Various levels of Simulation for Slybird MAV using Model Based Design

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Autonomous and remotely controlled Micro Aerial Vehicles (MAVs) have gained a high level of popularity during the last decade both in civilian and military applications. National Aerospace Laboratories (NAL) has been carrying out research and development activities on various supporting technologies crucial for the development of MAVs thereby enhancing the performance of the vehicle to accomplish various missions.

NAL Slybird is a mini-unmanned aerial vehicle (UAV) developed by NAL. Its primary users will be police and the military services. Design & implementation of an autopilot in such systems assumes the next priority in achieving an autonomously flying MAV. An essential requirement to achieve the above goal is through a suitable modeling & simulation platform. Thus, this presentation takes the audience through the strategies developed for performing various levels of MAV simulation.

The following levels of simulation are performed for Slybird MAV using MATLAB/Simulink:

- Open Loop Simulation (OLS)
- Model In the Loop Simulation (MILS)
- Software In the Loop Simulation (SILS)
- Processor In the Loop Simulation (PILS)
- Hardware In the Loop Simulation (HILS)

The OLS responses are validated with actual flight data and results will be shown. The MILS and SILS include various subsystems such as estimator, path planning and control algorithms all developed in SIMULINK. Demonstration of PILS for Slybird MAV using open source mission planner software and ARDU autopilot (APM 2.6) will also be performed. The HILS architecture discussed in this presentation is a demonstration of rapid prototyping technique using RTWT and XPC Target.

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Motivation

- In order to design robust and reliable flight guidance and control systems, it is essential to have mathematical models of the airframe dynamics and other subsystems of adequate fidelity.
- There is also a need to develop a simulation and testing framework that enables seamless integration of onboard software from design to onboard implementation.
- Accurate modeling and simulation of aircraft achieves significant reduction in flight testing time and hence is efficient.

Slybird MAV

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- Slybird is an Micro Air Vehicle (MAV) developed by National Aerospace Laboratories with surveillance as the main application.

Wind tunnel testing

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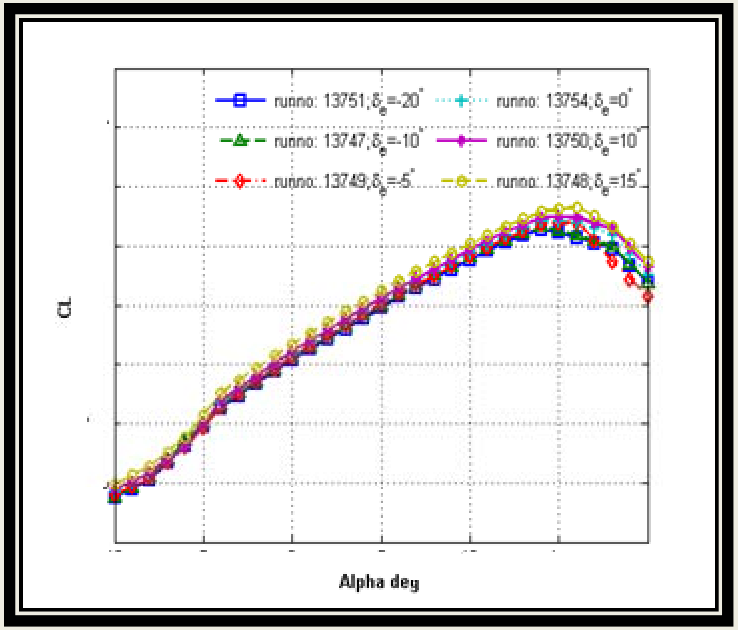
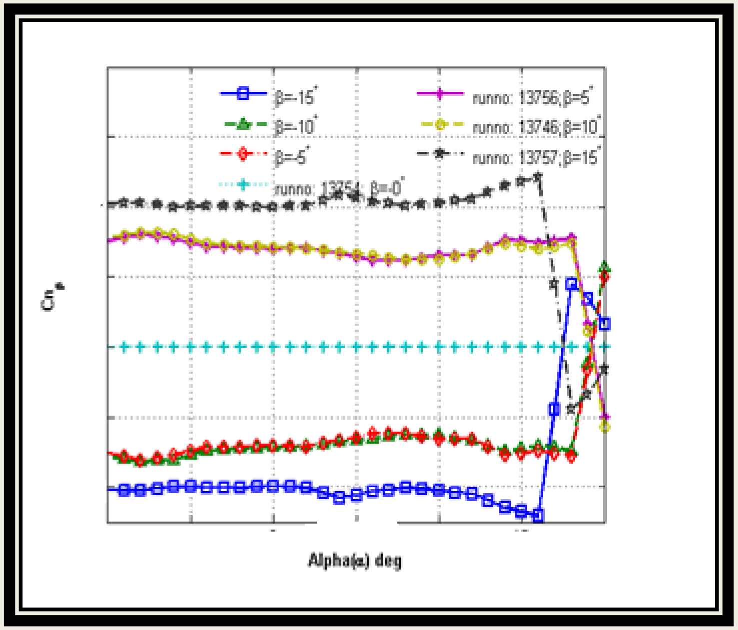
- At HAL, Bangalore low speed wind tunnel Slybird 1:1 model is tested to yield the aerodynamic data required for building up the simulation.
- The data is subsequently modeled as multi dimensional look up tables for making the aerodynamics block.





Other data requirement

- RPM versus thrust data to model the propeller.
- Mass, CG, Inertia data.
- Geometry data such as wing span, wing surface area and mean aerodynamic chord.

Trimming

- Trimming is a condition where all state derivatives are zero. This condition is essential to start the simulation with proper initial conditions.
- Numerical trim is performed using the linearization tool. This is optimization program whose cost function is xdot=0.
- Here wings level trim is performed that solves for elevator, throttle, angle of attack.

Screen shot for trimming

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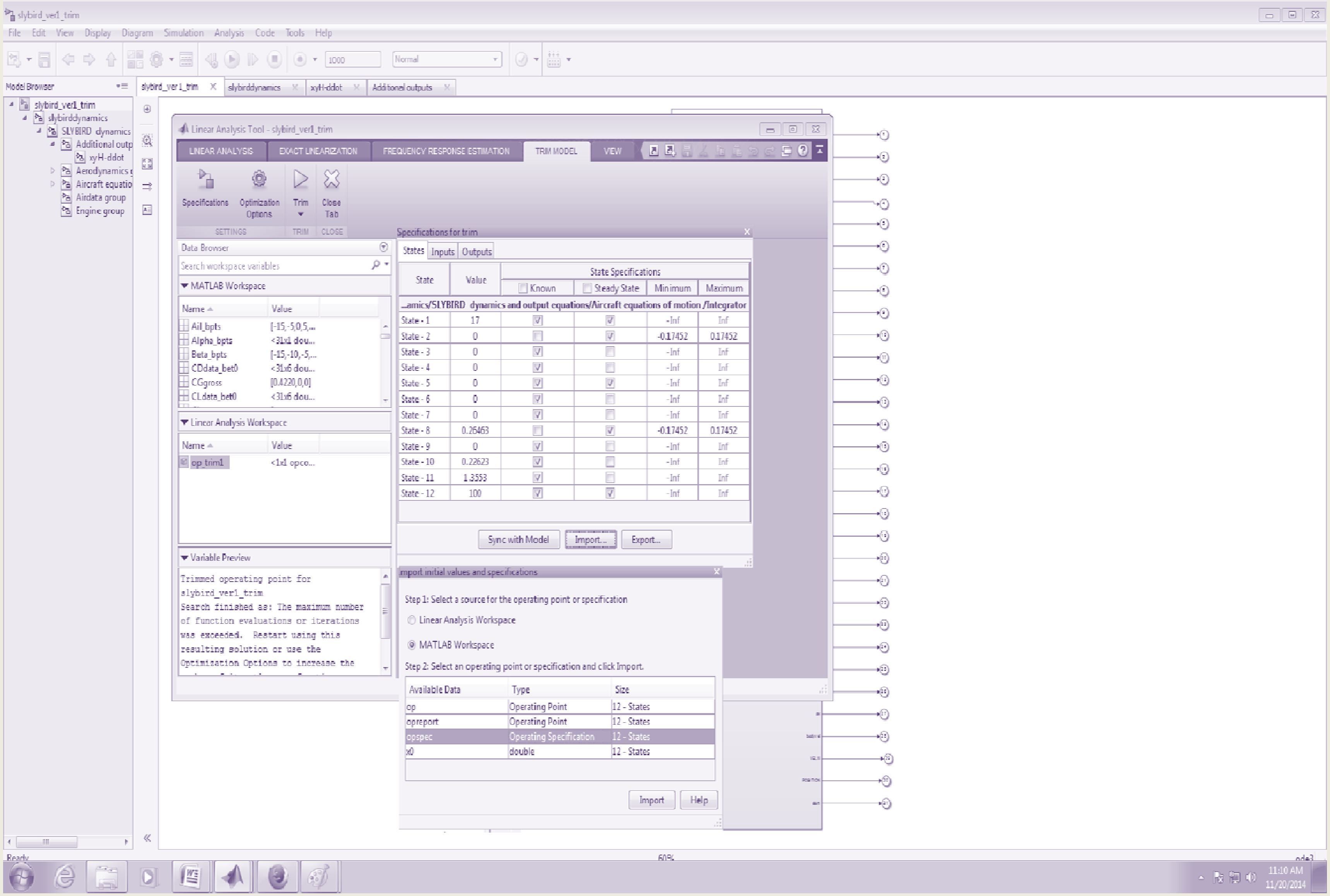

Linearization

- Linearization tool is used to achieve this.
- Linear analysis points are selected.
- Linear models are generated as per the required trim values.
- Based on the linear models, the control design is carried out.
- Matlab code can be generated for trimming and linearization from the tool for batch processing.

