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.
Various levels of Simulation for Slybird MAV using Model Based Design

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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

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

• 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 $\dot{x} = 0$.
- Here wings level trim is performed that solves for elevator, throttle, angle of attack.
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
Slybird - Closed loop architecture

Aileron Command

Elevator Command

Rudder Command

Throttle Command

Six DOF Simulation Model

Euler Angles

Position

Velocity

IMU and GPS Sensor Model

Euler Angles and Velocity

Position

Estimator

State Estimates

Inner Loop PID Controller

Outer Loop PID Controller

Heading Command

Altitude Command

Path Planning

CONTROLLER
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
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
Slybird - SILS

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

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 window 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
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.
Architecture of PILS with ARDUPLANE (APM 2.6) and Mission planner
PILS with APM 2.6 and Mission planner
NAL Autopilot

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

Technical Specification

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Range</th>
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<tbody>
<tr>
<td>Processor</td>
<td>ARM CortexM3 CPU core</td>
<td>32 - Bits</td>
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<td>Vdd</td>
<td>Input Voltage</td>
<td>1.8 - 3.3 Volt</td>
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<tr>
<td>Clock</td>
<td>Operating Frequency</td>
<td>24 MHz</td>
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<tr>
<td>ROM</td>
<td>Programmable memory</td>
<td>256 Kbyte</td>
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<tr>
<td>JTAG Connector</td>
<td>Programming, debugging</td>
<td>10 Pin</td>
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<tr>
<td>I2C Interface</td>
<td>4 I2C Interface</td>
<td>100/400 Kbps</td>
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<tr>
<td>UART Interface</td>
<td>2 UART Port</td>
<td>9.6/57.6 Kbps</td>
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<tr>
<td>SPI Interface</td>
<td>3 SPI Port</td>
<td>&gt;1 Mbps</td>
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<td>PWM</td>
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<tr>
<td>Dimensions</td>
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<td>50mm x 50mm</td>
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<tr>
<td>Weight</td>
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<td>12.2 grams</td>
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</table>
Procedure to deploy auto code in to an Embedded Target
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

- Host PC
  - MATLAB/Simulink
  - Real Time flight model

- Visualization PC
  - Mission Planner

- XPC Target (Slybird Model)
  - Baseboard (RS-232)
  - Quatech (RS-232)
  - MAX 232

- NAL Autopilot
  - XBEE

- Via Ethernet

- Customized packets wireless

- XBEE

- XBEE

- XBEE

- XBEE
Communication Protocol

Protocol Data frame

Check Sum Range

Total Count= Datalength(byte)+5 bytes
HILS with xPC Target and NAL Autopilot board

Host PC

XPC Target

Visualization PC

NAL Autopilot

Via Ethernet

Via Serial

UART to USB converter
HILS-NAL autopilot
Slybird Flight data comparison

Longitudinal Dynamics - Flight vs. Simulated Output

Lateral Dynamics - Flight vs. Simulated Output
Future work proposed on HILS

6DOF System

RT Target

OBC (UUT)

I²C (8 Channels)

SPI (4 Channels)

UART I²C (4 Channels)

RS 232 (2 Channels)

CAN (2 Channels)

PWM (10 Channels)

ADC (16 Channels)

DAC (16 Channels)

DIO (16 Channels)

DIO (16 Channels)
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• Dr. Abhay A Pashilkar, Group head, Flight Simulation
• Dr. Ramesh G, Head, MAV unit.
References


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Thank You