

# MATLAB EXPO

## 2021

### Autonomous UAV Development and Evaluation with MATLAB® and Simulink®

*Julia Antoniou*

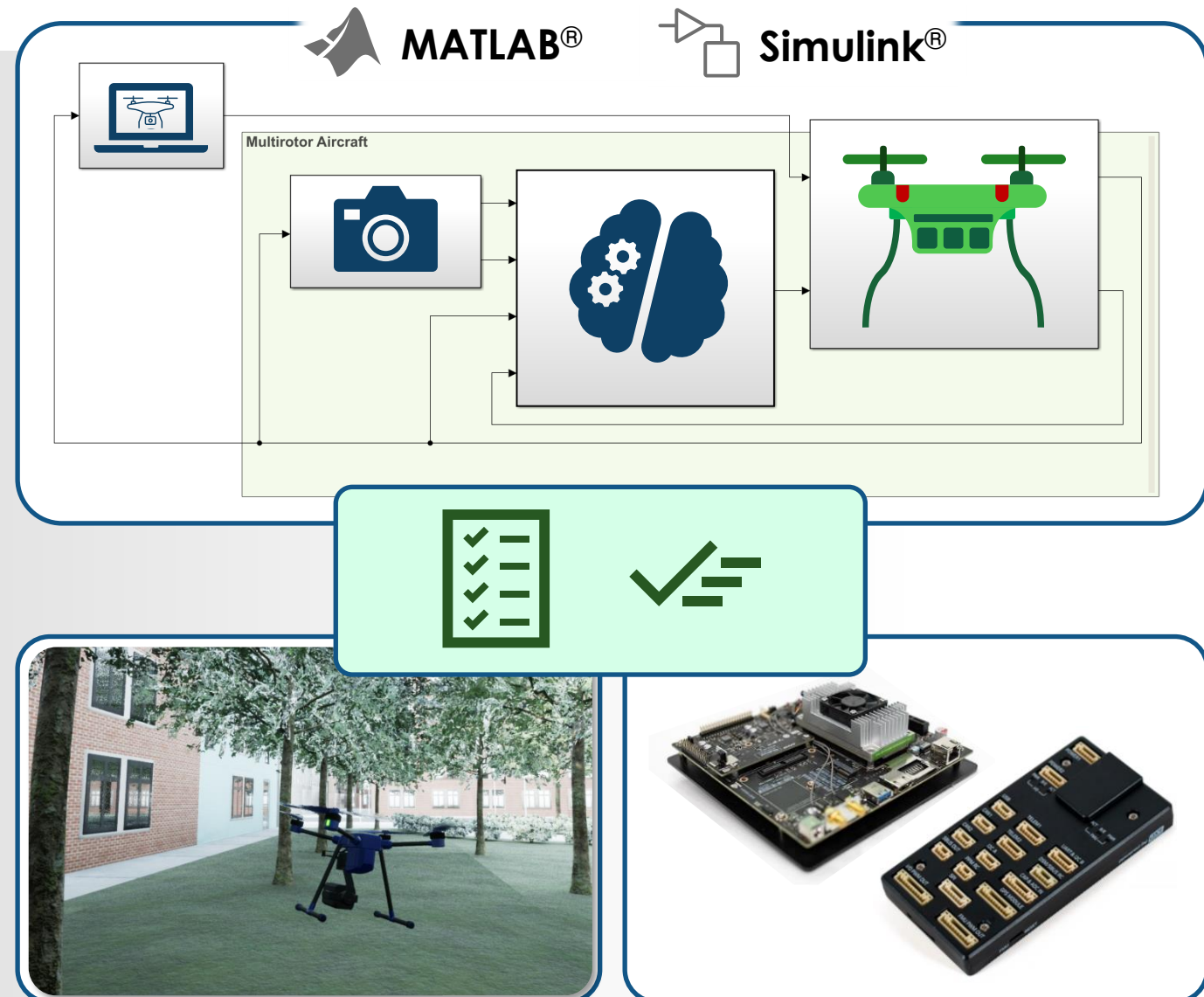


*Andrew Grabowski*



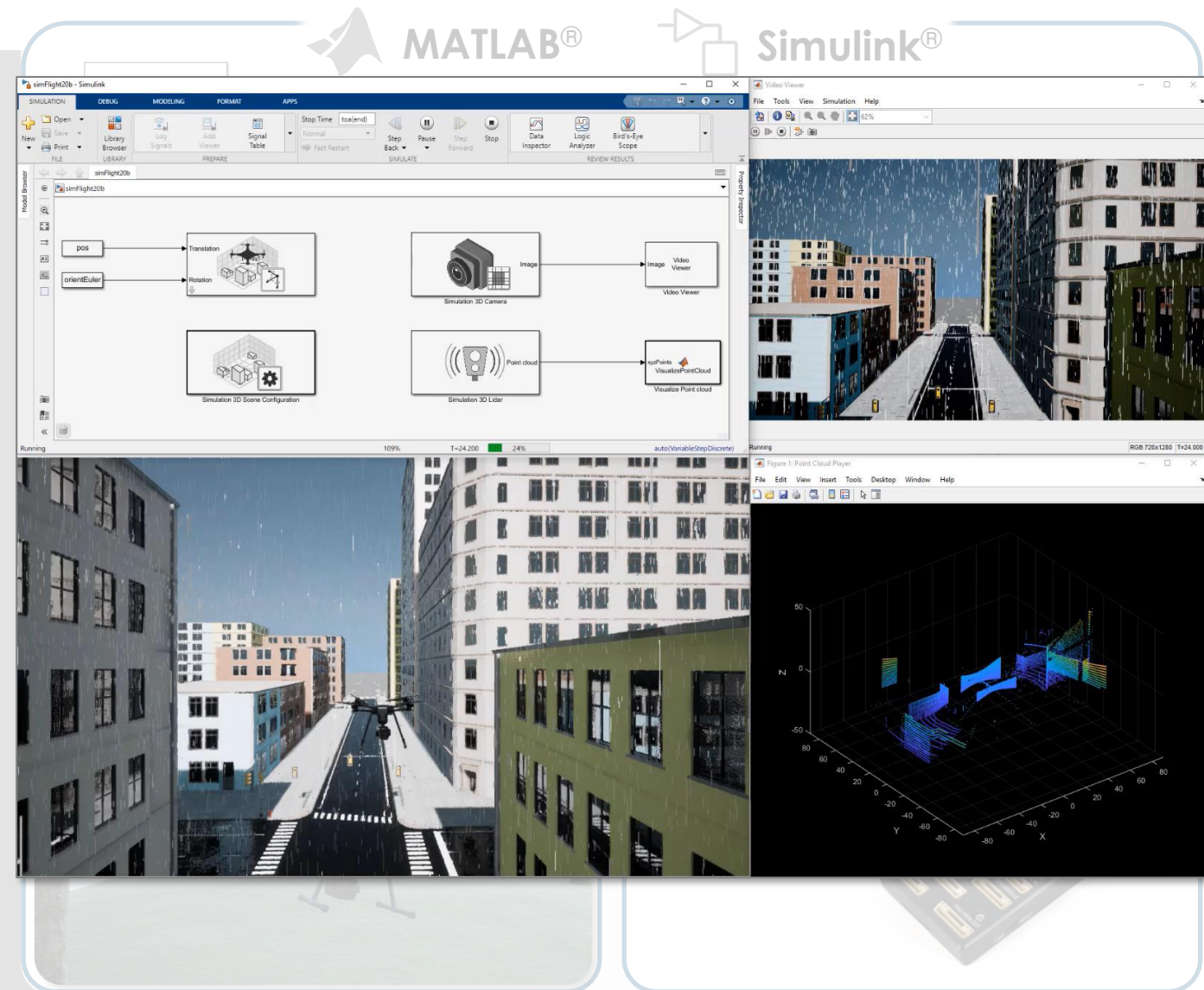
# Autonomous UAV Development and Evaluation

- Integrated workflows enabled by MATLAB and Simulink
- Tools to design UAV systems and autonomous applications
- Select appropriate methods for your UAV development tasks
- Evaluating systems through closed-loop simulations with sensor models

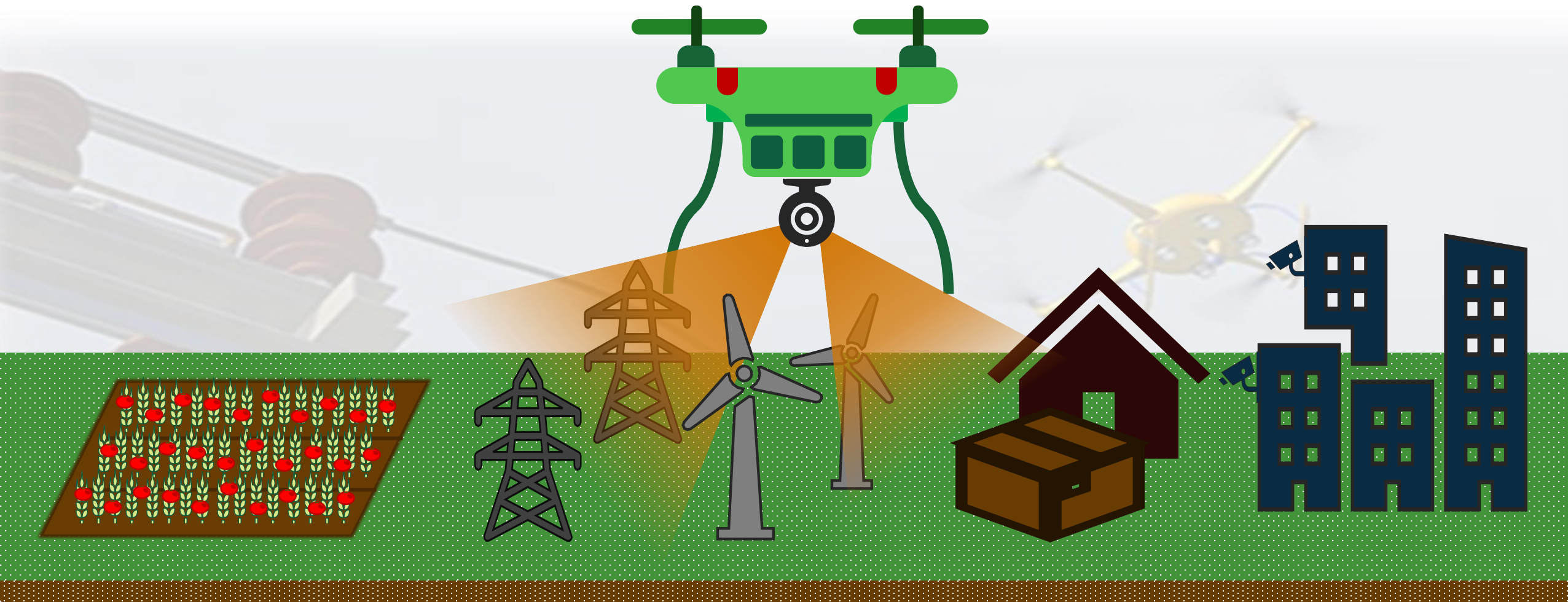


# Autonomous UAV Development and Evaluation

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# Increase in autonomous UAV usage



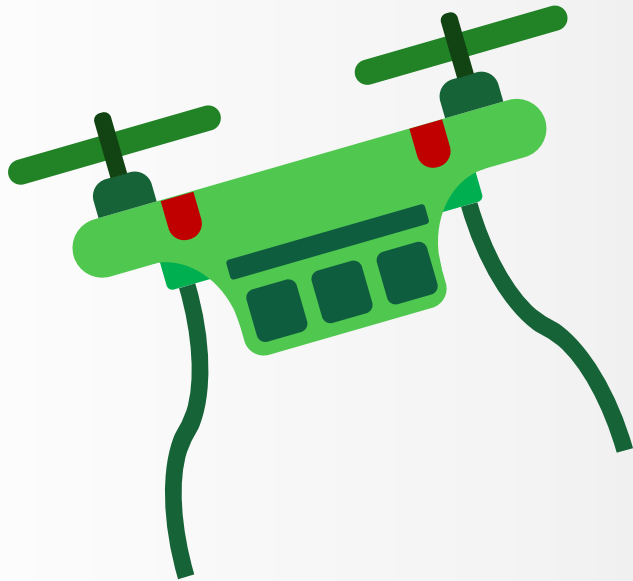
Mapping &  
Surveying

Inspections &  
Monitoring

Delivery &  
Transport

Security &  
Defense

# Challenges in developing autonomous UAV systems & applications



Complexity of advanced autonomous algorithms

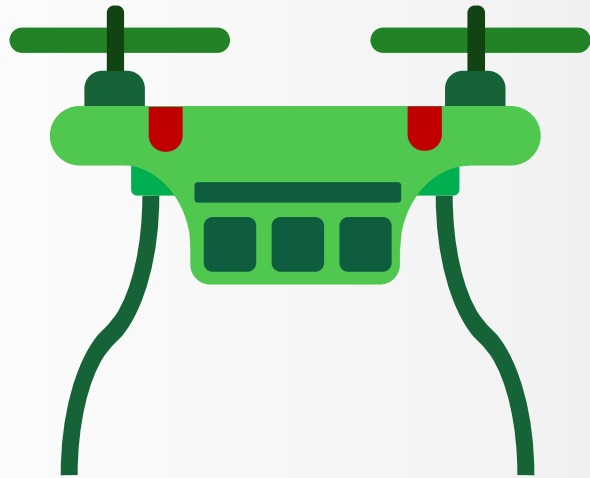


Need of end-to-end workflows



Ensuring system quality and reducing flight risk

# Solutions for developing autonomous UAV systems & applications



Robust tools and features for designing and testing UAV systems and algorithms

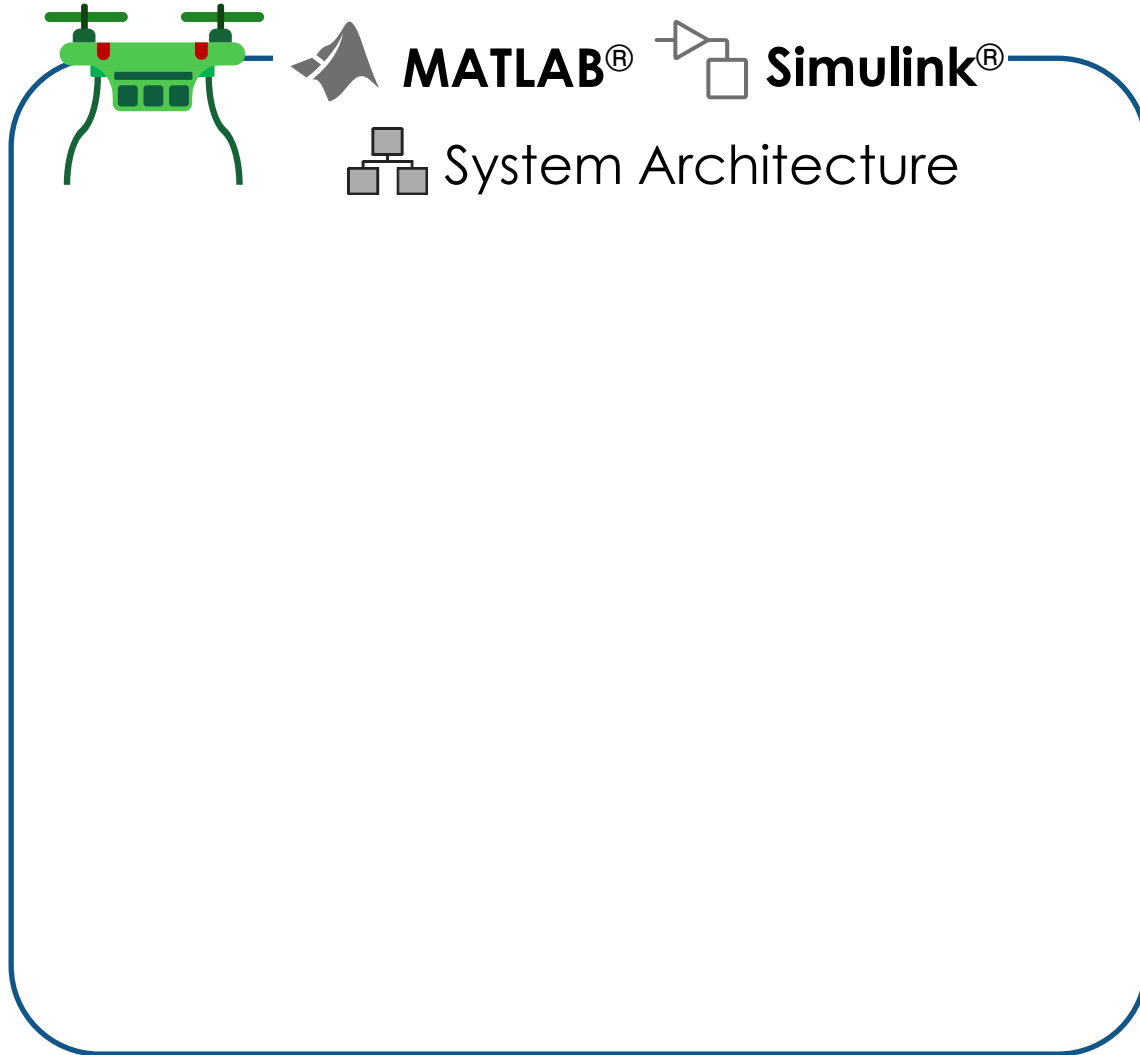


Integrated development environment that covers development from ideas to production