Screen shot for linearization and Matlab code generation

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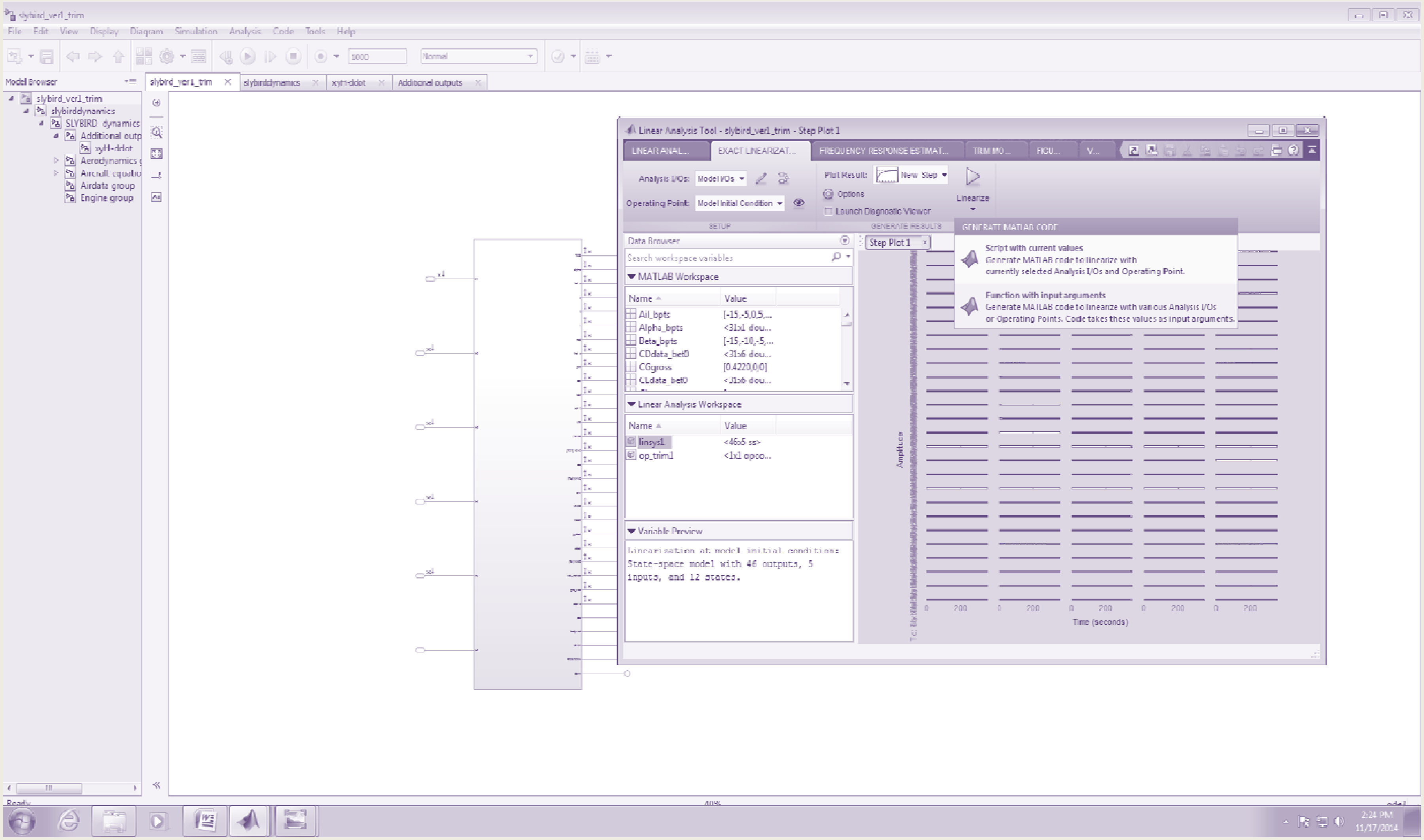

Slybird - Closed loop architecture

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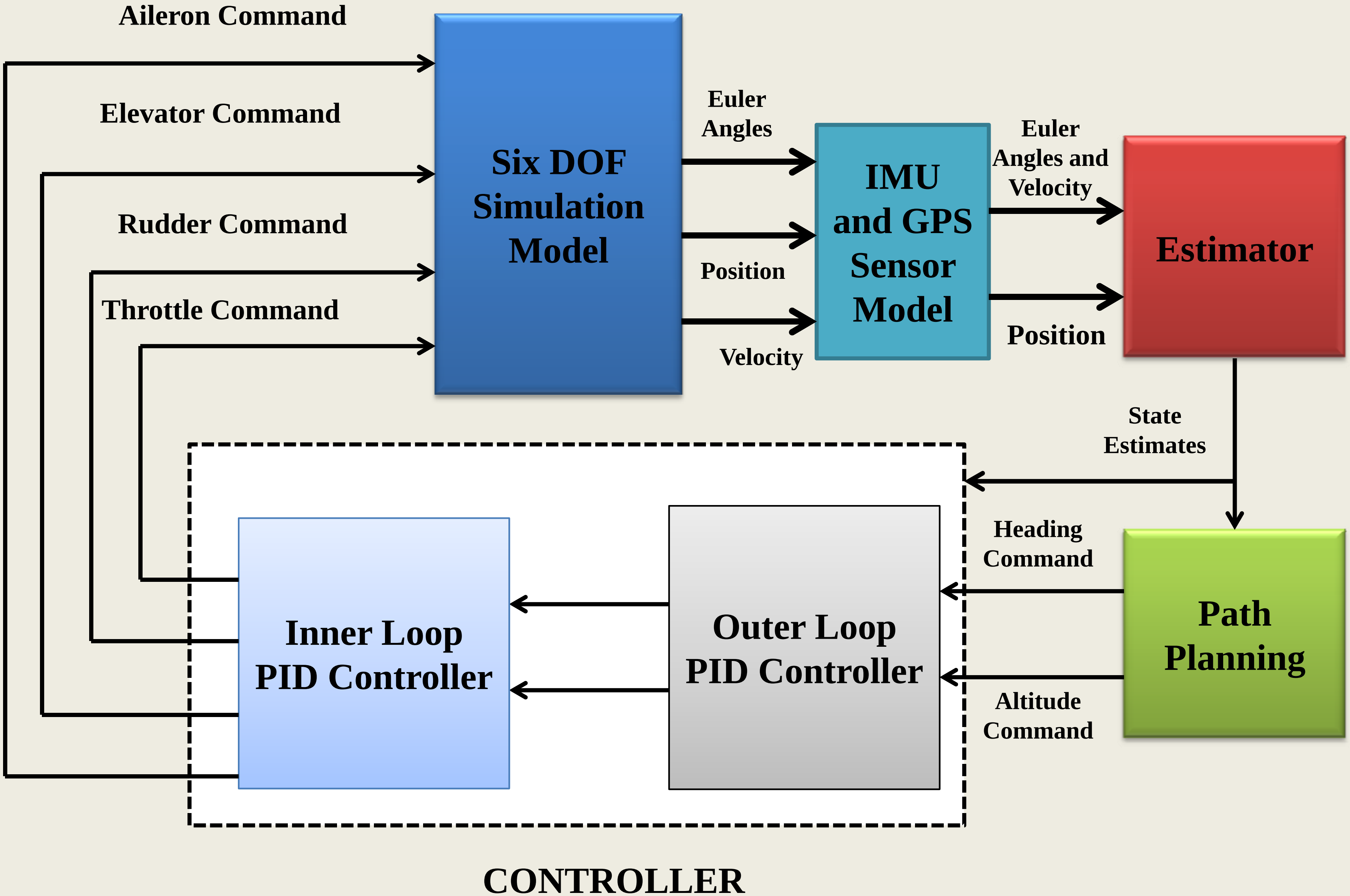

Various levels of Simulation

- Open Loop Simulation
- Model In the Loop Simulation (MILS)
- Software In the Loop Simulation (SILS)
- Processor In the Loop Simulation (PILS)
- Hardware In the Loop Simulation (HILS)

