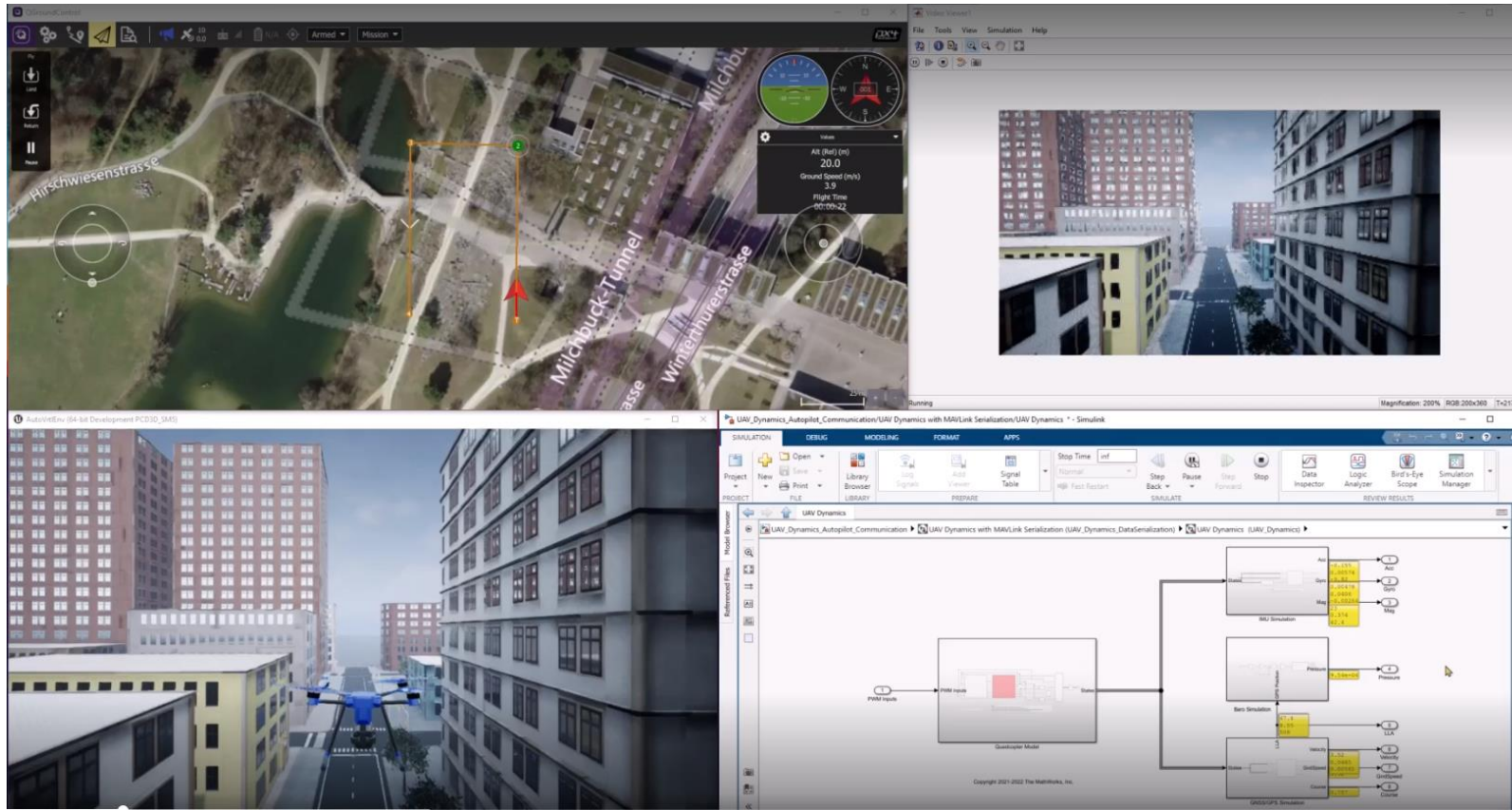


NVIDIA Jetson

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 displays a Hardware-in-the-Loop (HIL) setup for a drone. It consists of four main visual components:

- QGroundControl (Top-Left):** A ground station interface showing a 3D map of an urban environment. A mission path is outlined in orange, and a 'Start Mission' button is visible. A status panel on the right shows flight parameters: Alt (Rel) (m): 0.0, Ground Speed (m/s): 0.0, Flight Time (DD:MM:SS): 00:00:00.
- Video Viewer (Top-Right):** A window showing a first-person view from the drone, looking down a street with buildings and a red awning.
- 3D Drone Model (Bottom-Left):** A 3D model of a blue quadcopter drone on a street, with a red barrier in the background.
- Simulink (Bottom-Right):** A MATLAB/Simulink block diagram for 'UAV Dynamics'. The diagram includes a 'Quadcopter Model' block, an 'IMU Simulation' block, a 'Baro Simulation' block, and a 'GNSS/SPS Simulation' block. The diagram shows the flow of data between these components, including inputs like 'Pwm Inputs' and outputs like 'Acc', 'Gyro', 'Mag', 'Pressure', 'UVA', 'Velocity', 'RollYaw', and 'Course'.