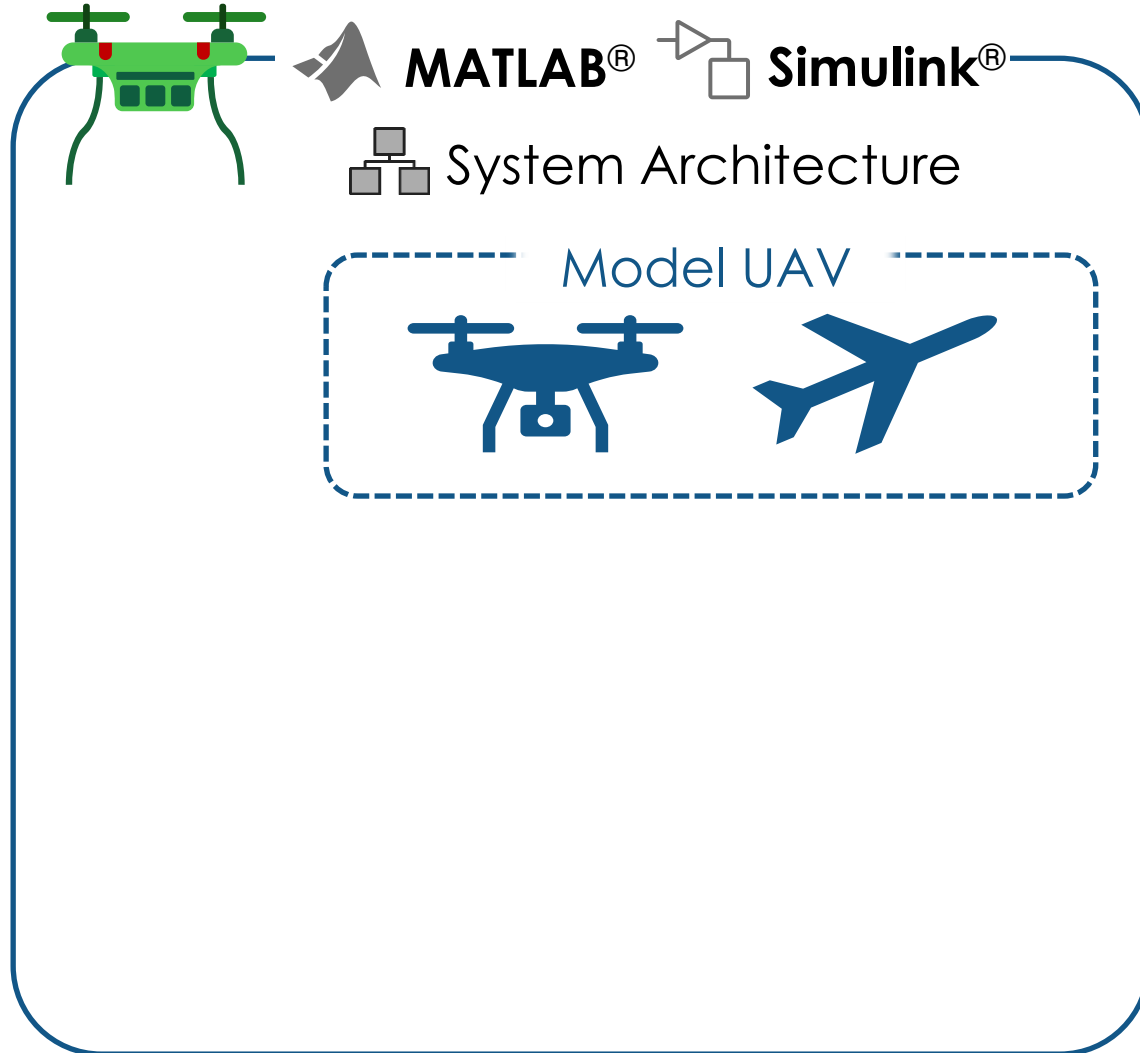


Extensive verification and validation tools to evaluate design quality through virtual testing

# Integrated workflows for developing UAV applications

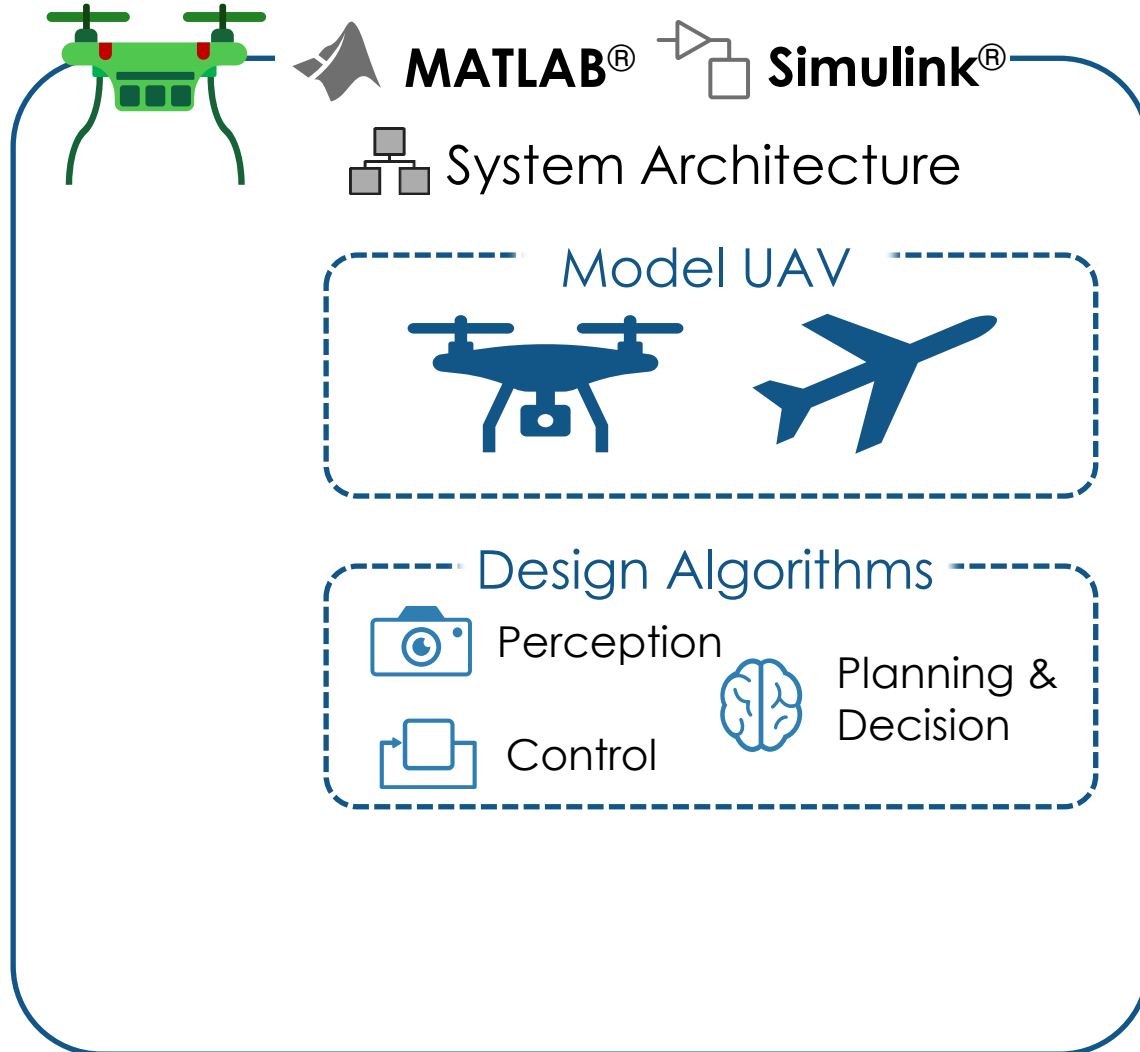


# Integrated workflows for developing UAV applications

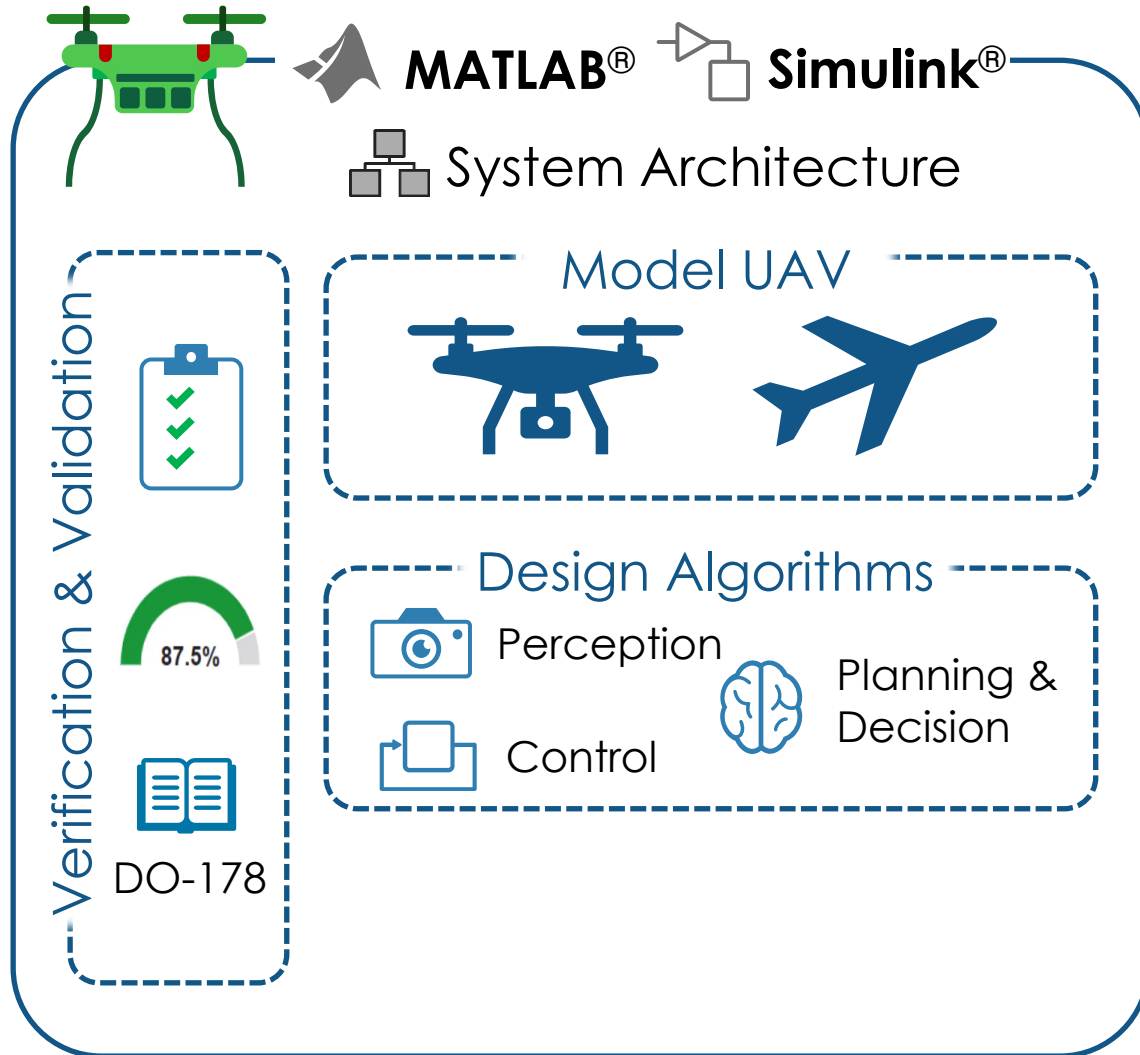




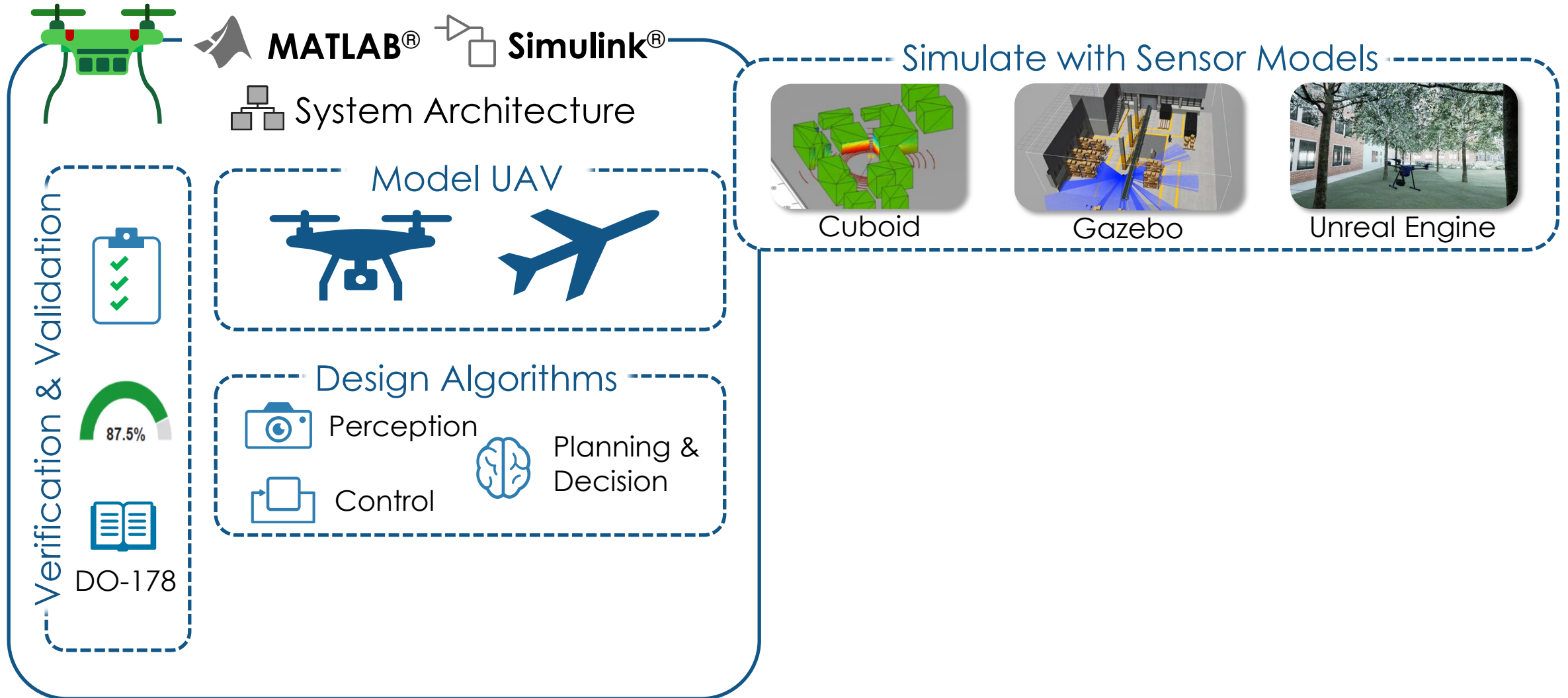
# Integrated workflows for developing UAV applications