Open Loop Simulation-Slybird

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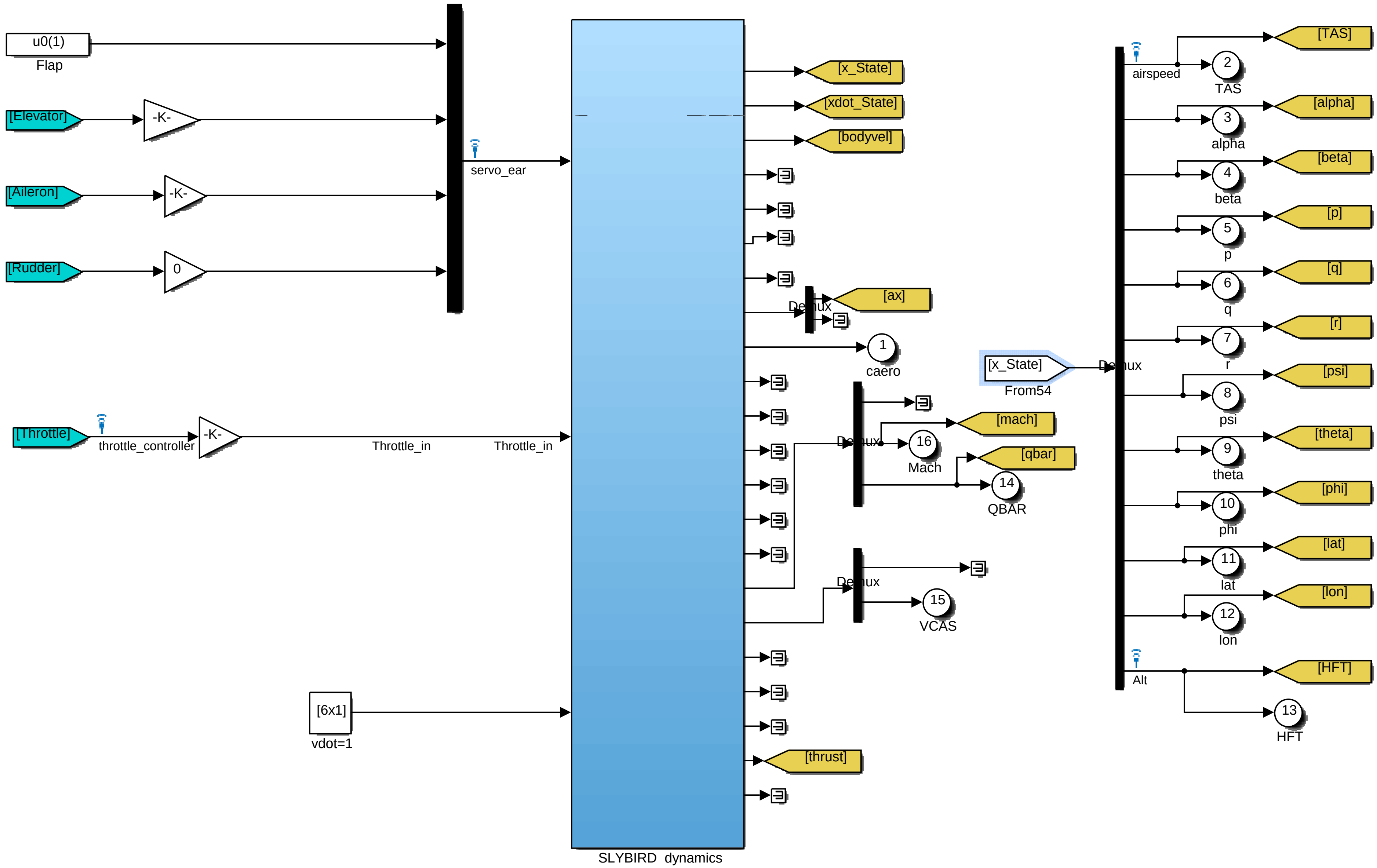
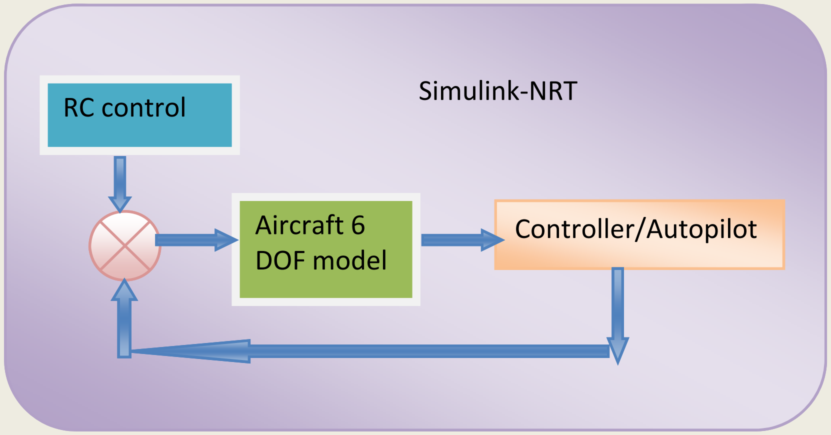


Autopilot Modes

- Manual
- Stabilized
- Return to launch
- Loiter
- Fly by wire
- Auto (Take off, landing and way point navigation)

Model in the Loop Simulation

- Here the aircraft OL model and the controller model run in the same PC in offline mode.
- This simulation required to design the control guidance and estimation algorithm.



Slybird - MILS

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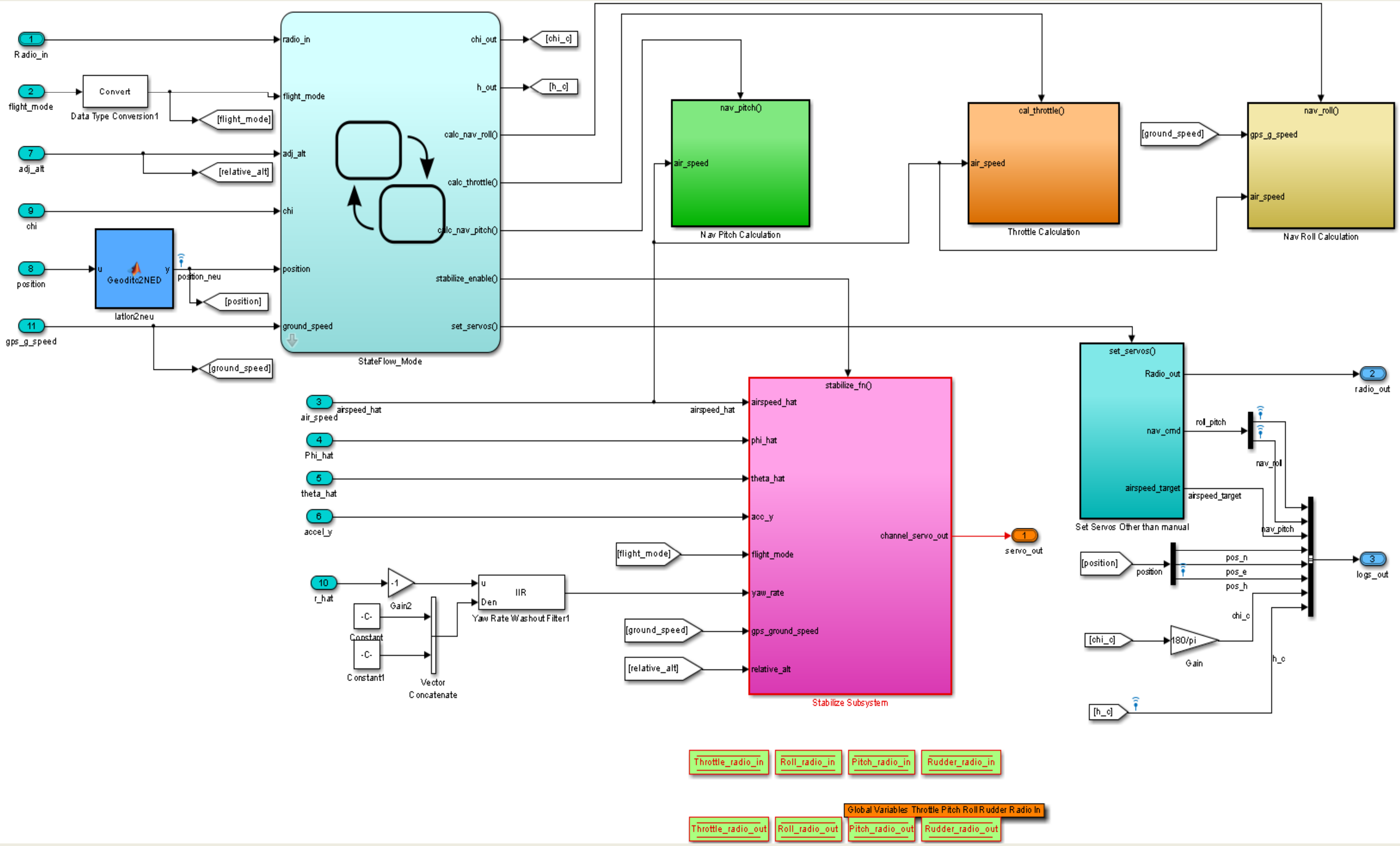

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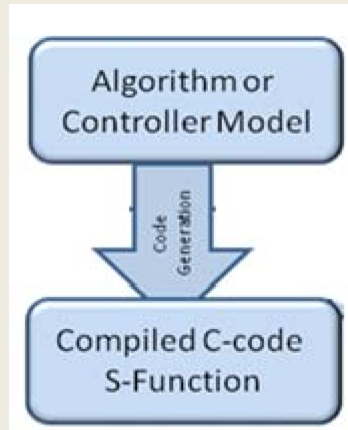
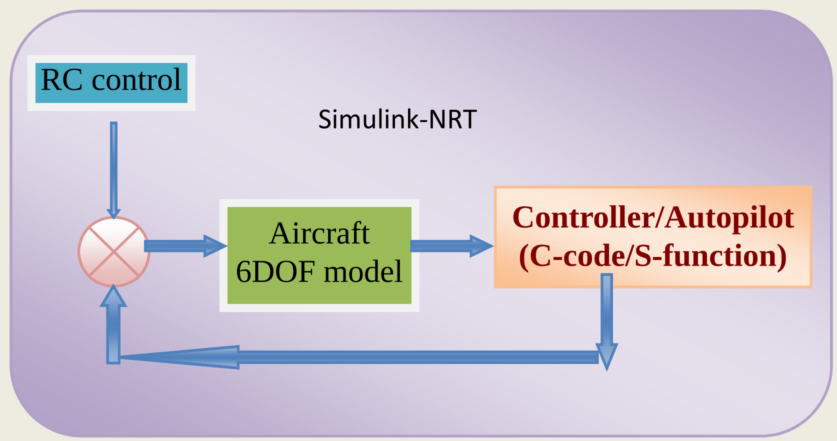
Slybird - SILS

- Compiled code is incorporated into the overall simulation
- Required for evaluation of onboard auto code functionality in designer's desk .