Deployed Flight Controller with Scenario Simulation

HIL with Scenario Visualization

The image displays three Simulink windows illustrating the HIL setup:

- Top Left:** A Simulink model titled 'Quadcopter_ControllerWithNavigation' is shown. A red box highlights the 'PixHawk Hardware' target. A blue box at the bottom of this window reads 'Flight Controller deployed to Autopilot'. The model includes blocks for Estimator Output, Navigation, Position & Rate Controller, and Mixer & Send to Actuator.
- Top Right:** A Simulink model titled 'UAV_Dynamics_Autopilot_Communication' is shown. A green box highlights the text 'Running in Simulink'. A blue box at the bottom of this window reads 'Plant Model running in Simulink'. The model shows data flow from MAVLink Bridge Source (COM3) through input signal conditioning to UAV Dynamics with MAVLink Serialization, and then through output signal conditioning to MAVLink Bridge Sink (COM3).
- Bottom:** A Simulink model titled 'px4demo_3DVisualization' is shown. A blue box at the bottom of this window reads 'Connected to the Plant Dynamics model'. The visualization area shows a 3D scene with a drone and text: 'PX4 HITL Flight visualization with Depth data streaming to onboard computer'. A blue box at the bottom of this window reads 'Scenario Simulation with Unreal Engine Interface'.

HIL with Scenario Visualization

The image displays three Simulink windows used in a Hardware-in-the-Loop (HIL) setup:

- QGroundControl:** A ground station interface showing a 3D map of a flight area. A yellow notification box states: "There is a newer version of QGroundControl available. You can download it from qgroundcontrol.com." The data panel shows: Alt (Rel) (m): 0.0, Ground Speed (m/s): 0.0, Flight Time: 00:00:00.
- UAV_Dynamics_Autopilot_Communication:** A Simulink block diagram showing the communication link between the ground station and the UAV. It includes blocks for "MAVLink Bridge Source (COM3)", "From_Autopilot", "Data Length", "Input Signal Conditioning", "UAV_Dynamics_DataSerialization", "HL_ACTUATOR_bytes", "HL_GPS_bytes", "HEARTBEAT_bytes", "Output Signal Conditioning", "To_Autopilot", and "MAVLink Bridge Sink (COM3)". A label "Plant Model running in Simulink" is overlaid on this window.
- px4demo_3DVisualization:** A Simulink block diagram showing the integration of the PX4 HIL flight simulation with Unreal Engine for 3D visualization. It includes blocks for "PX4 HIL", "Unreal Engine", and "3D Visualization". A label "Scenario Simulation with Unreal Engine" is overlaid on this window.

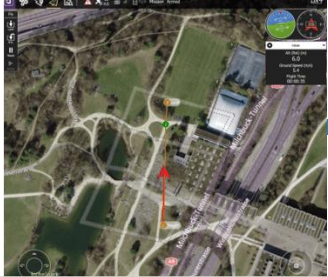
HIL with Scenario Visualization

The image displays a multi-window simulation environment. At the top left is a ground control station (GCS) interface with a satellite map, a yellow notification box, and a status panel showing Alt (Rel) (m) at 0.0, Ground Speed (m/s) at 0.0, and Flight Time at 00:00:00. At the top right is a video viewer window showing a first-person perspective of a street scene with buildings and a red barrier. At the bottom left is a 3D scene from AutoVirtEnv showing a blue drone on a street with buildings and a red barrier. At the bottom right is a Simulink block diagram for 'UAV Dynamics' with sub-blocks for 'MU Simulation', 'Baro Simulation', and 'GNSS-GPS Simulation', each with associated data outputs like Acc, Gyro, Mag, Pressure, LLA, Velocity, GroundSpeed, and Course.