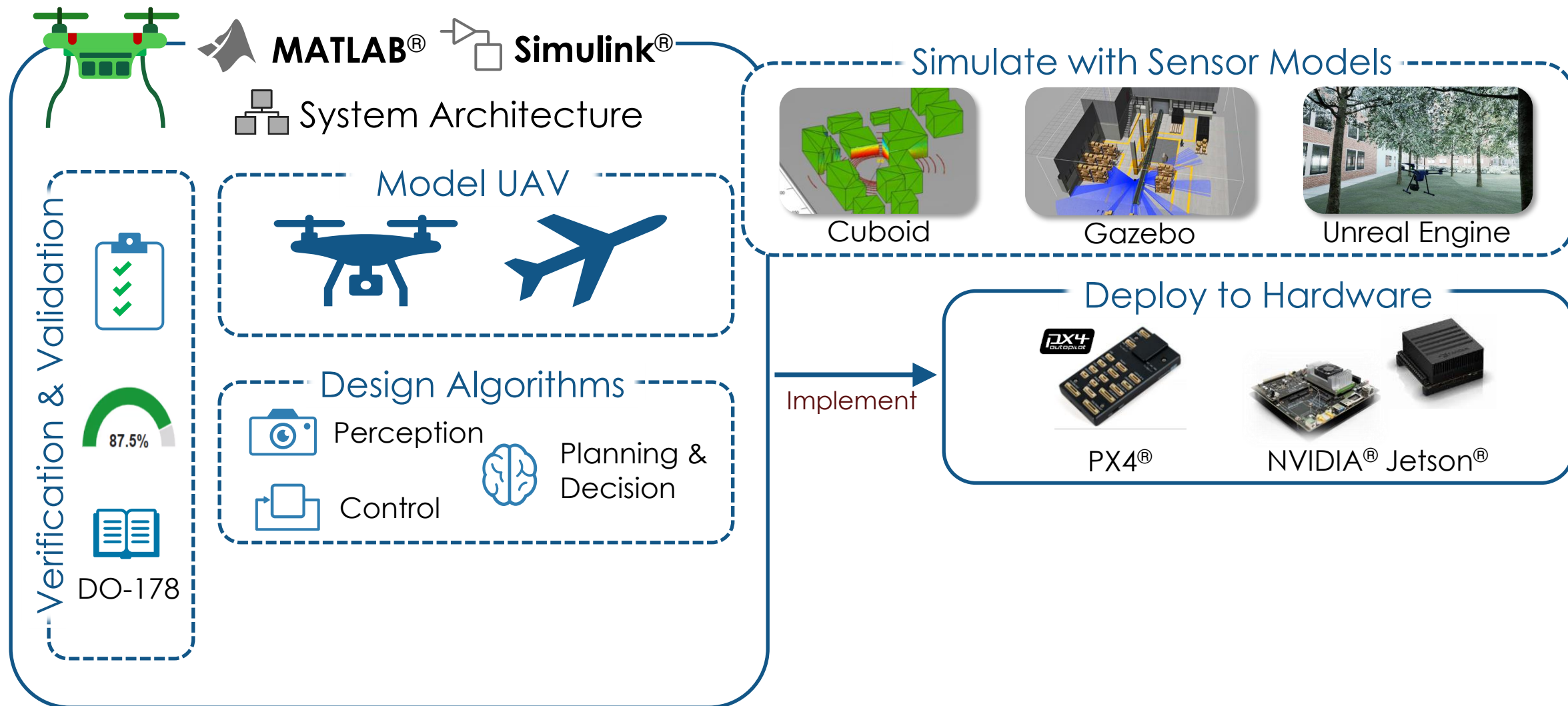
# Integrated workflows for developing UAV applications



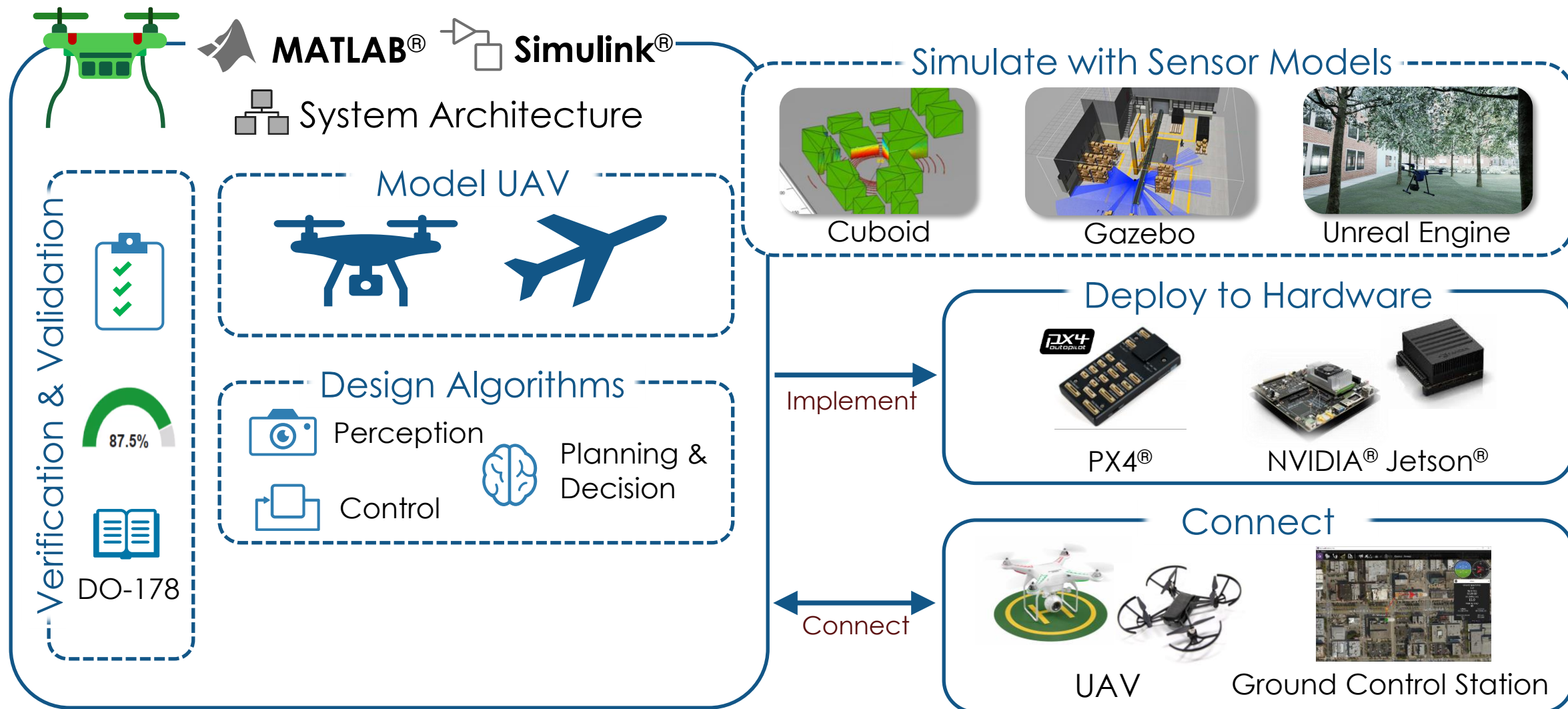
# Integrated workflows for developing UAV applications



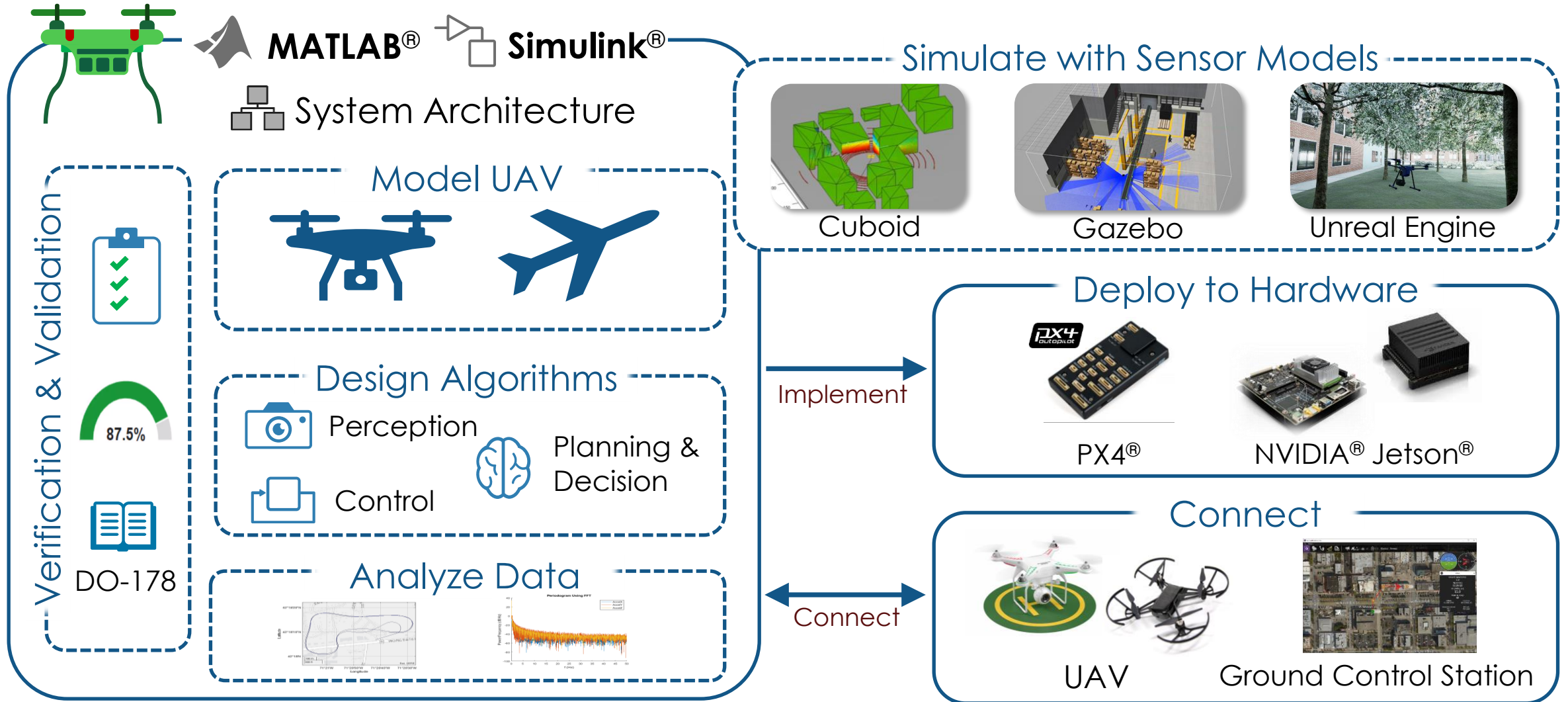
# Integrated workflows for developing UAV applications



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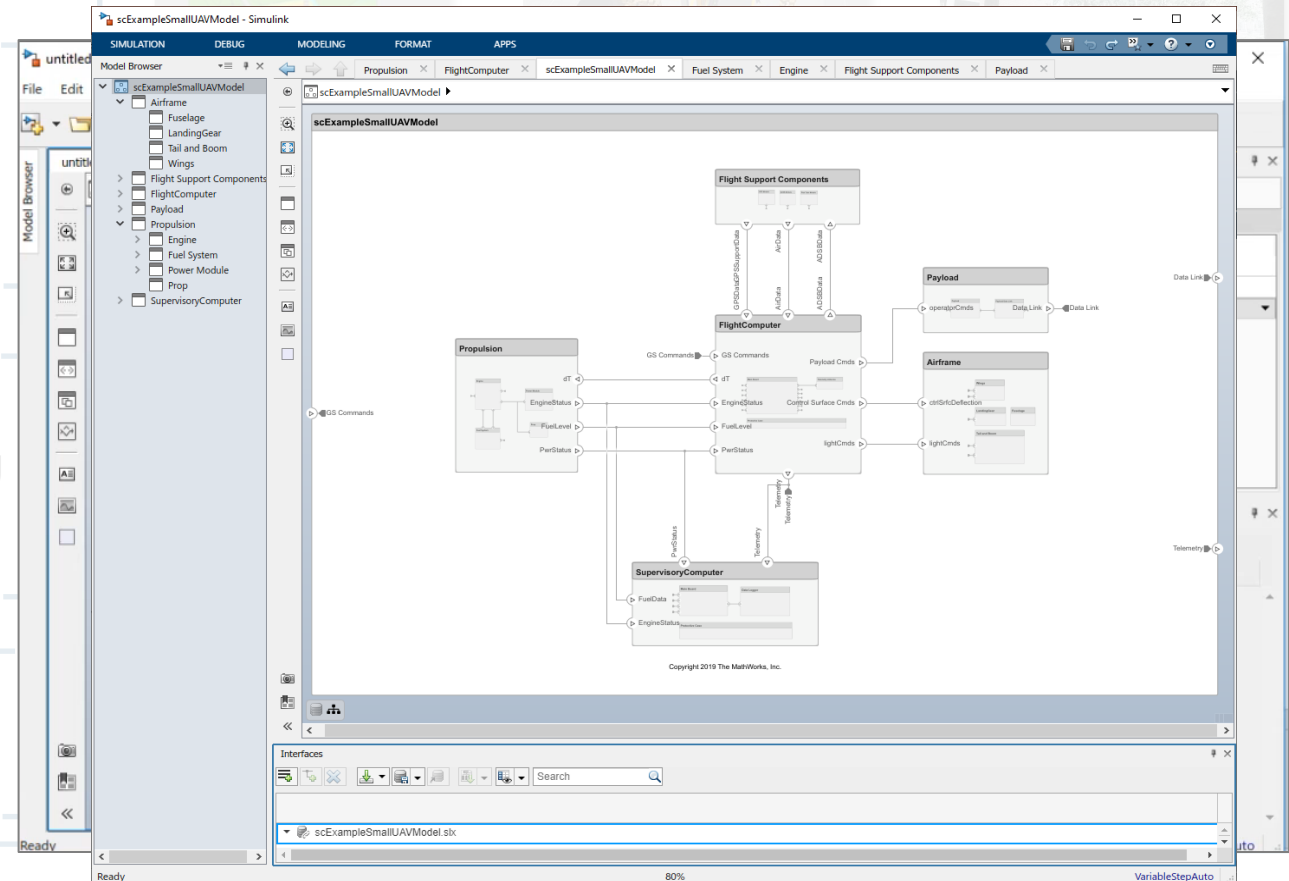
# Integrated workflows for developing UAV applications