Execution on
Host Computer
Non Real Time
No I/O



Rapid Control prototyping

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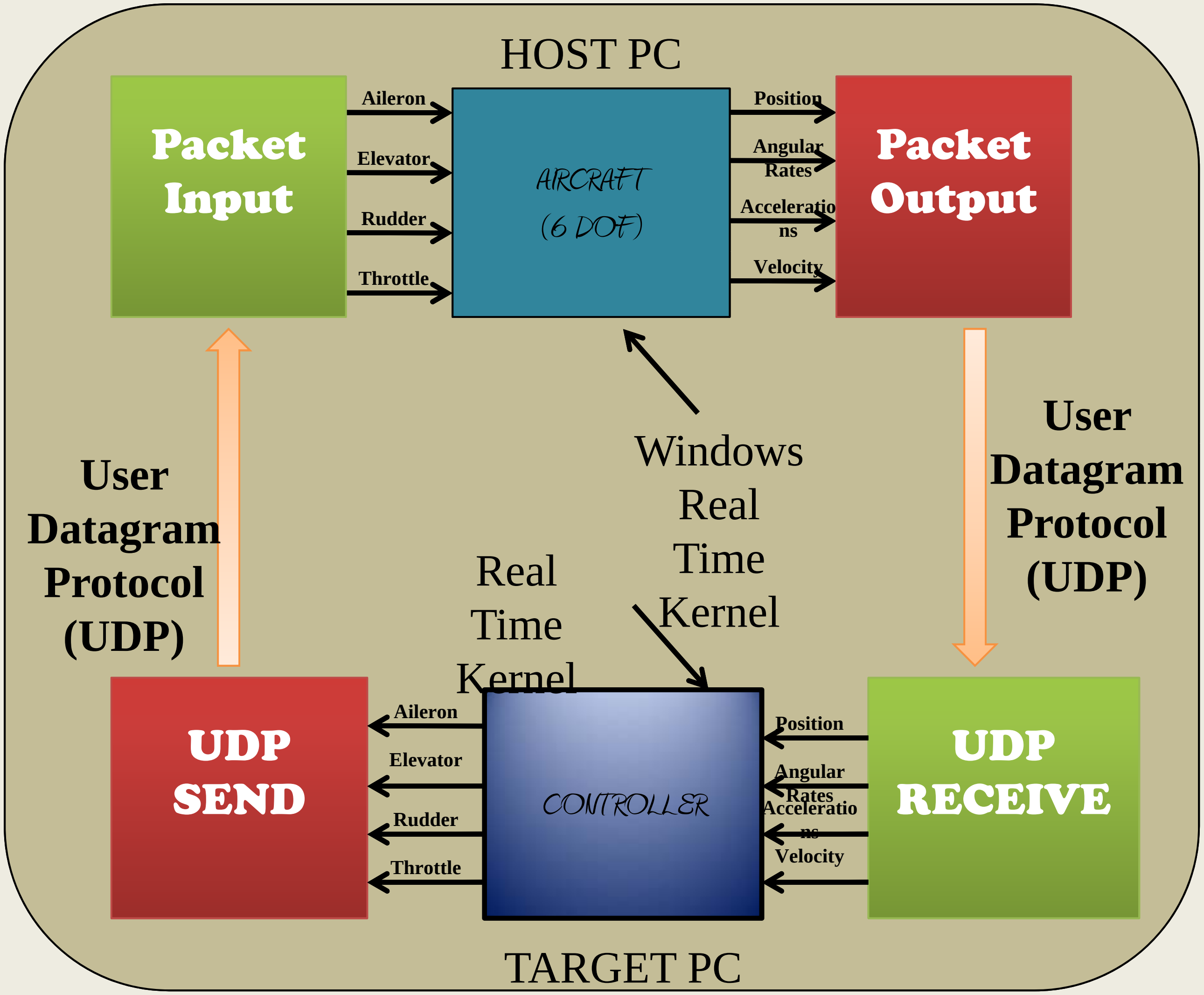
This is intended to verify the onboard code on a generic target before burning the code on the actual target hardware.

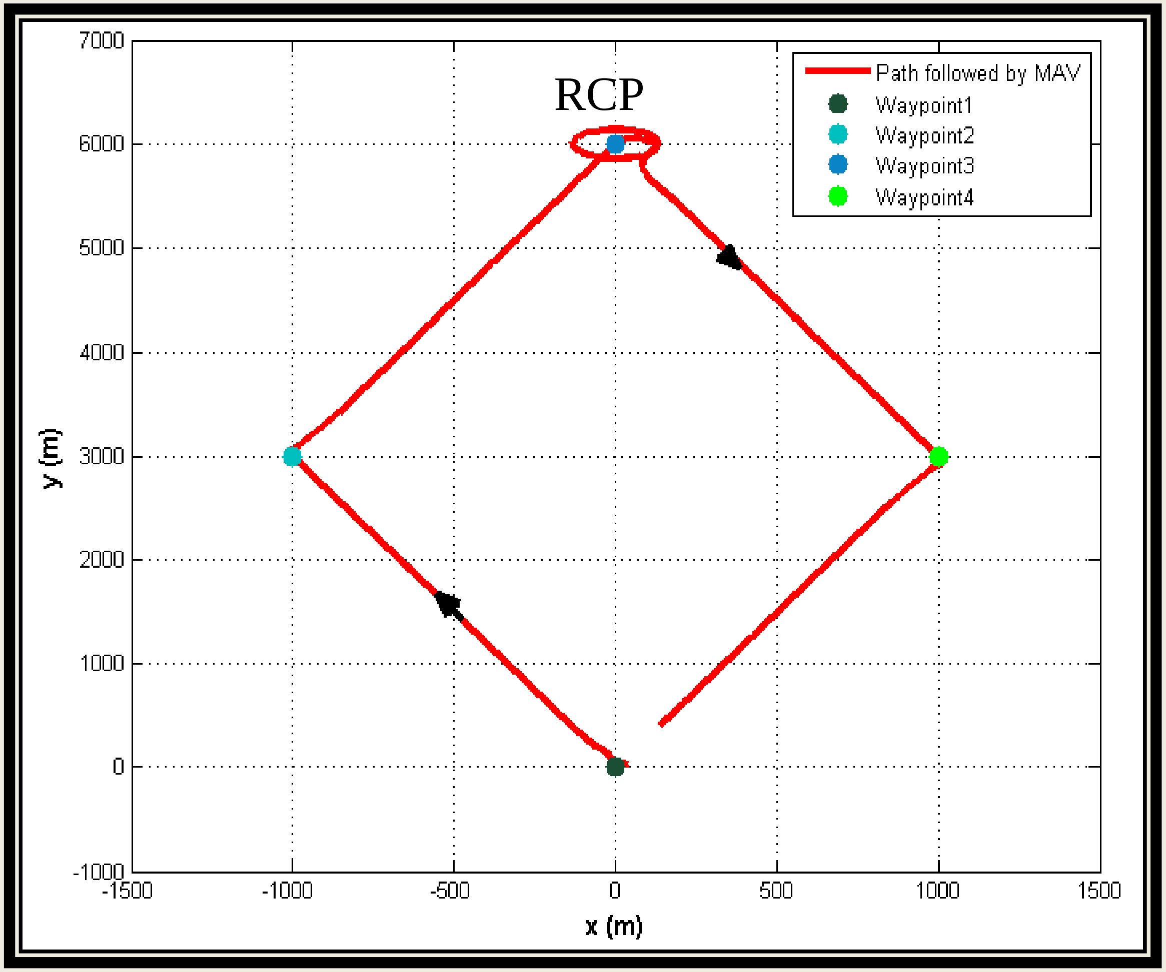
- The aircraft 6 DOF simulation application will be running in the windows real time environment

- Controller simulation application will be running in the xPC target environment.

- The data's are exchanged by using an UDP protocol in real time.



Results


RCP
Path followed by MAV
Waypoint1
Waypoint2
Waypoint3
Waypoint4
7000
6000
5000
4000
3000
2000
1000
0
-1000
-1500
-1000
-500
0
500
1000
1500
y (m)
x (m)

PILS

- Aircraft model runs in the accelerated mode.
- The controller runs on the target micro controller (autopilot hardware)
- No input/output cards are used, a USB connection is used to exchange data between the control system and the model.
- The purpose of this simulation is to test that all functionalities of the controller are correctly computed in the target hardware.

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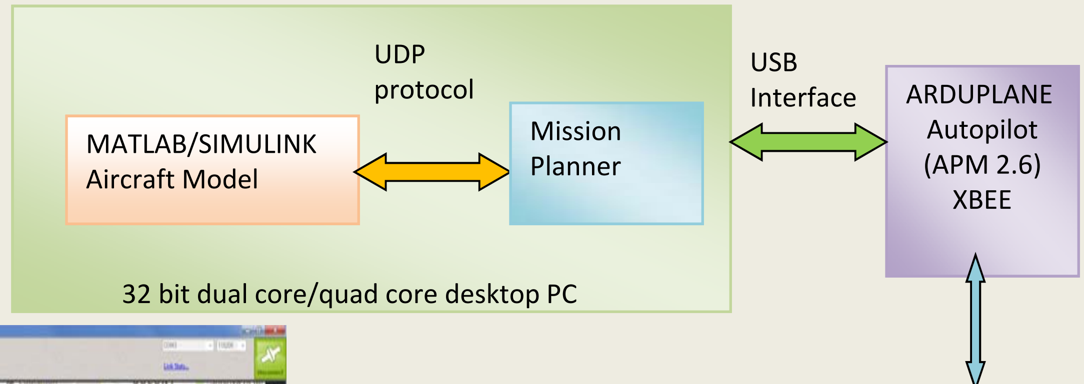
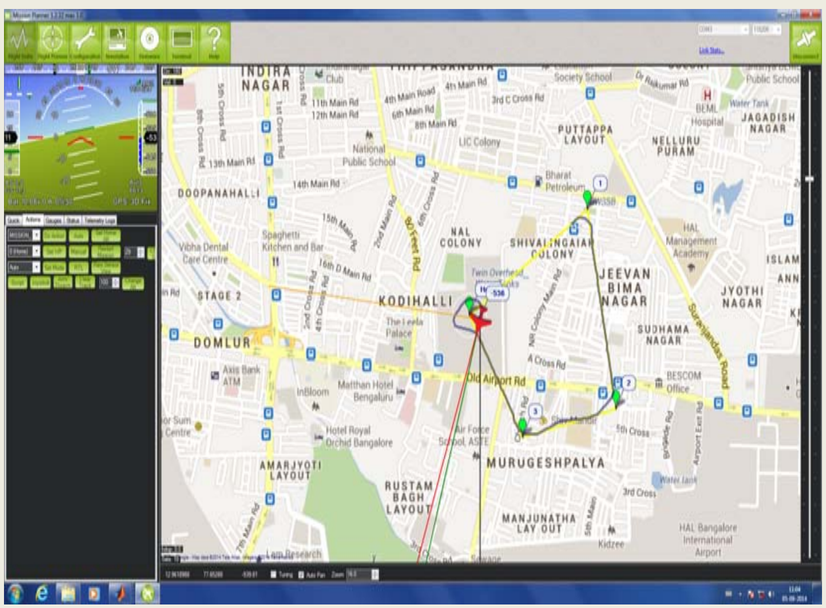
Architecture of PILS with ARDUPLANE (APM 2.6) and Mission planner