Deployed Flight Controller with Scenario Simulation

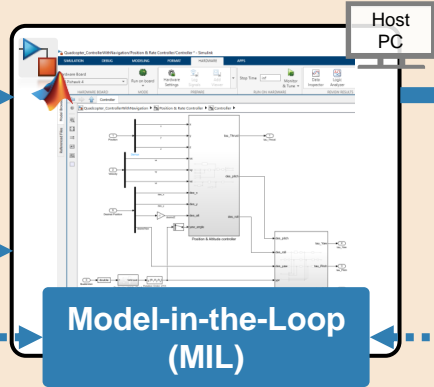
UAV Simulation Workflow with PX4 and Simulink

Inputs

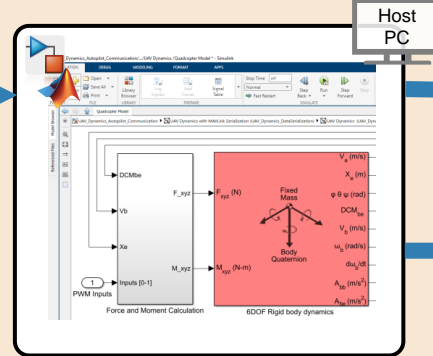


Ground Control Station

Flight Controller



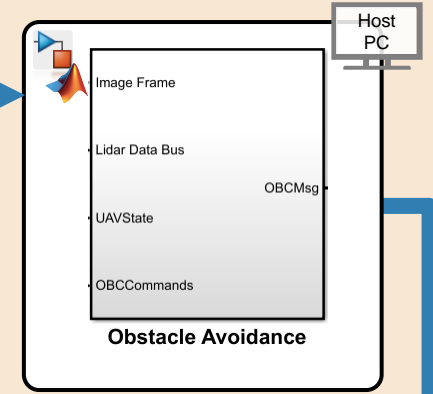
Plant Model



Scenario Simulation



Onboard Autonomy



C++ EXE on Host PC

```

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_jar:
copy_res:
BUILD SUCCESSFUL
Total time: 0 seconds
Waiting for simulator to connect on TCP port 4560
Starting QRT...
INFO [Info] Hicore: etc/rtosrc/pxd-y_min.nix on /dev/pwm_out0@
Jul 19, 2024 9:11:34 AM java.util.prefs.windowsPreferences.cinit
    
```

Software-in-the-Loop

Deploy on Hardware



Hardware-in-the-Loop

Deploy on Hardware



NVIDIA Jetson



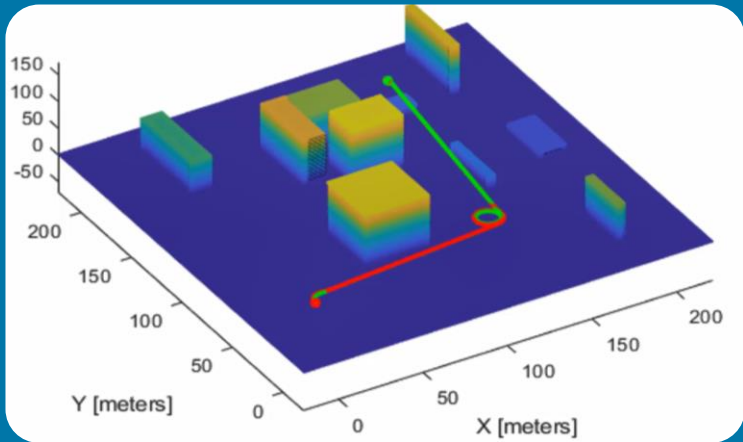
Simulate and Deploy UAV Applications with SIL and HIL Workflows

- Why SIL and HIL?
 - Ensure safety in real flights
 - Test flight behavior in simulation

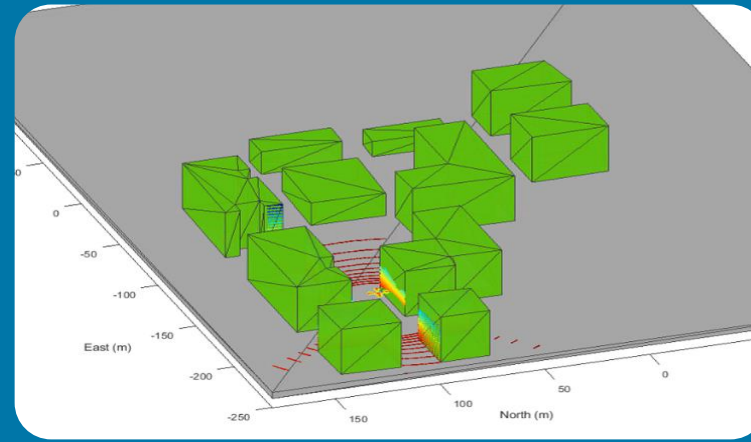
- Why MATLAB & Simulink?
 - Integrate with external autopilots
 - Generate C/C++ code for onboard computers
 - Scenario simulation with MATLAB and Unreal Engine