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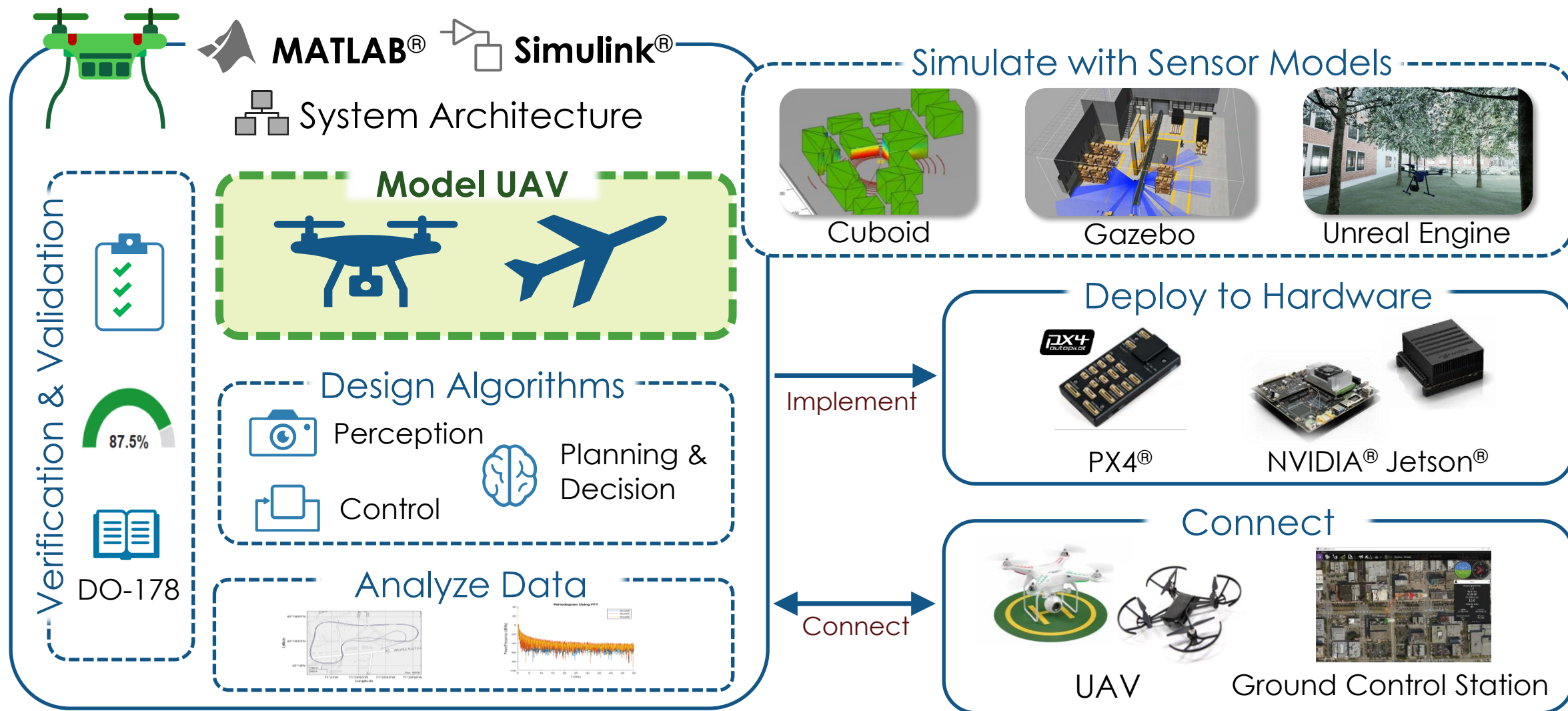
## System Architecture

- System Composer™ for designing and analyzing system and software architecture
- Simulink integration and requirement allocation for traceability



[Link](#)

# Integrated workflows for developing UAV applications





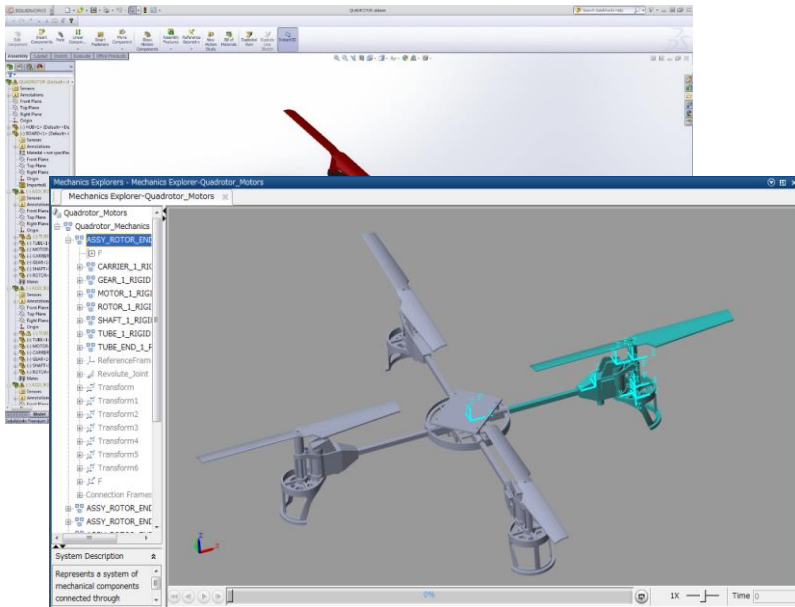
## UAV Plant Modeling: Selecting the appropriate fidelity



# UAV Plant Modeling: Selecting the appropriate fidelity

**High-Fidelity**  
*Building UAV*

**Approximate**  
*Programming UAV*

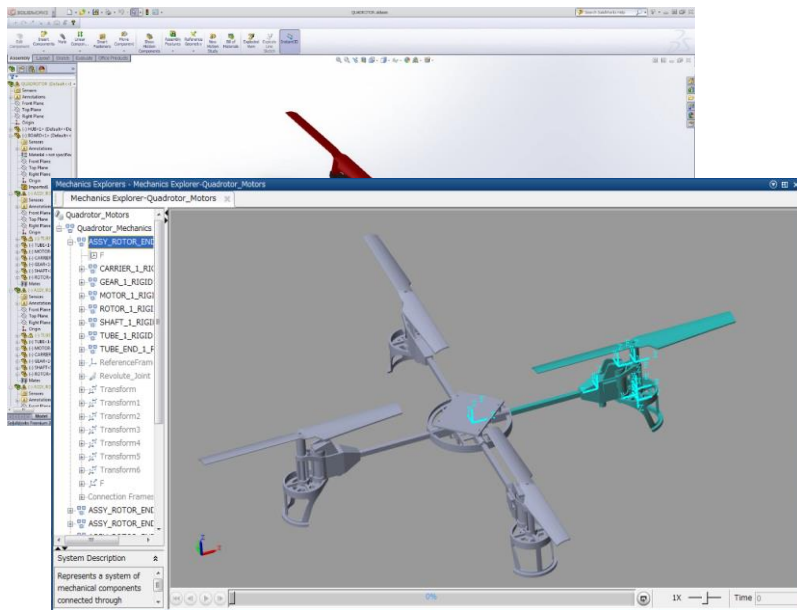


## Physical Modeling

[Link](#)

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

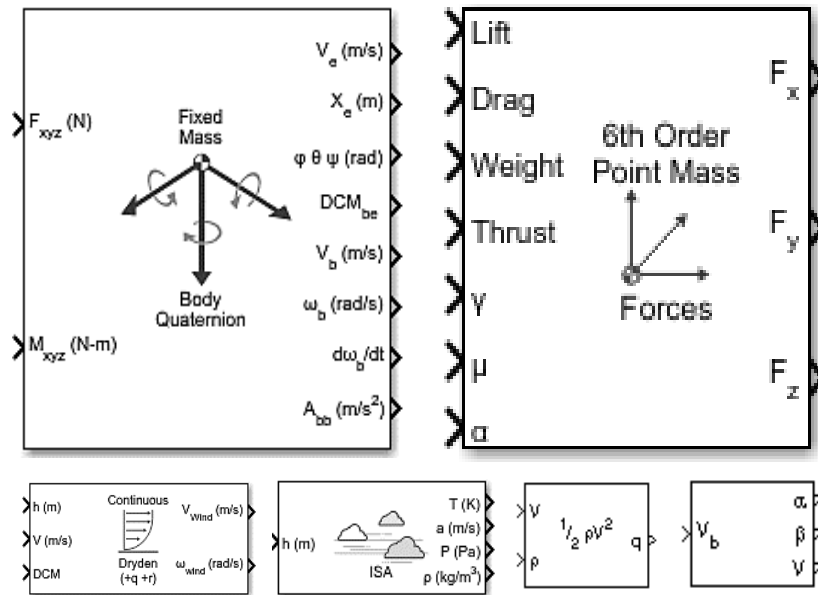
# UAV Plant Modeling: Selecting the appropriate fidelity



## Physical Modeling

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

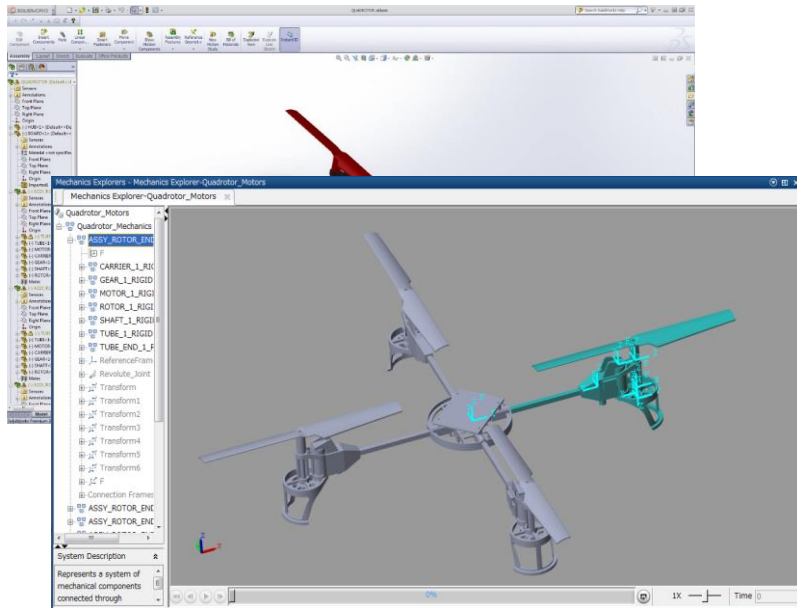


## Vehicle Dynamics

[Link](#)

Model aerodynamics, propulsion, and motion of aircraft and spacecraft

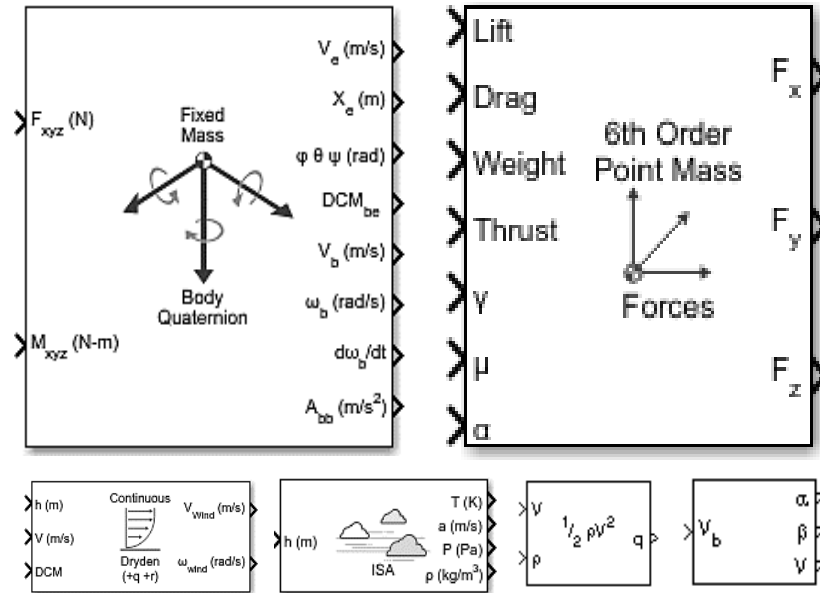
# UAV Plant Modeling: Selecting the appropriate fidelity



## Physical Modeling

[Link](#)

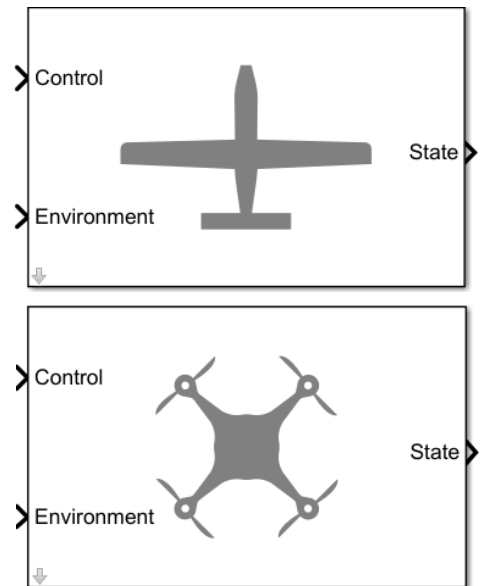
Model construction techniques and best practices, domain-specific modeling, physical units



## Vehicle Dynamics

[Link](#)

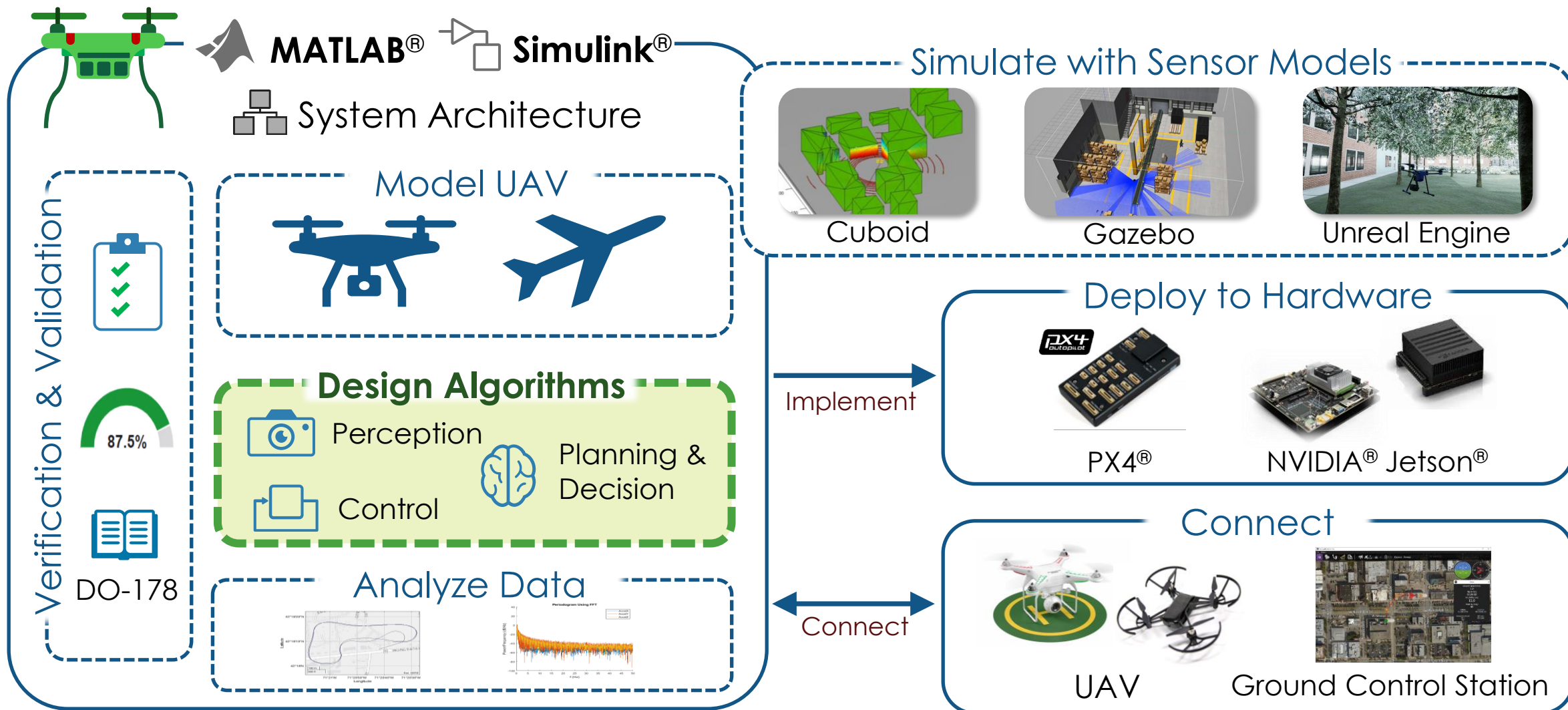
Model aerodynamics, propulsion, and motion of aircraft and spacecraft