PILS with APM 2.6 and Mission planner

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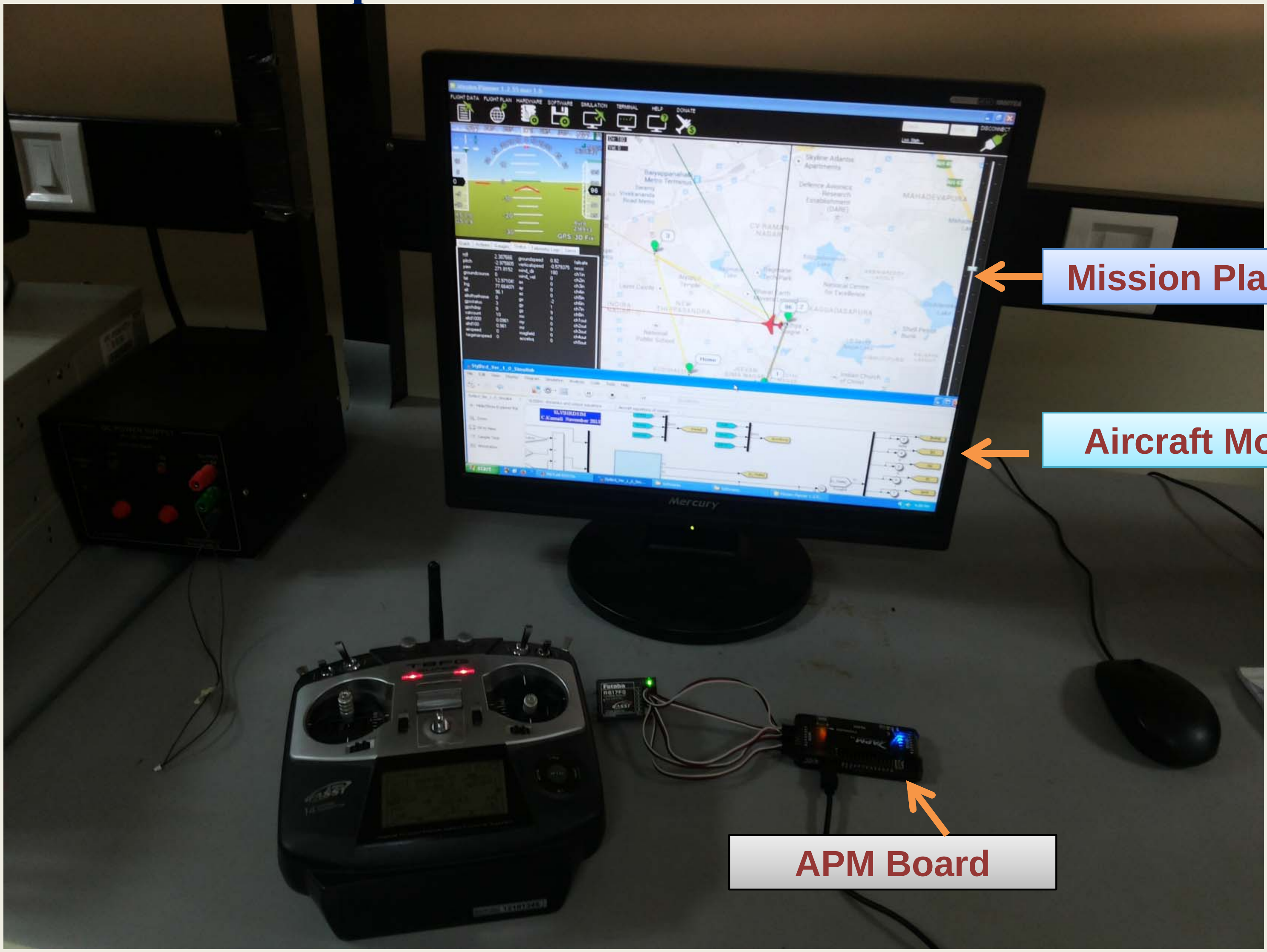

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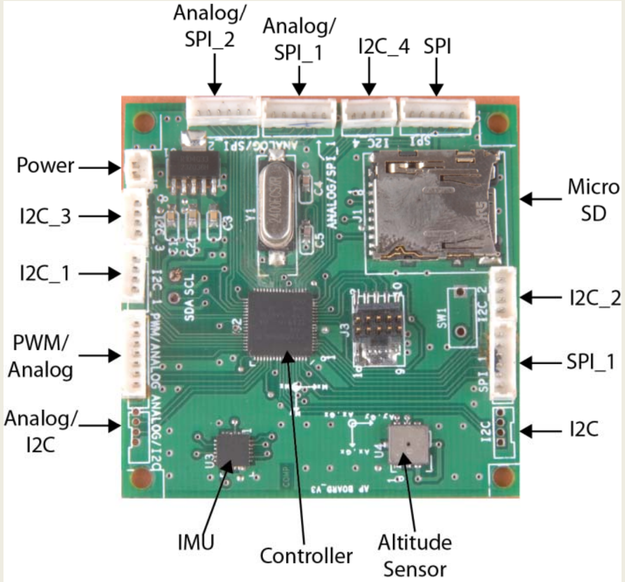
NAL Autopilot

- Designed with four layer PCB fabrication technology.
- Onboard IMU, onboard pressure sensor
- Data logging in micro SD card

Technical Specification

Parameter	Description	Range
Processor	ARM CortexM3 CPU core	32 - Bits
Vdd	Input Voltage	1.8 - 3.3 Volt
Clock	Operating Frequency	24 MHz
ROM	Programmable memory	256 Kbyte
JTAG Connector	Programming, debugging	10 Pin
I2C Interface	4 I2C Interface	100/400 Kbps
UART Interface	2 UART Port	9.6/57.6 Kbps
SPI Interface	3 SPI Port	>1 Mbps
PWM	16 Channels	3.3 V
Temperature	Industrial temperature	-40 to +85°C
Sensors	3 Axes (Gyro, Accelerometer, Magnetometer) + Static Pressure	
Dimensions	---	50mm x 50mm
Weight	---	12.2 grams



NAL Autopilot Version 3 (APV3)

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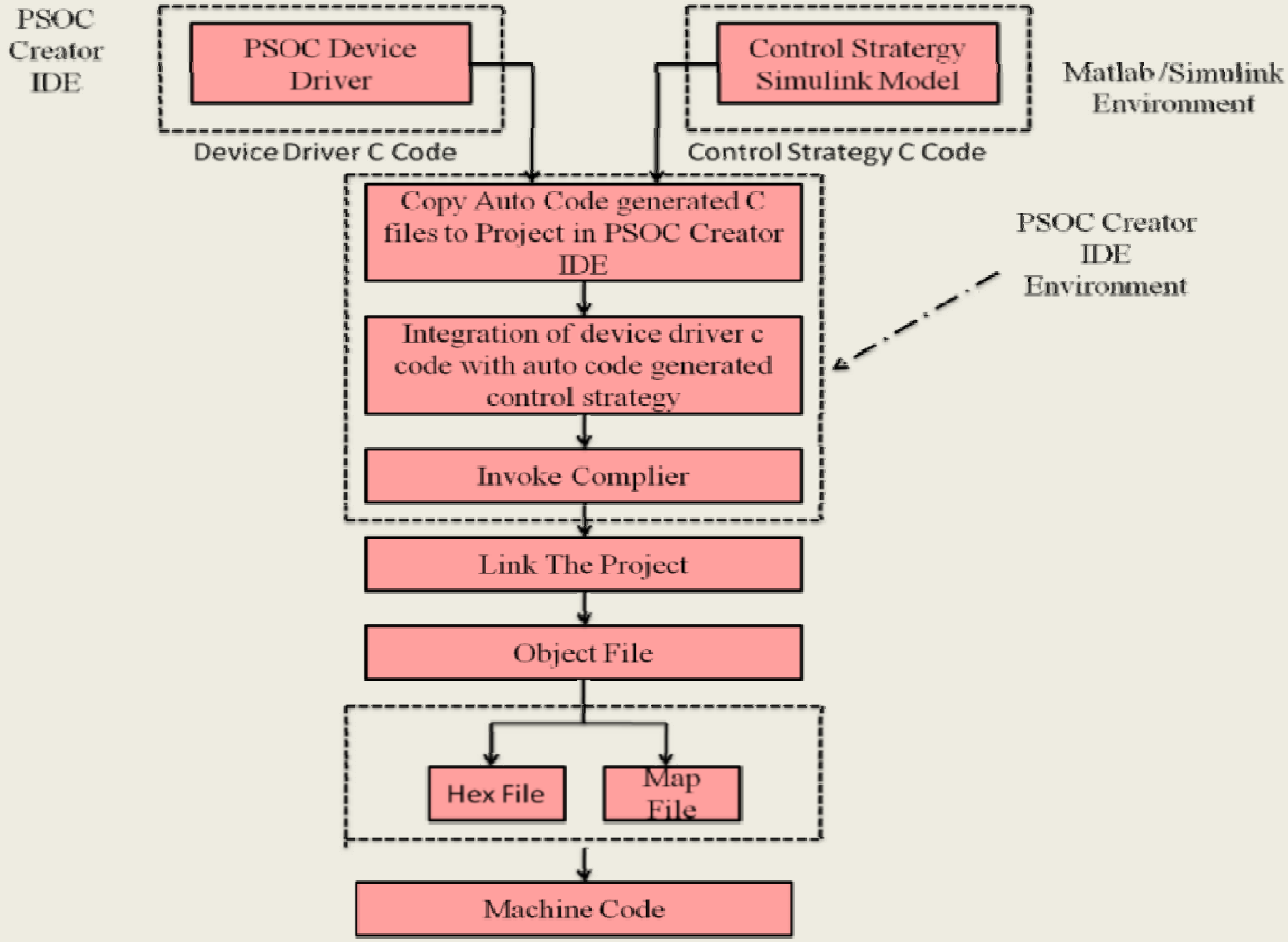
Procedure to deploy auto code in to an Embedded Target