UAV Toolbox

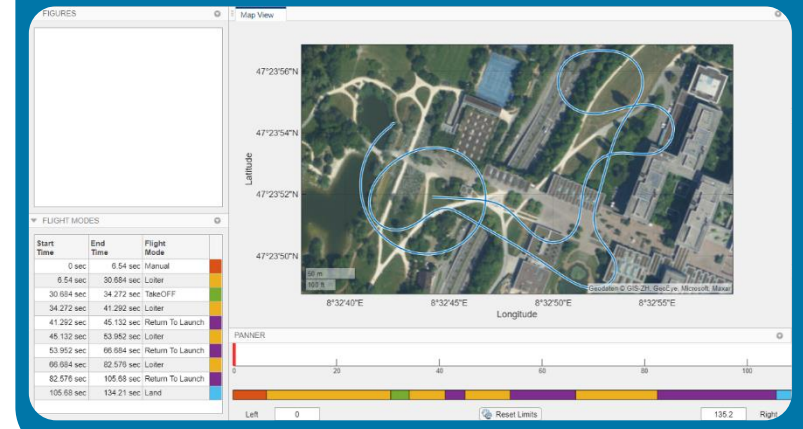
UAV Algorithms for Planning and Control



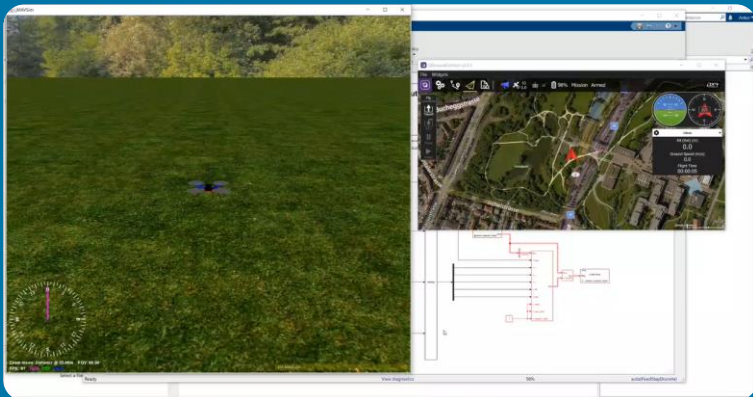
Scenario Design & Low-Fidelity Sensor Simulation



Flight Telemetry Data Analysis Flight Log Analyzer App



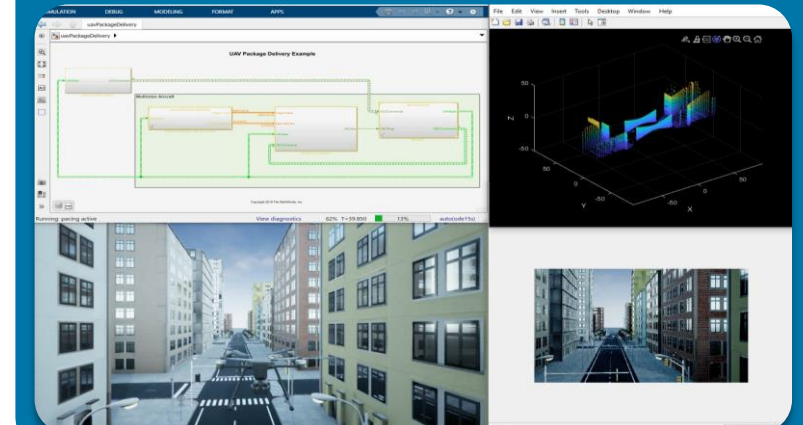
Connectivity and Deployment with MAVLink and PX4



Unreal Engine Co-Simulation with Sensor Models



Reference Applications



Resources

- Product Page
 - www.mathworks.com/products/uav.html
- 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
- Documentation
 - www.mathworks.com/help/uav/
- Examples
 - www.mathworks.com/help/uav/examples.html

MATLAB EXPO

Thank you



© 2022 The MathWorks, Inc. MATLAB and Simulink are registered trademarks of The MathWorks, Inc. See [mathworks.com/trademarks](https://www.mathworks.com/trademarks) for a list of additional trademarks. Other product or brand names may be trademarks or registered trademarks of their respective holders.