## Guidance Model [Link](#)

Reduced-order model for UAV

# Integrated workflows for developing UAV applications



# Autonomous UAV Algorithm Development

## Design Algorithms



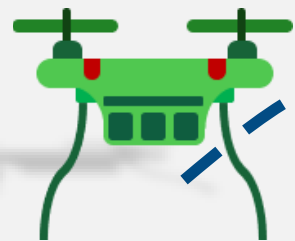
Perception



Planning &  
Decision

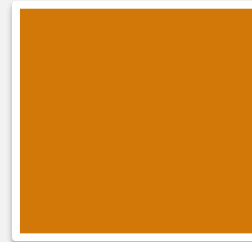


Control



Startpoint

Map Data



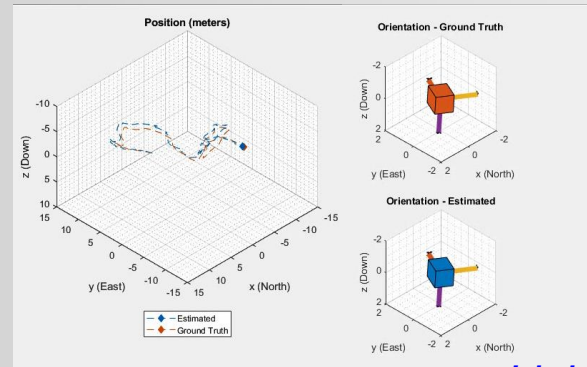
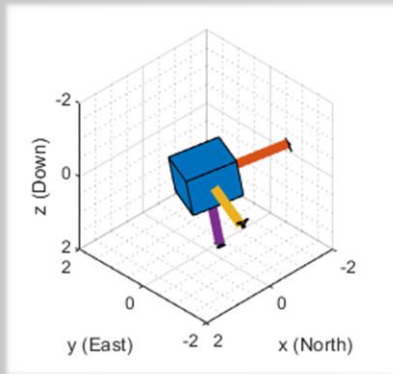
Planned Path

Endpoint

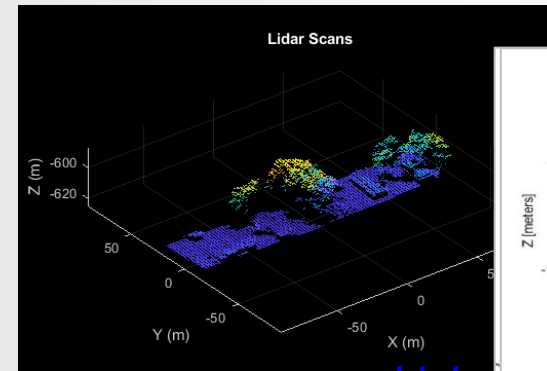
# Autonomous UAV algorithm design with robust capabilities



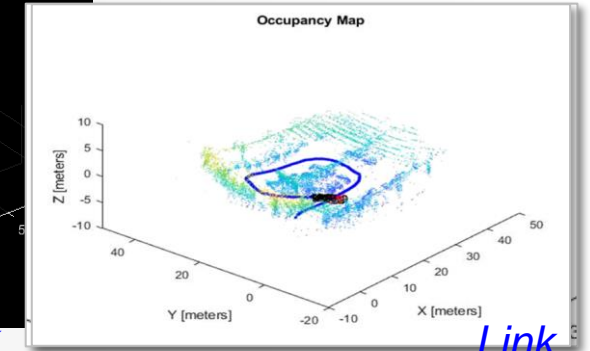
Self Awareness



[Link](#)

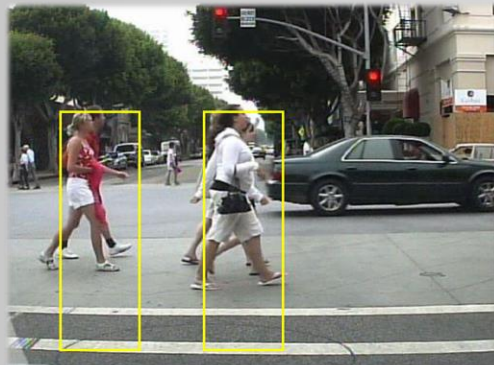


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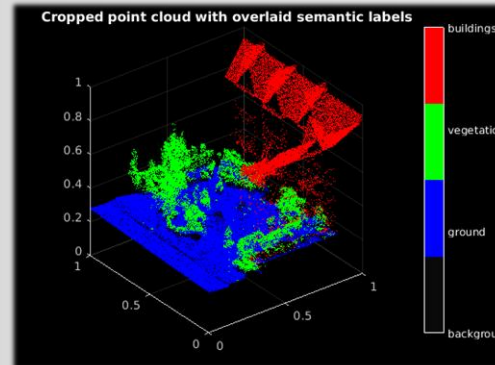


[Link](#)

Situational Awareness

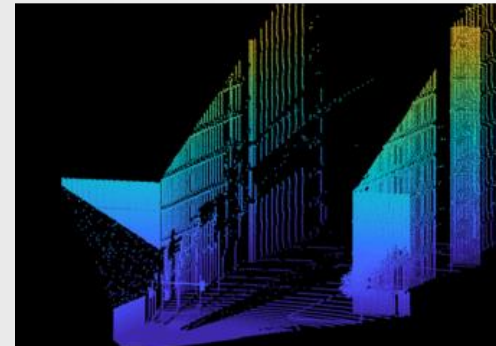


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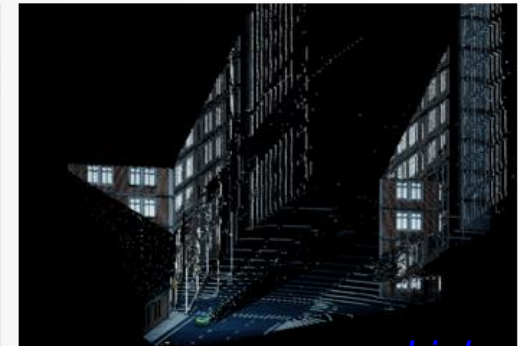


[Link](#)

Lidar point cloud data



Fused lidar and camera data



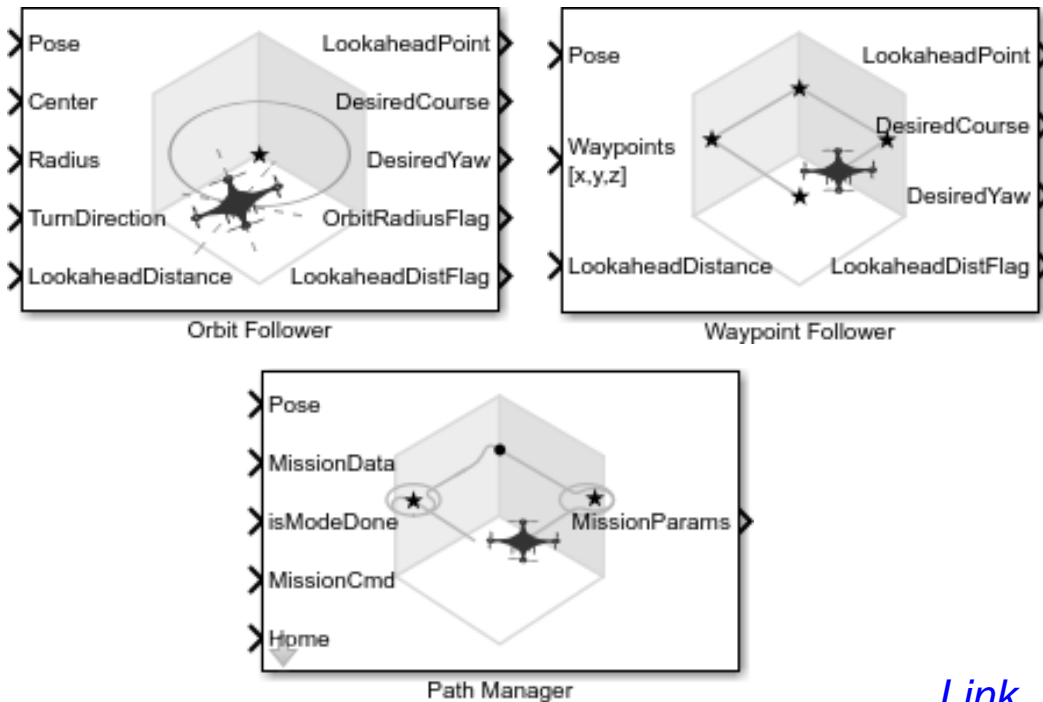
[Link](#)

# Autonomous UAV algorithm design with robust capabilities

 Perception

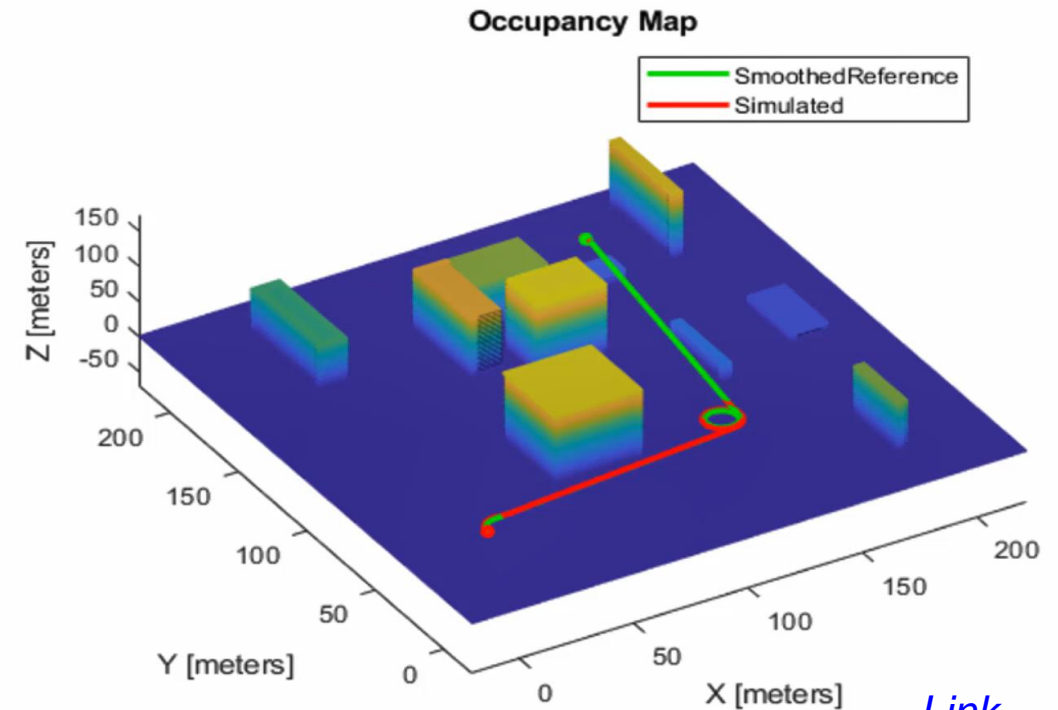
 **Planning & Decision**

 Control



[Link](#)

Define UAV missions with waypoint and trajectory-following algorithms



[Link](#)

UAV motion planning with advanced path planners

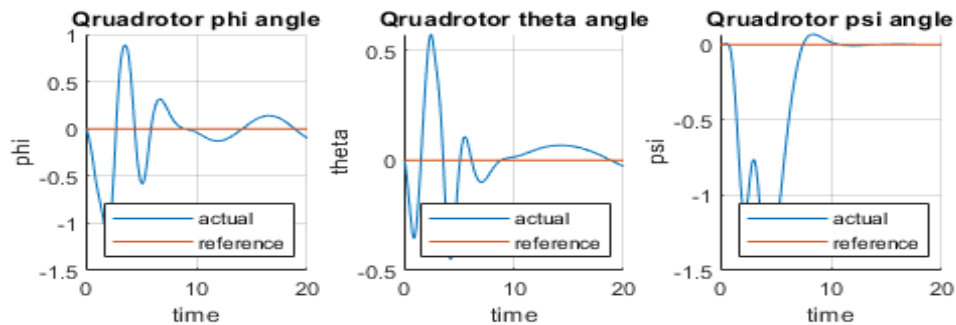
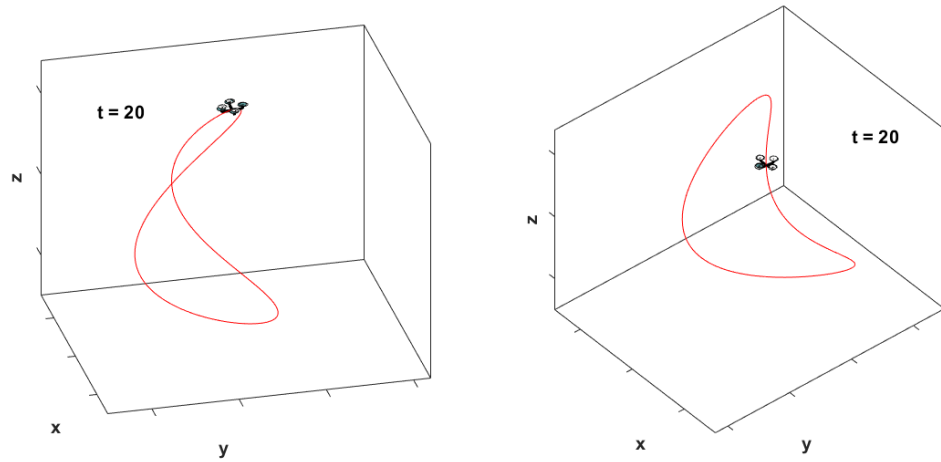


# Autonomous UAV algorithm design with robust capabilities

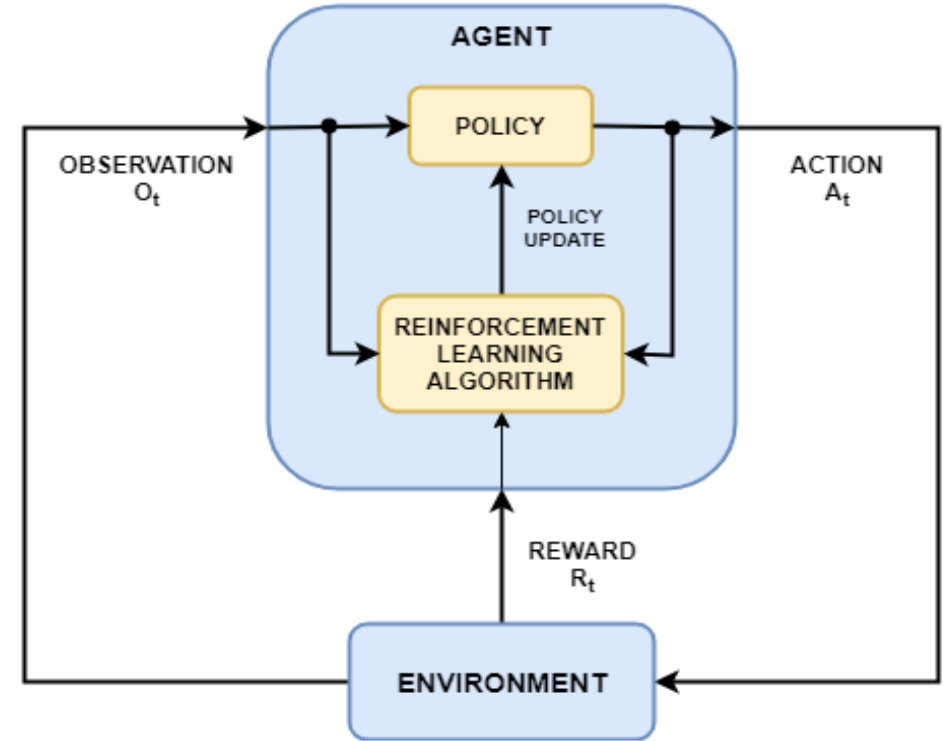
 Perception

 Planning & Decision

 **Control**



[Link](#)