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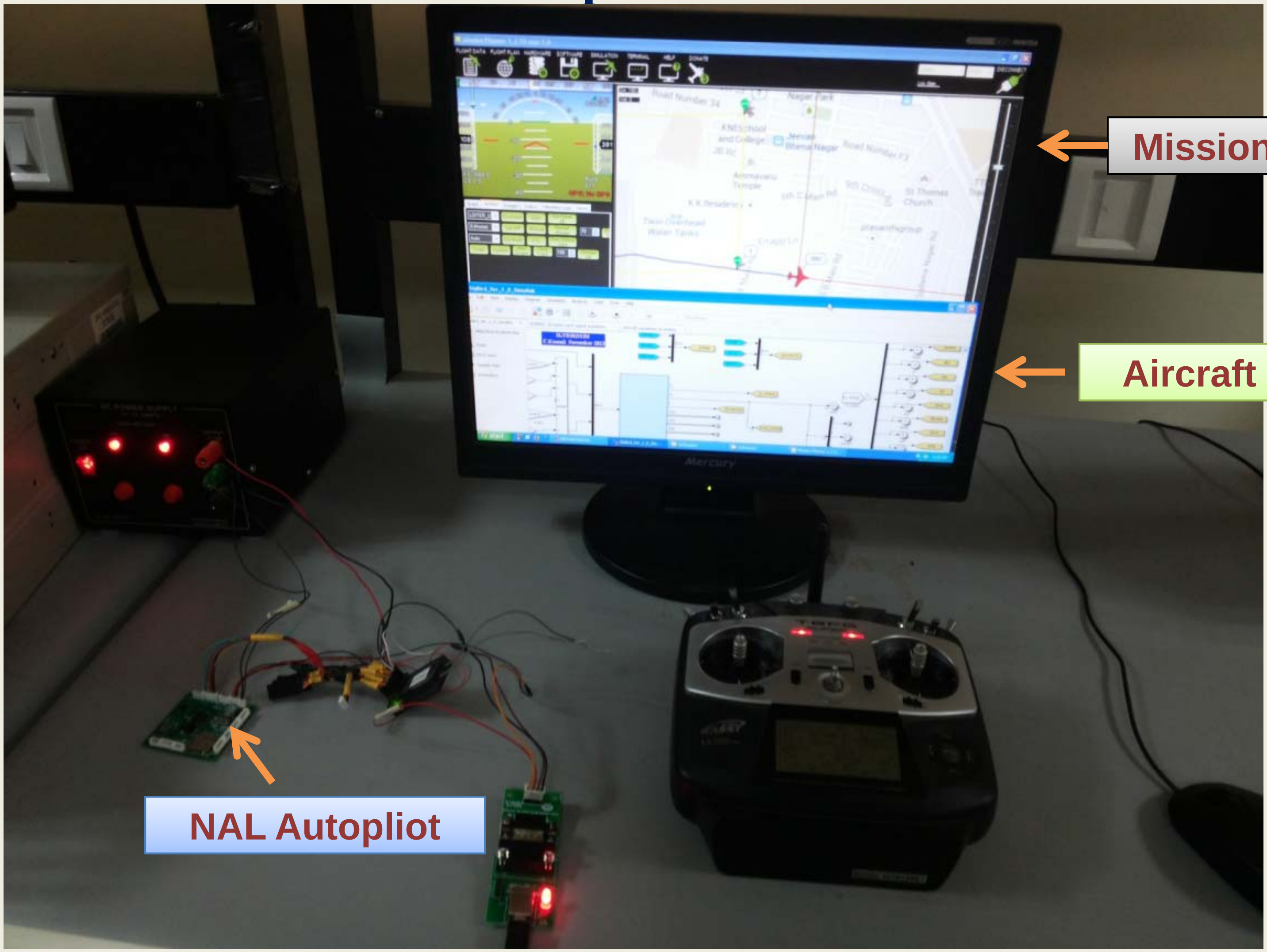
PILS with NAL Autopilot board and Mission planner

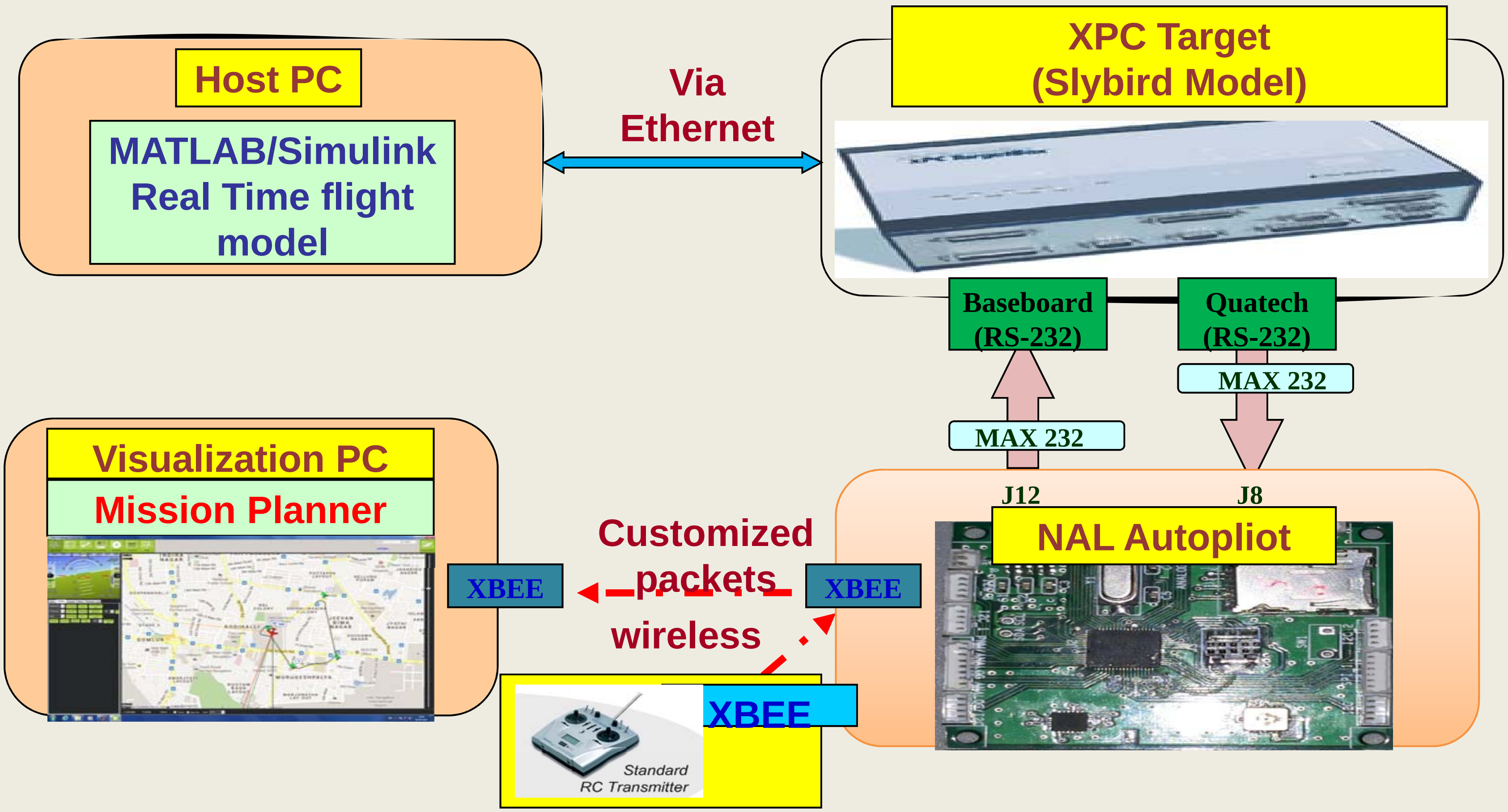


HILS

- Similar to PIL simulation, the autopilot runs on the hardware.
- Now aircraft model runs in real time using XPC target.
- Moreover the **input-output data acquisition cards** are used to model the **sensors** and to drive the actuators.

Slybird HILS setup

Schematic of Hardware in loop simulator



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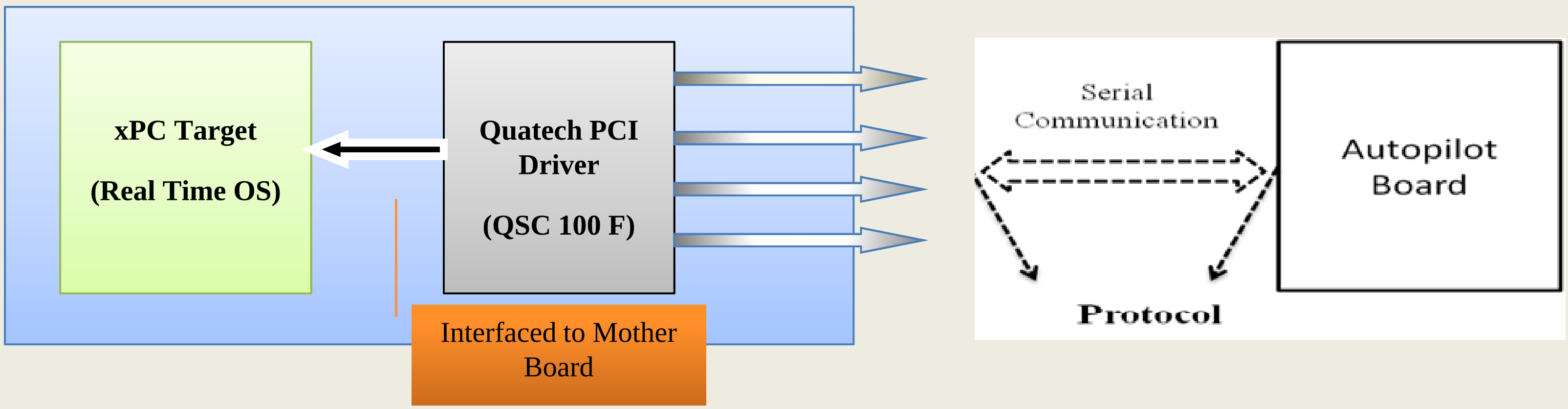
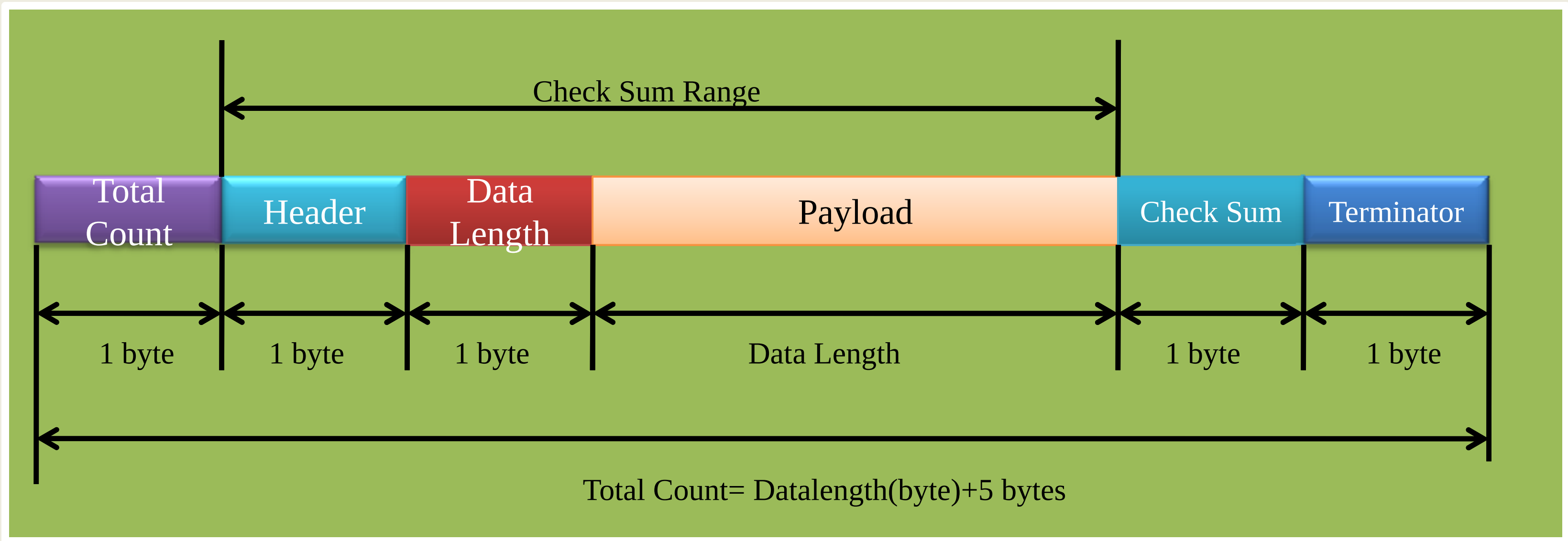
Communication Protocol





Protocol Data frame

Message Construction

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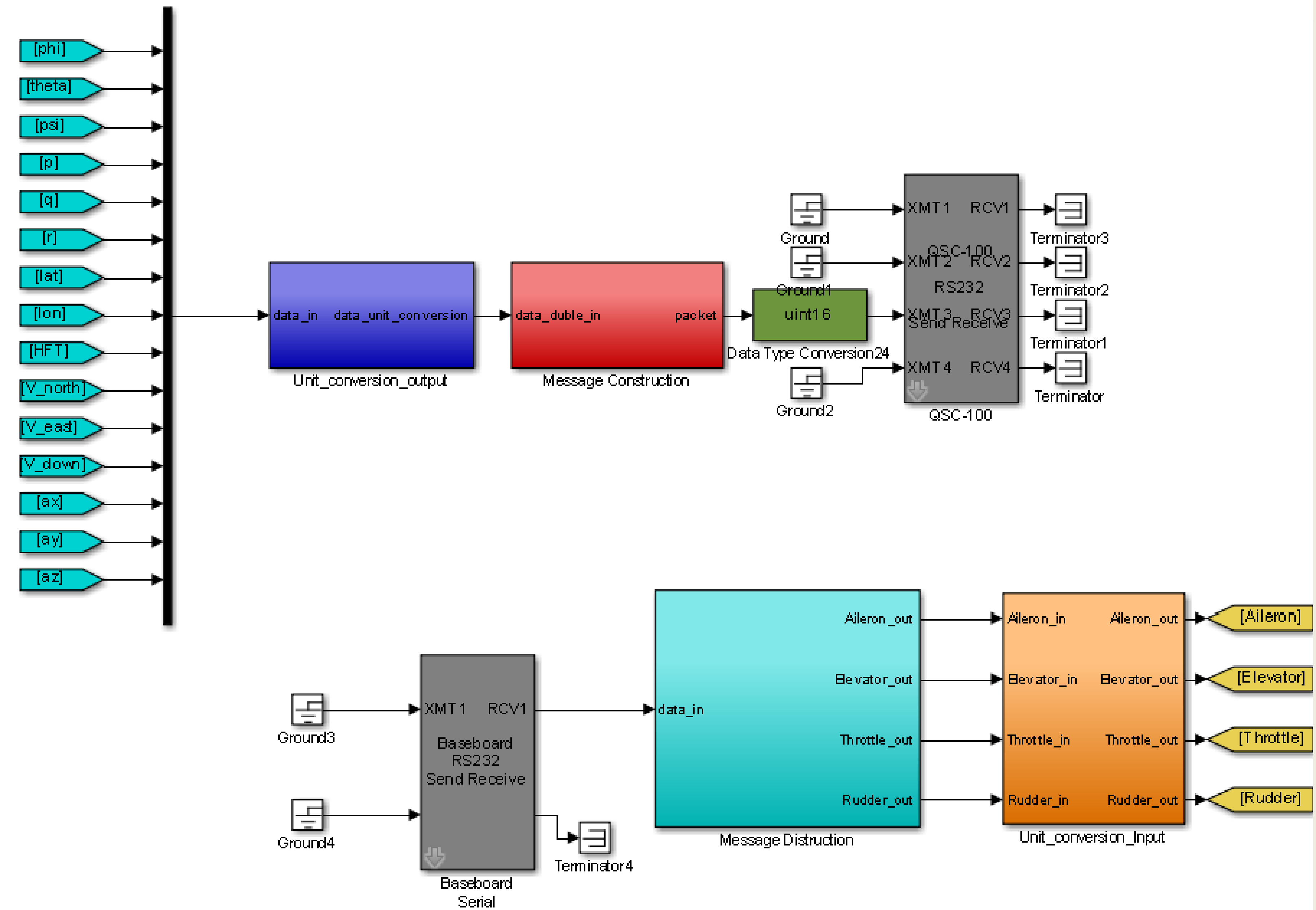
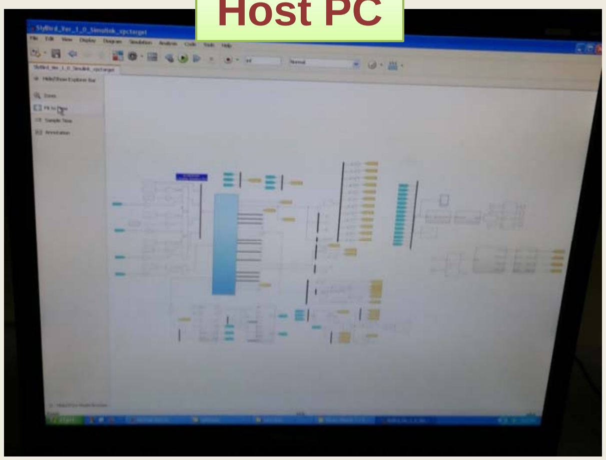


HILS with xPC Target and NAL Autopilot board

Host PC

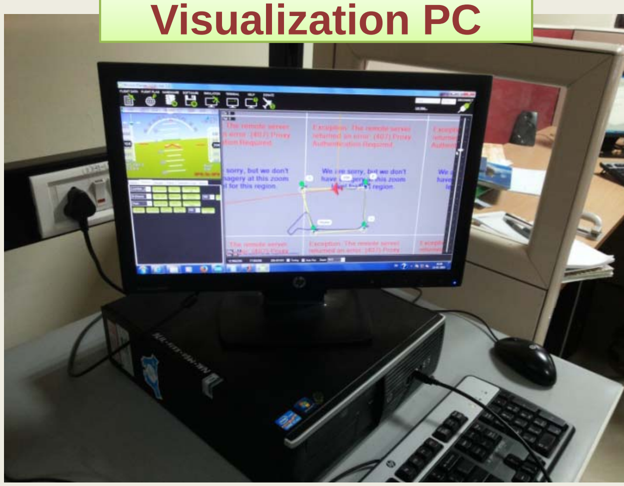


Via Ethernet

XPC Target

Via Serial

Visualization PC



UART to USB converter

NAL Autopliot

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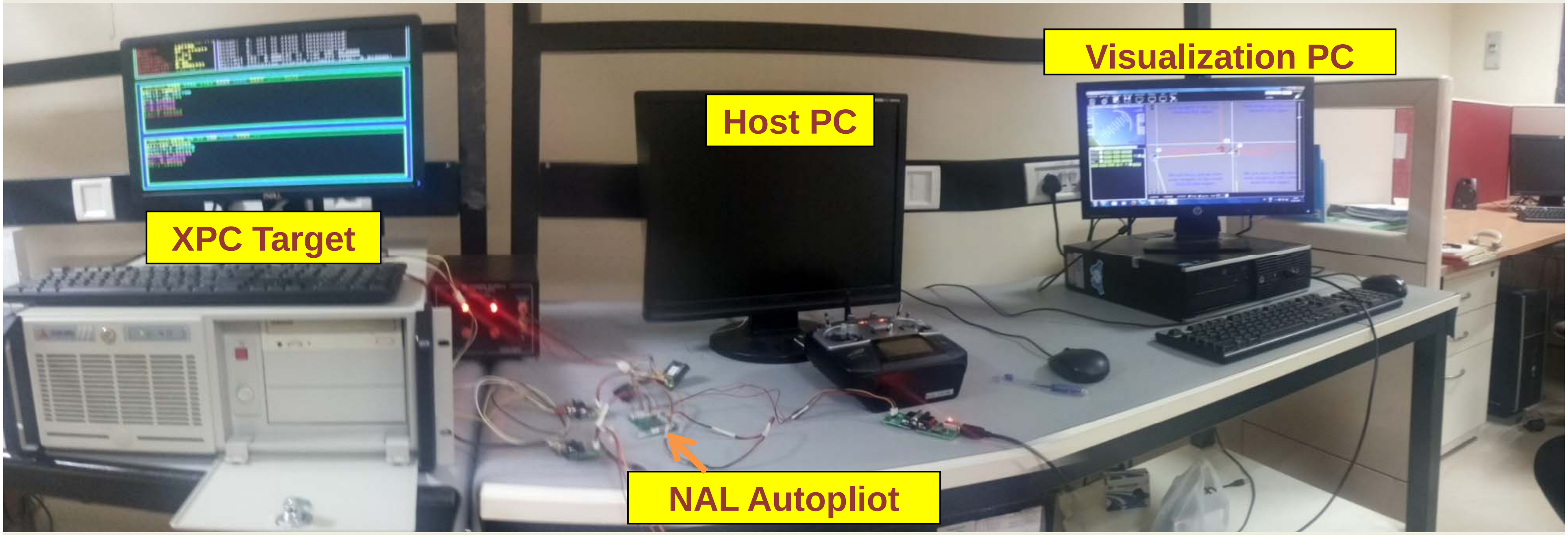
HILS-NAL autopilot