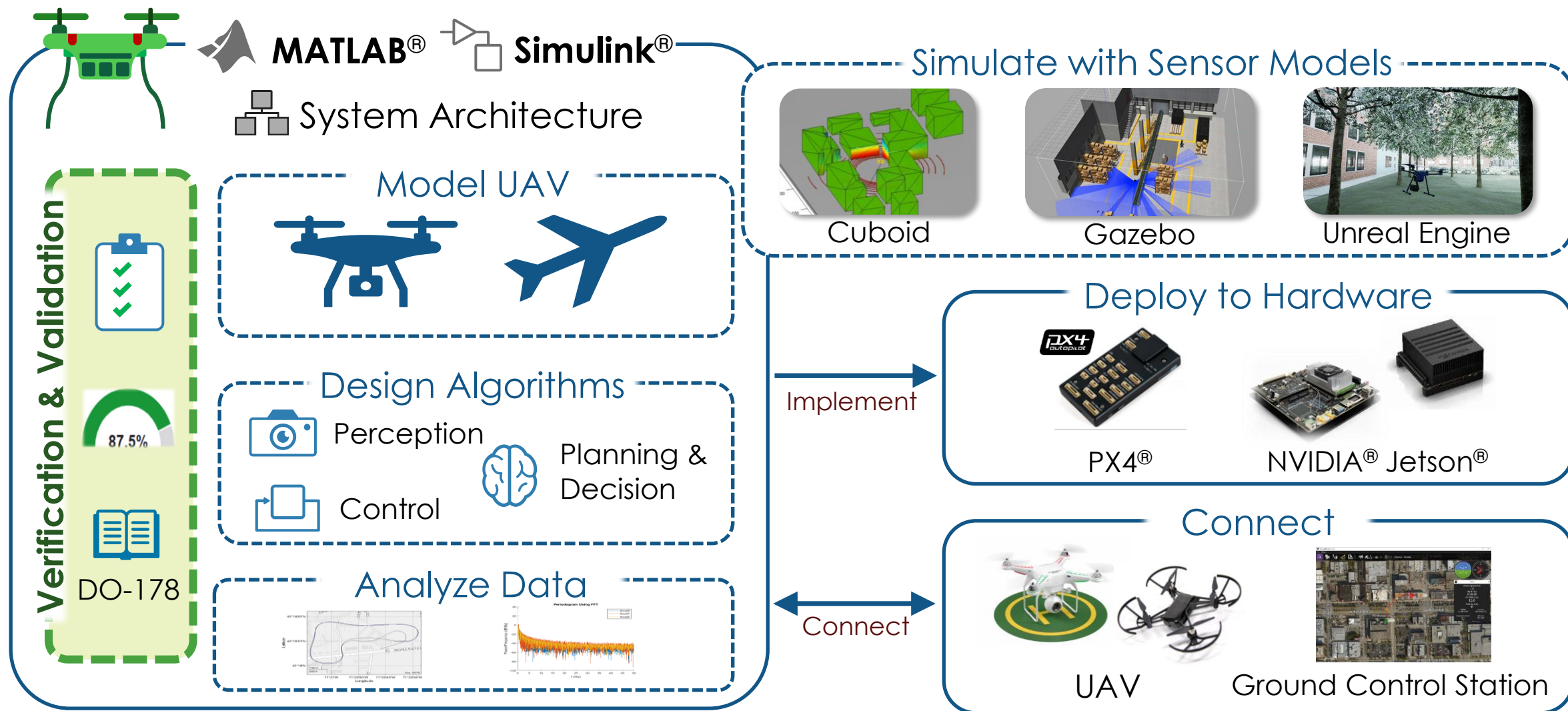


[Link](#)

Trajectory tracking controller with nonlinear model predictive control (MPC)

Train policies for trajectory generation using reinforcement learning algorithms

# Integrated workflows for developing UAV applications



# Tracking and automating verification and validation activities

## Requirements Traceability

The screenshot shows the Simulink Requirements Traceability Matrix. At the top, a block diagram of a driver switch request handler is visible. Below it, a table lists requirements and their verification status:

Requirement ID	Summary	Implemented	Verified
1	Driver Switch Request Handling	Yes	Yes
1.1	Switch precedence	Yes	Yes
1.2	Avoid repeating commands	Yes	Yes
1.3	Long Switch recognition	Yes	Yes
1.4	Cancel Switch Detection	Yes	Yes
1.5	Set Switch Detection	Yes	Yes
1.6	Enable Switch Detection	Yes	Yes

Below the table is a 'Traceability Matrix' grid showing links between requirements and model elements. A 'Link' button is visible at the bottom right of the grid.

## Test Management & Automation

The screenshot displays the Simulink Test Management interface. It shows a 'Test Browser' with a list of test suites, including 'New Test Suite 1' and 'rtwdemo\_sil\_block\_Harness1'. The 'Properties' pane for the selected test suite shows details like 'Index: 1.6' and 'Summary: Enable Switch Detection'. Below, a 'Simulation' window shows the configuration for 'SIMULATION 1' and 'SIMULATION 2'. A 'Comparison' window shows a plot of 'Out:1 (Sim Output)' over time, with a 'Tolerance' line and a 'Difference' line. A 'Link' button is visible at the bottom right.

## Evaluate Completeness

The screenshot shows two dashboards. The top one is a 'Dashboard' for 'db\_DriverSwRequest' with various charts and tables. The 'TEST CASE ANALYSIS' section includes:

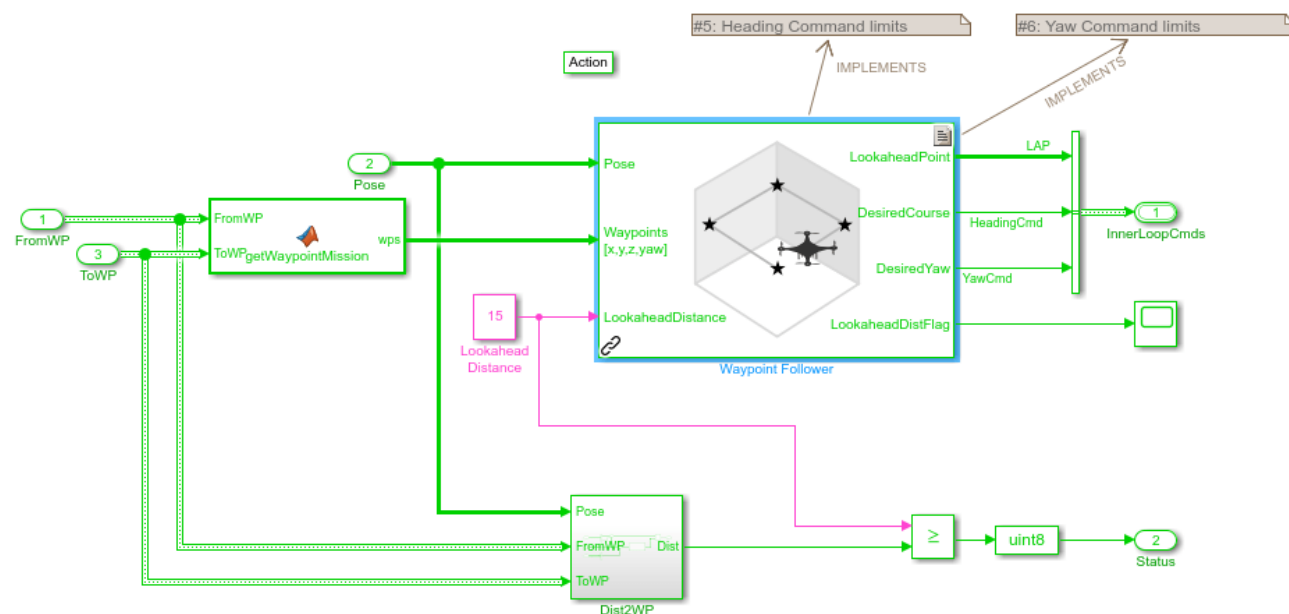
- Requirements Linked To Tests: 42.9% (12 Unlinked)
- Tests Linked to Requirements: 87.5% (1 Unlinked)
- Tests per Requirement: 0.12
- Requirements per Test: 8.33

The 'TEST RESULT ANALYSIS' section shows:

- 75% Passed
- 1 Failed
- 0 Untested
- 1 Disabled

The 'Model Coverage' bar chart shows coverage for Evolution, Condition, Decision, and MCDCC. A 'Link' button is visible at the bottom right.

# Example: Automating UAV testing with requirements linking



Requirements linking for traceability

Test Browser Results and Artifacts

Filter results by name or tags, e.g. tags: test

NAME	STATUS
Results: 2020-Dec-21 15:19:38	3 ✓
MulticopterModelTest	3 ✓
GuidanceLogicSuite	1 ✓
Test Guidance State Transiti	✓
ControlSystemSuite	2 ✓
Test Control System Cmd Lin	✓
Test Control System Perform	✓

Automating test execution and evaluation

Requirement: #19

Index	Summary
1	Flight Controller
1.1	Guidance
1.1.1	Heading Command limits
1.1.2	Yaw Command limits
1.1.3	Not start until flight is started
1.1.4	Transition to Descend
1.1.5	Finishing Flight
1.1.6	Transition out of Takeoff
1.2	Control
1.2.1	Control Commands Limits

Details

Type: Functional

Index: 1.2.1.4

Custom ID: #19

Summary: Pitch Command Limits

Description: Commanded Pitch angle shall not exceed 25 degrees in either direction

REQUIREMENTS

Index	Summary	Implemented	Verified
1	Flight Controller	✓	✓
1.1	Guidance	✓	✓
1.1.1	Heading Command limits	✓	✓
1.1.2	Yaw Command limits	✓	✓
1.1.3	Not start until flight is started	✓	✓
1.1.4	Transition to Descend	✓	✓
1.1.5	Finishing Flight	✓	✓
1.1.6	Transition out of Takeoff	✓	✓
1.2	Control	✓	✓
1.2.1	Control Commands Limits	✓	✓
1.2.1.1	Velocity Command Limits	✓	✓
1.2.1.2	Lateral Acceleration Command Limits	✓	✓
1.2.1.3	Vertical Acceleration Command Limits	✓	✓
1.2.1.4	Pitch Command Limits	✓	✓

Requirement: #25

Type: Functional

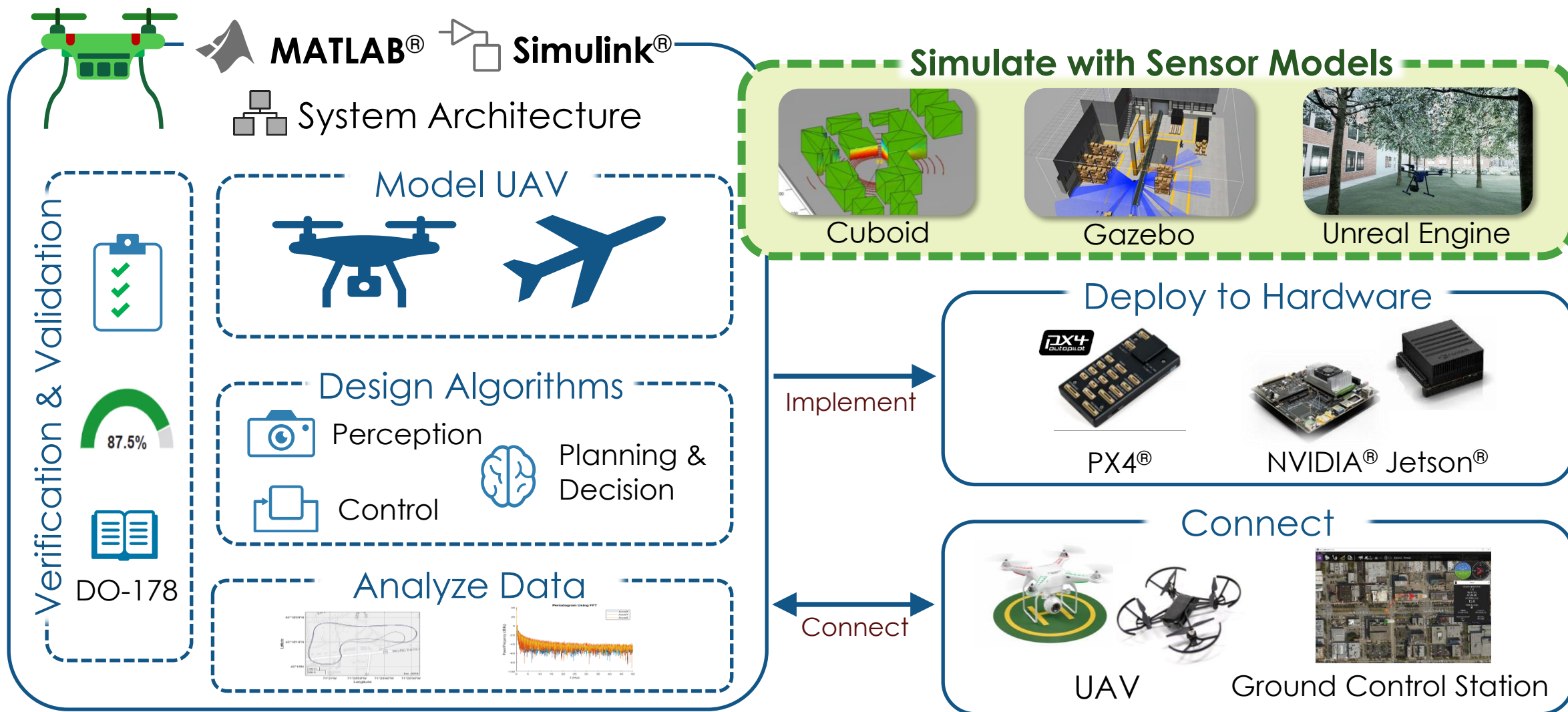
Index: 1.2.2.1

Custom ID: #25

Summary: Lateral Position Steady State

Description: Vehicle shall reach a steady state within 50 cm of its lateral (XY) commanded position

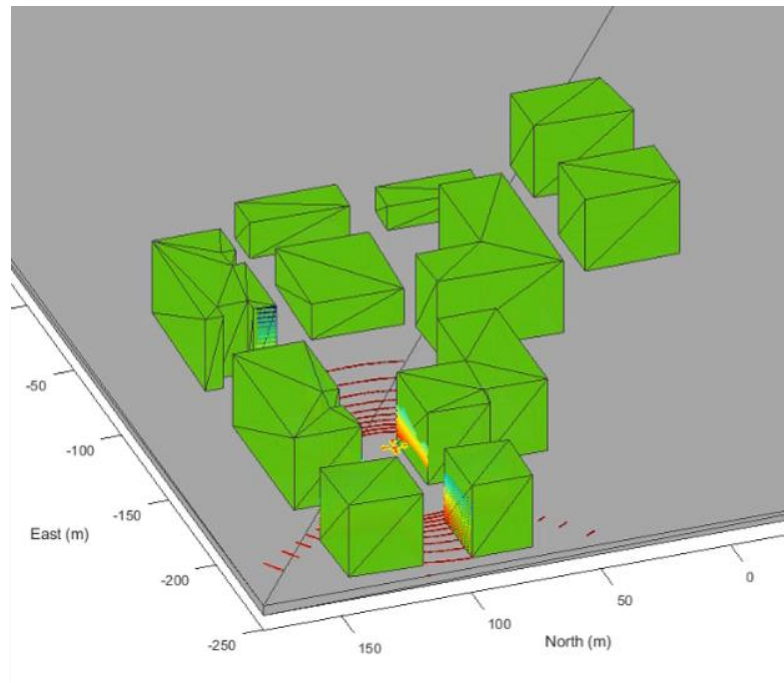
# Integrated workflows for developing UAV applications