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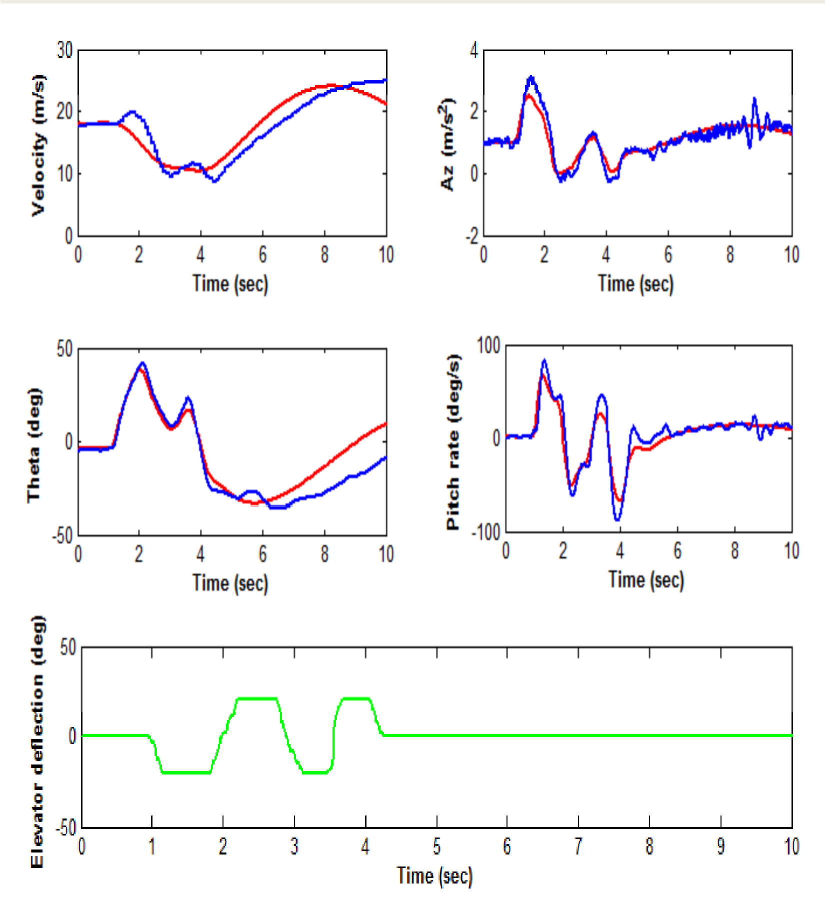
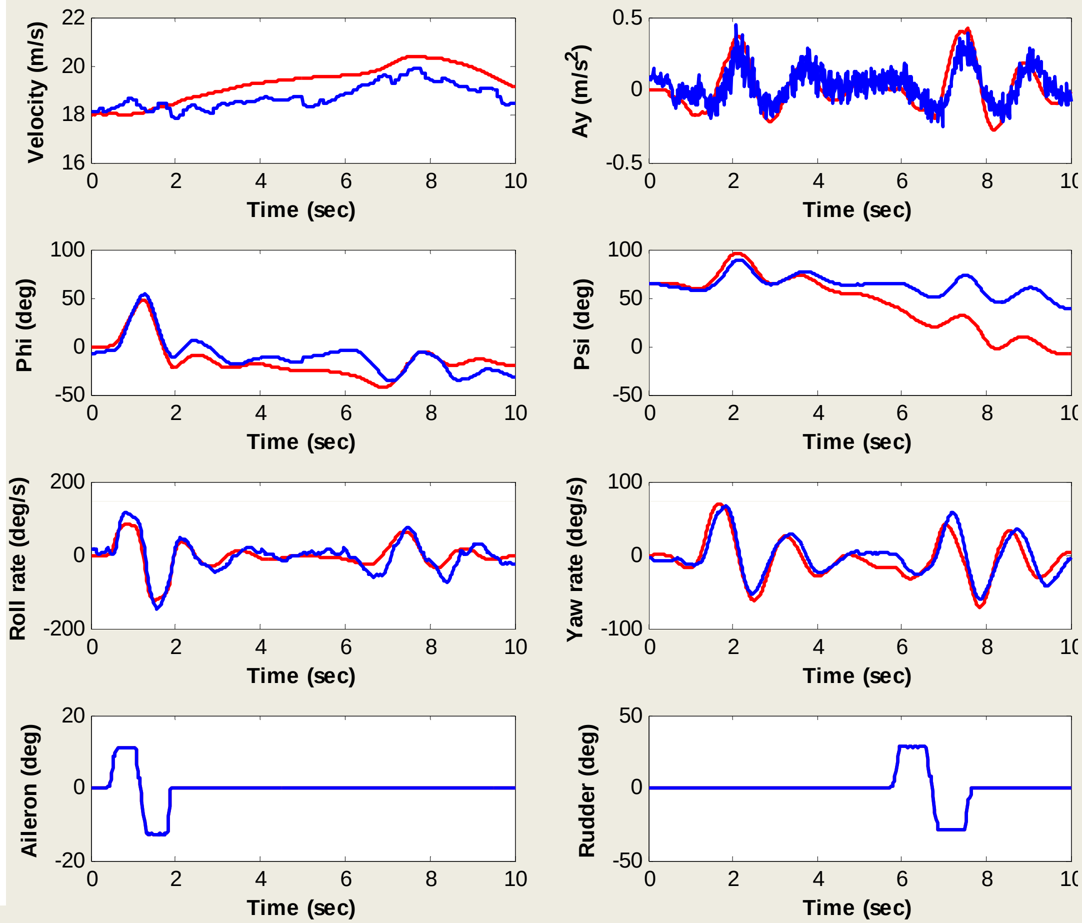
Slybird Flight data comparison



Longitudinal Dynamics - Flight vs. Simulated Output



Lateral Dynamics - Flight vs. Simulated Output

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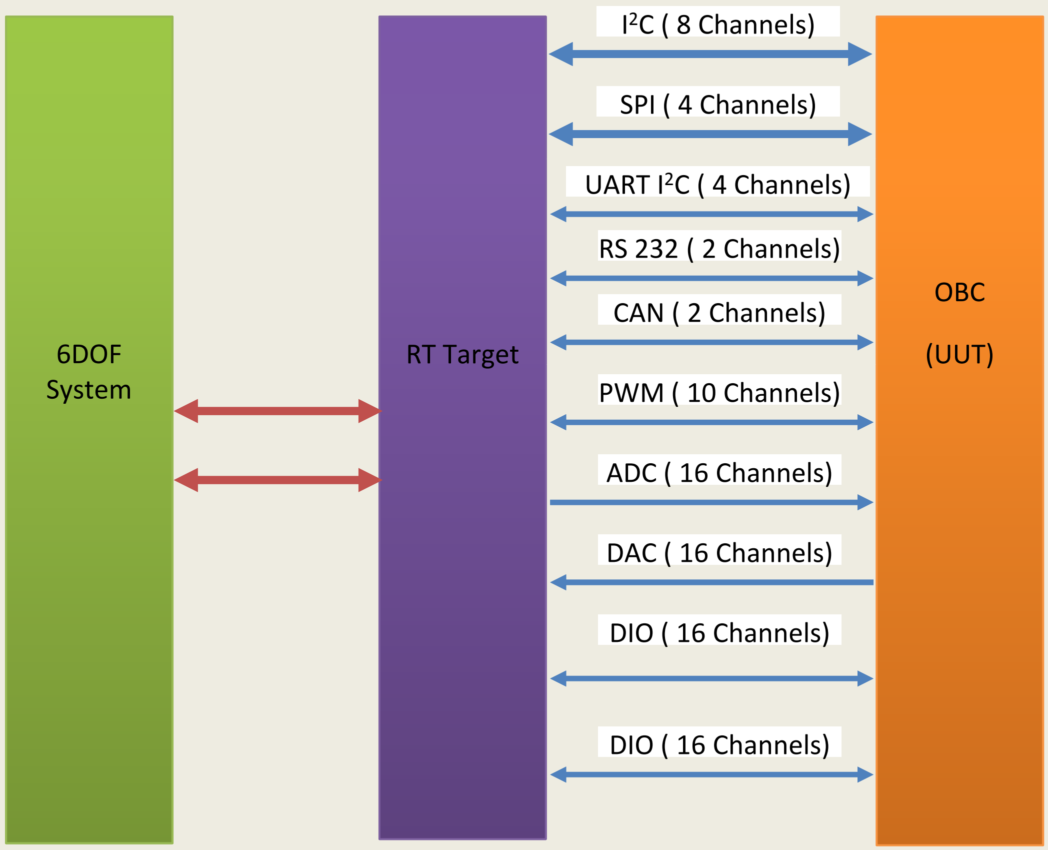
Future work proposed on HILS



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Thank You