# Integrated simulations with sensor models

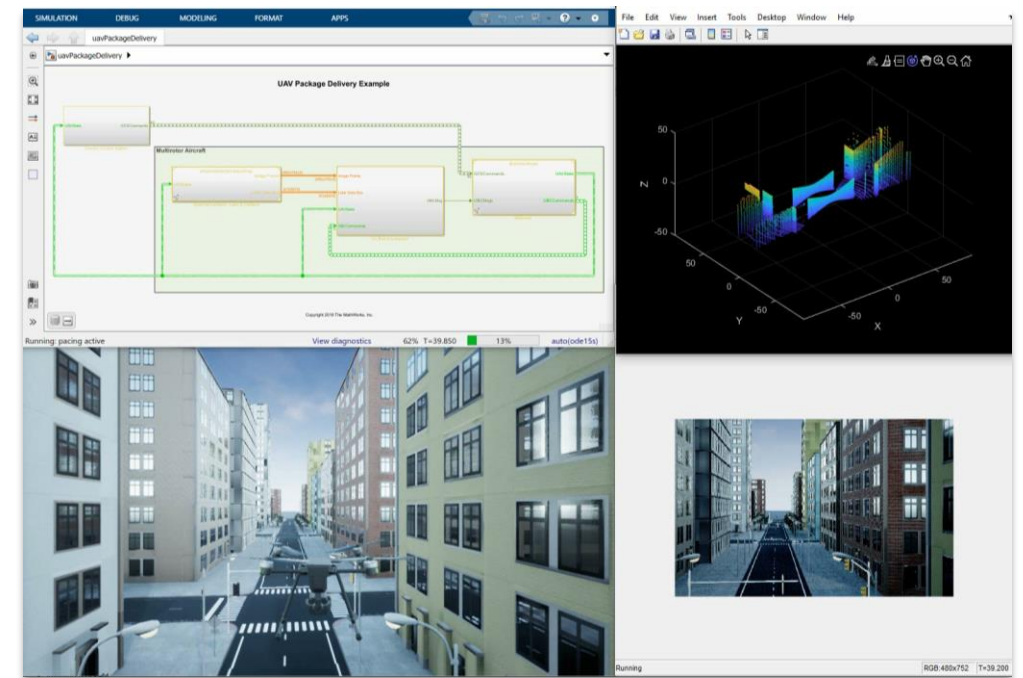
**Cuboid**  
*Performance*

**Unreal Engine®**  
*Photorealistic*



Rapidly author scenarios and generate sensor data

[Link](#)



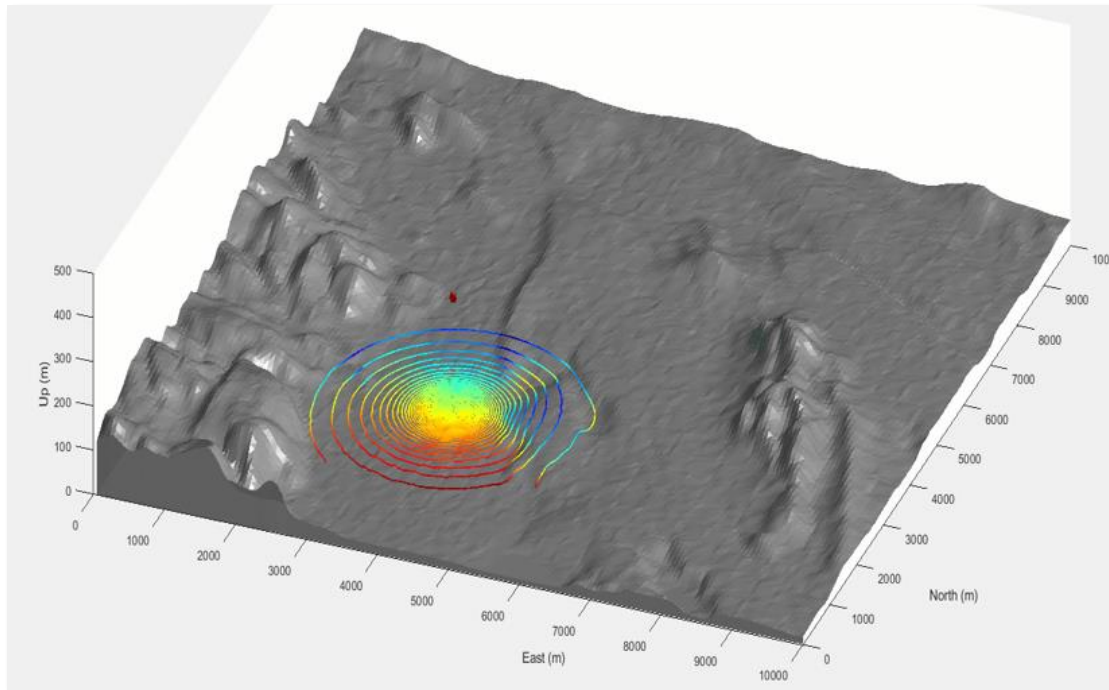
Realistic graphics to test autonomous algorithms in closed-loop simulations

[Link](#)

# Integrated simulations with sensor models

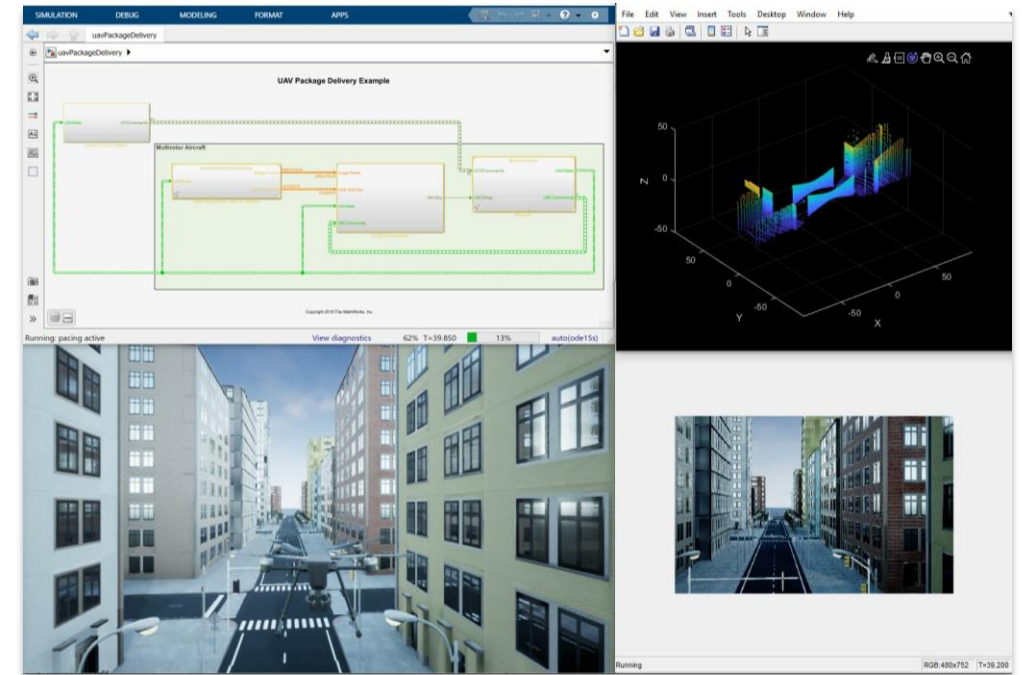
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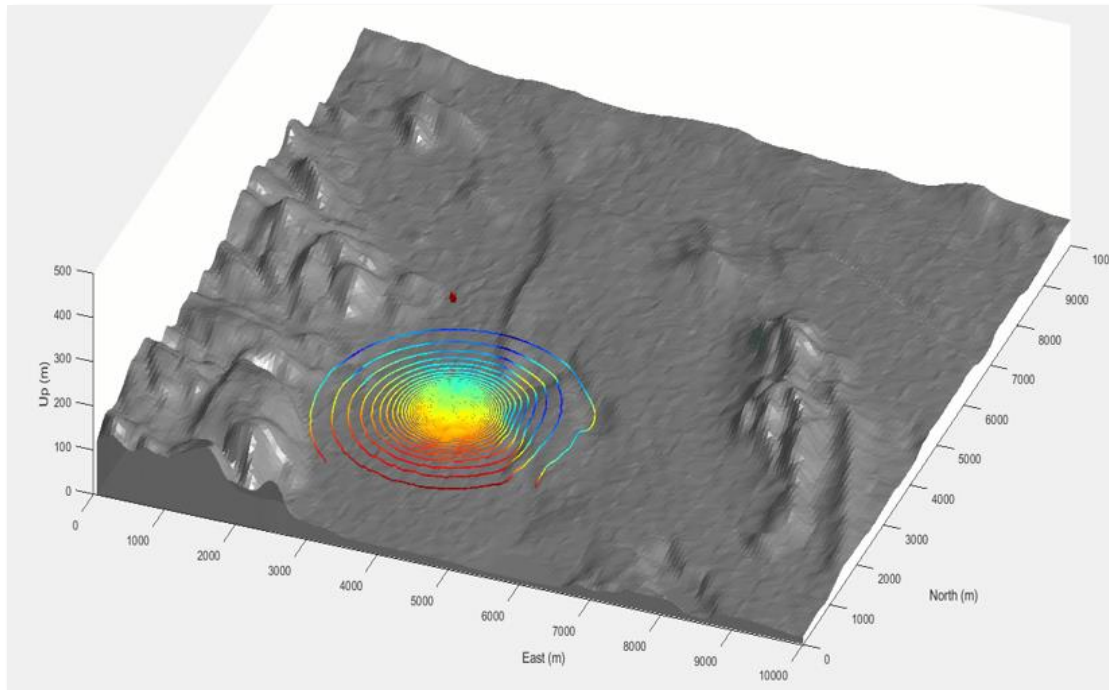
Realistic graphics to test autonomous  
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[Link](#)

# Integrated simulations with sensor models

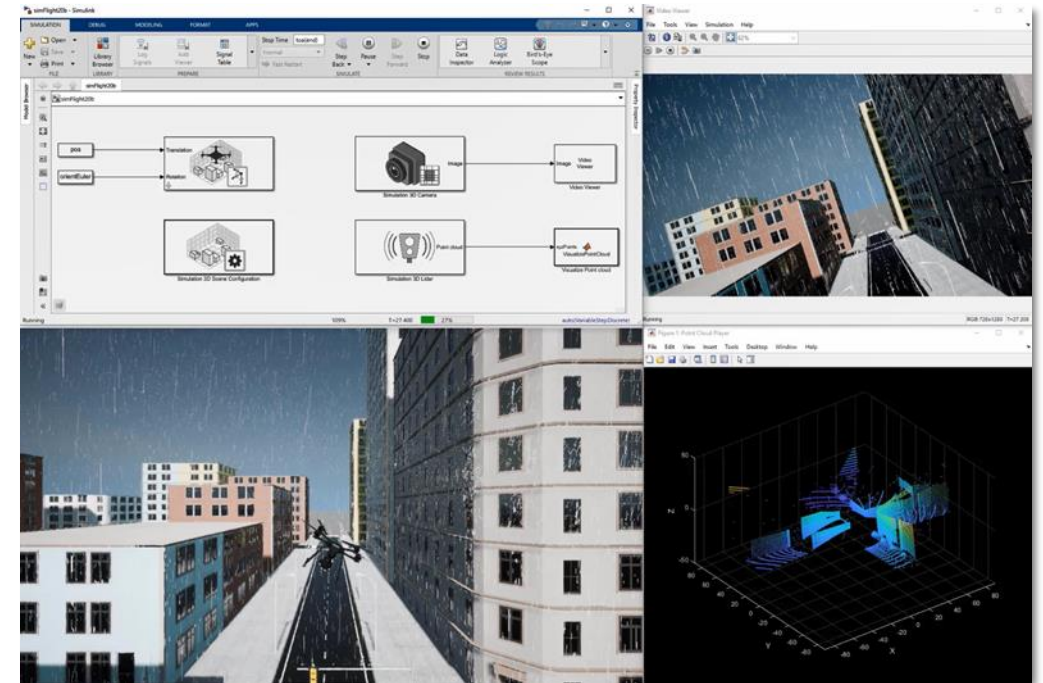
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Rapidly author scenarios and generate sensor data

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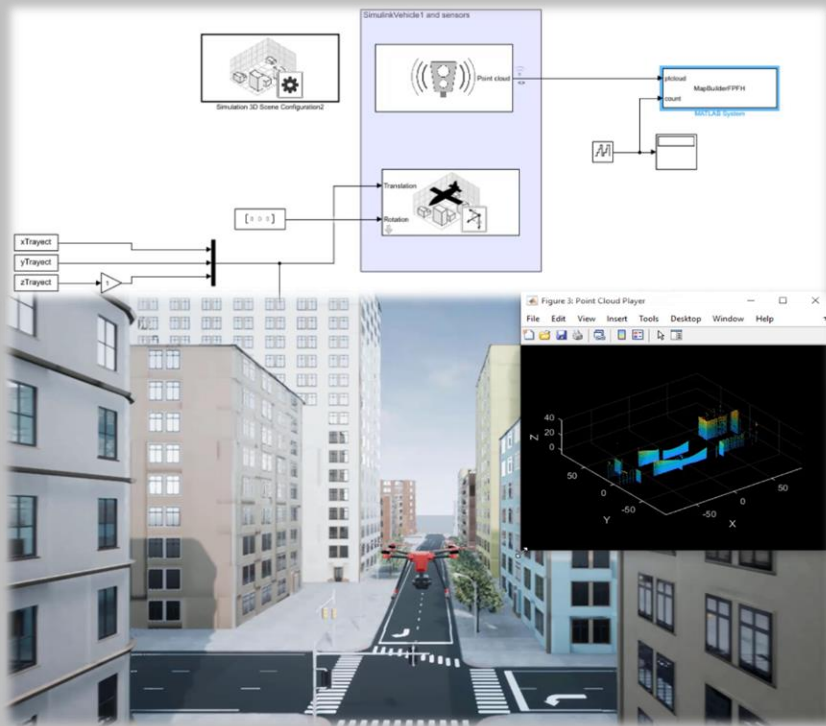


Realistic graphics to test autonomous algorithms in closed-loop simulations

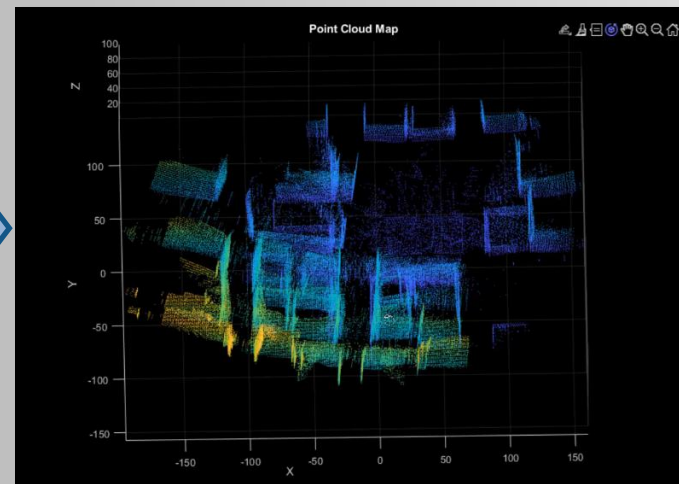
[Link](#)



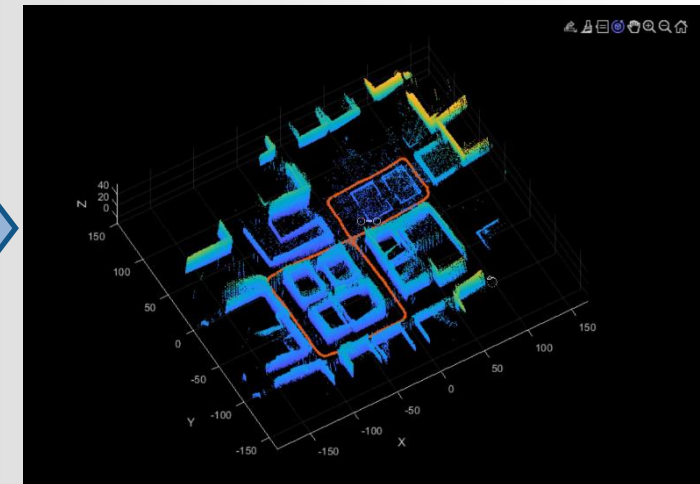
# Example: Build 3D map using simulation Lidar point cloud data



Execute simulation  
Obtain sensor data

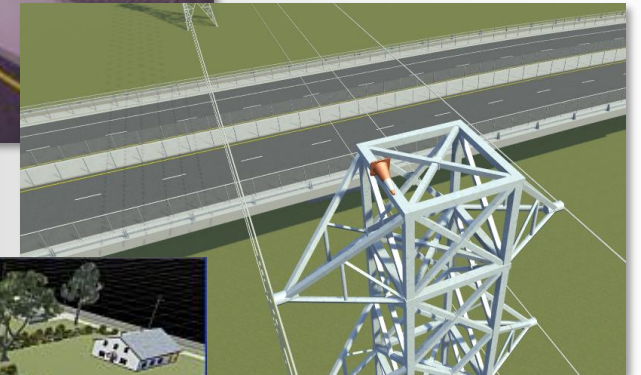


Extract and match features  
Register and align point cloud



Detect loop-closures  
Create pose graph  
Optimize poses

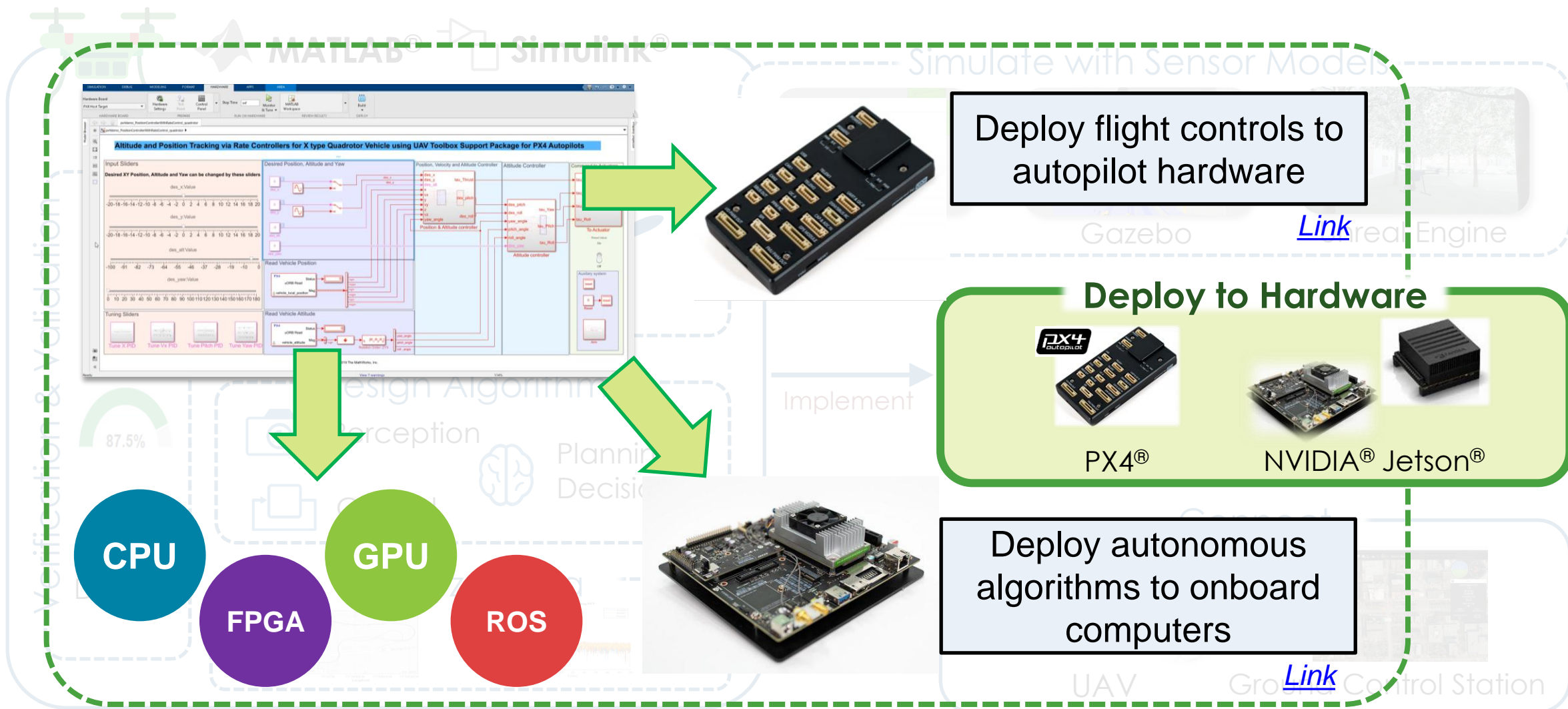
# Create 3D scenes for UAV simulations



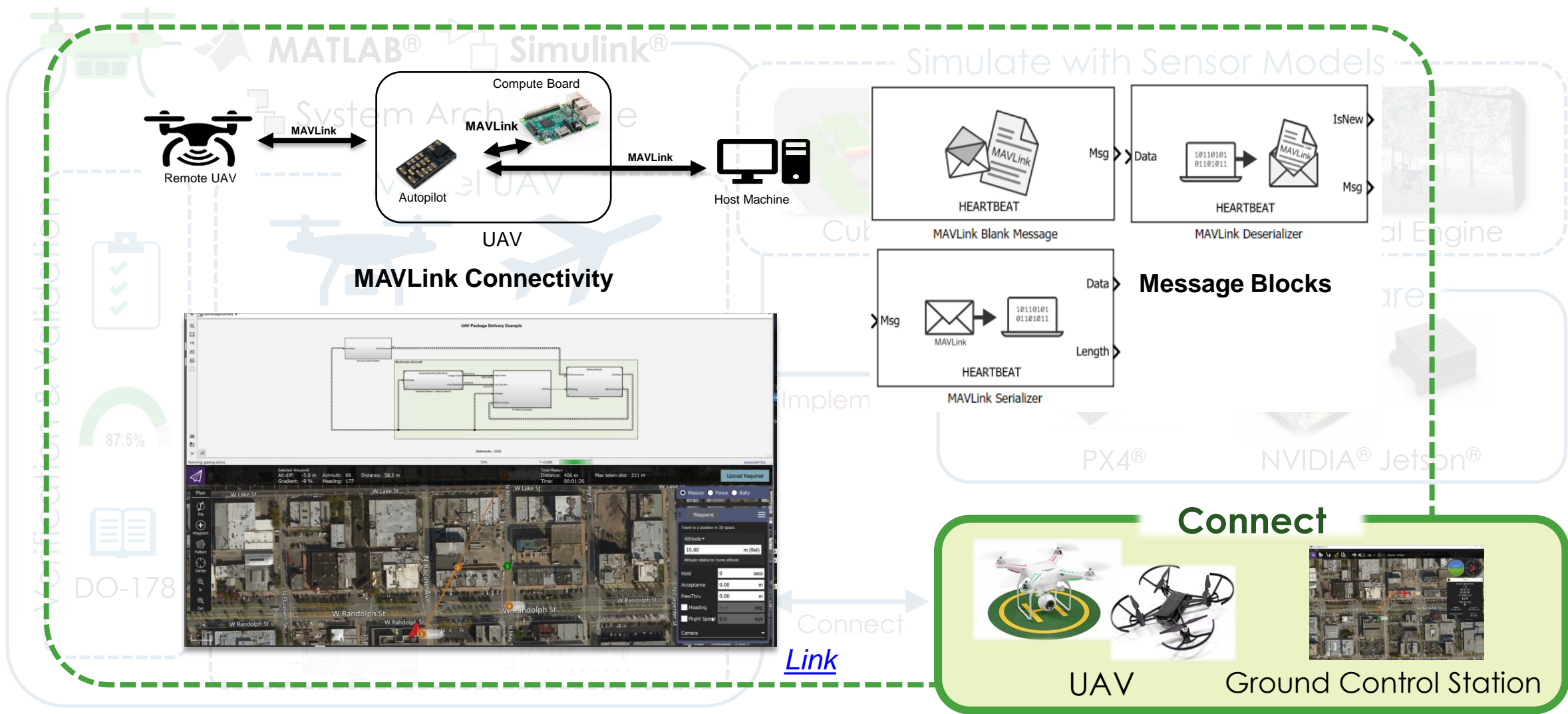
[Link](#)

Design 3D scenes for simulating and testing autonomous algorithms

# Automatic code generation for hardware implementation



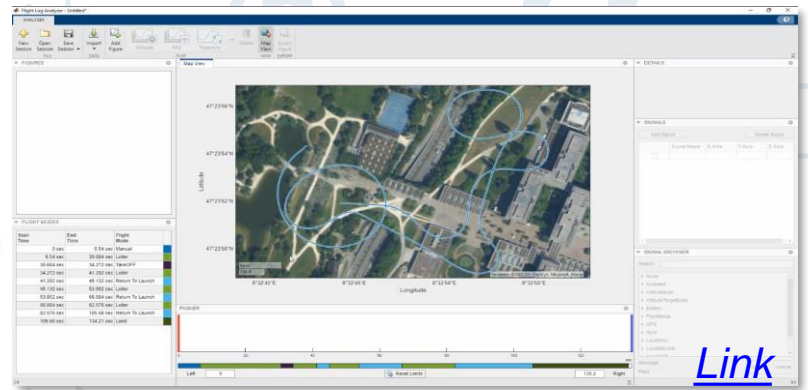
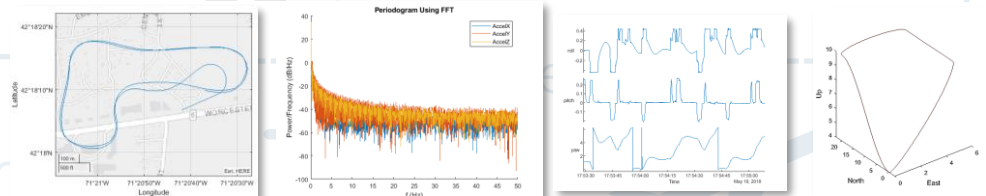
# Connecting to UAV hardware through MAVLink protocol



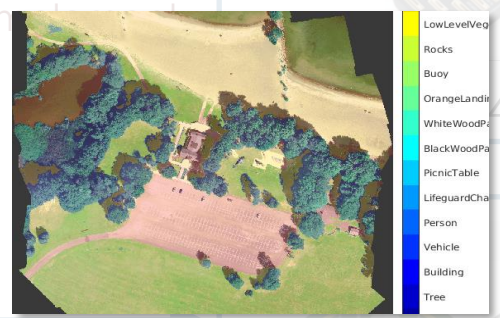
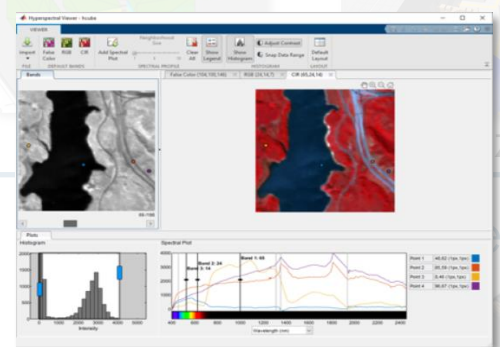
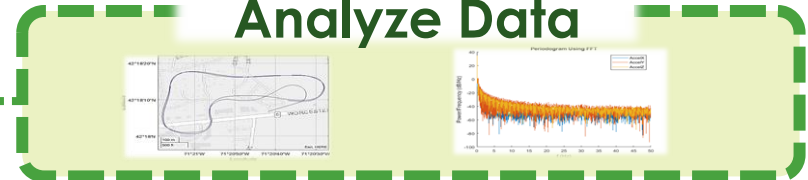
# Post-flight data analysis

## Flight Log Analysis

## Payload Data Analysis



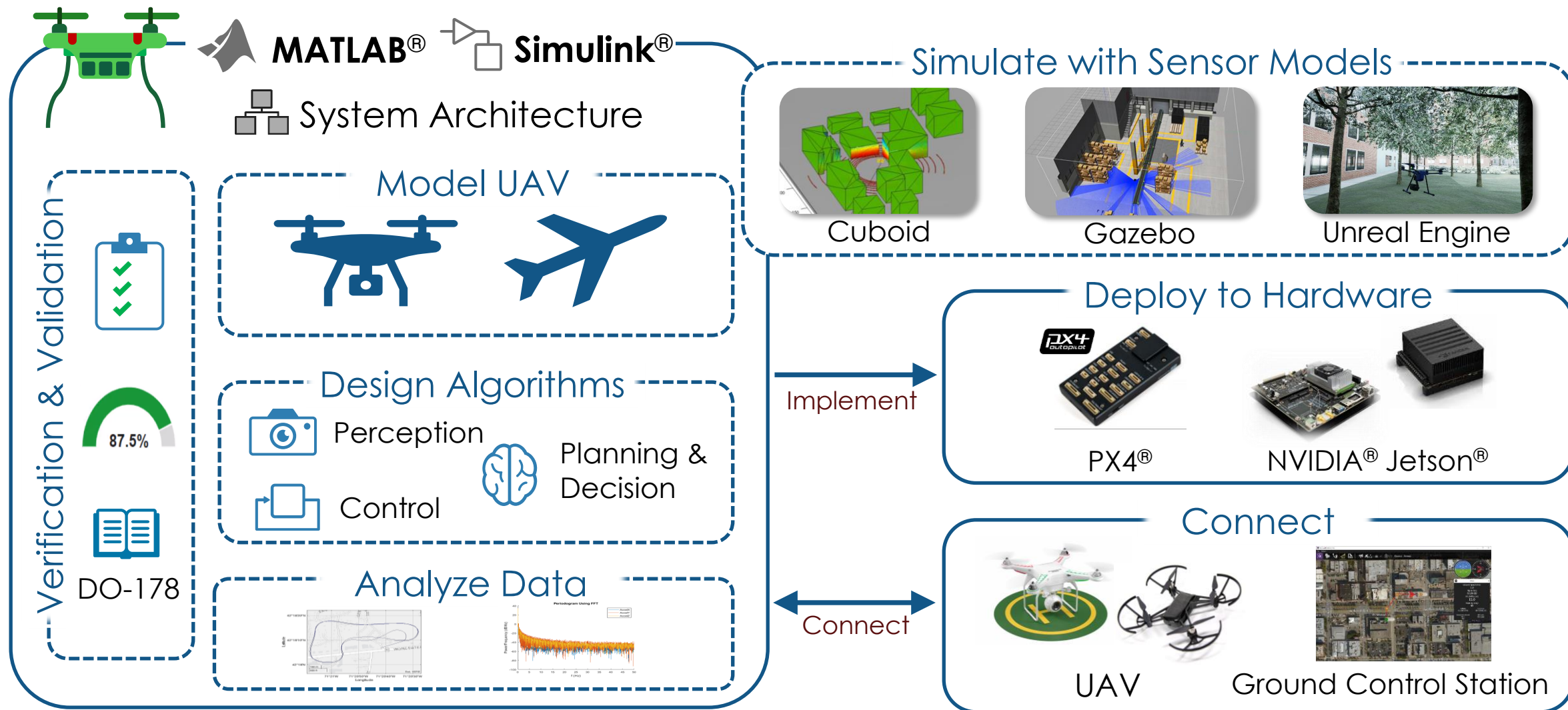
## Analyze Data



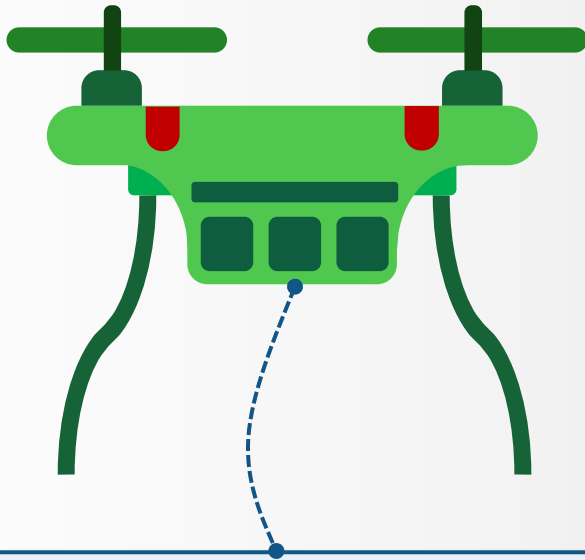
Connect [Link](#) [Link](#) [Link](#)

UAV Ground Control Station

# Integrated Workflows for Developing UAV Applications



## Key Takeaways



### Call To Action:

- Download presentation file and investigate linked examples and pages
- Contact us for to learn more details or for trials



Integrated development workflows from prototyping to productization with MATLAB and Simulink



Robust tools/features for autonomous UAV design and simulations with sensor models



Quality through verification & validation tools for traceability, test completeness, and test management/automation

# MATLAB EXPO

## 2021

Thank you



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# Q&A

