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.
Screen shot for trimming
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
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)
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

State Estimates

Heading Command

Altitude Command

Inner Loop PID Controller

Outer Loop PID Controller

Path Planning

CONTROLLER
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 - 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 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

![Graph showing the path followed by MAV with waypoints labeled Waypoint1, Waypoint2, Waypoint3, and Waypoint4. The path consists of a diamond shape with the starting point at the center and the waypoints marked at each vertex.]
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

MATLAB/SIMULINK Aircraft Model

UDP protocol

Mission Planner

32 bit dual core/quad core desktop PC

USB Interface

ARDUPLANE Autopilot (APM 2.6) XBEE

NATIONAL AEROSPACE LABORATORIES
BANGALORE-560 017 INDIA
CSIR-NAL
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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<tr>
<td>Processor</td>
<td>ARM CortexM3 CPU core</td>
<td>32 - Bits</td>
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<tr>
<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>
</tr>
<tr>
<td>I2C Interface</td>
<td>4 I2C Interface</td>
<td>100/400 Kbps</td>
</tr>
<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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<tr>
<td>PWM</td>
<td>16 Channels</td>
<td>3.3 V</td>
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<tr>
<td>Temperature</td>
<td>Industrial temperature</td>
<td>-40 to +85°C</td>
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<td>Sensors</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 into an Embedded Target

PSOC Creator IDE

- PSOC Device Driver
- Device Driver C Code

Control Strategy Simulink Model

- Control Strategy C Code
- Matlab/Simulink Environment

Copy Auto Code generated C files to Project in PSOC Creator IDE

Integration of device driver C code with auto code generated control strategy

Invoke Compiler

Link The Project

Object File

- Hex File
- Map File

Machine Code
PILS with NAL Autopilot board and Mission planner

NAL Autopilot

Mission Planner

Aircraft Model
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

Host PC
MATLAB/Simulink Real Time flight model

XPC Target (Slybird Model)

Visualization PC
Mission Planner

NI PCI 6229

Quatech (RS-232)

Actuators

Max 232

NAL Autopilot

Host PC

MATLAB/Simulink Real Time flight model

Visualization PC
Mission Planner

Customized packets wireless

NI PCI 6229

Quatech (RS-232)

Actuators

Max 232

NAL Autopilot
Data Acquisition

AIRCRAFT

xPC Target

National Instruments PCI6229

Quatech QSC100

Servo Motor

RC Transceiver

Autopilot Board

CONTROLLER

PWM Signal

Wireless

Serial Communication

Analog voltage
Simulink block diagram for data acquisition
HILS with xPC Target and NAL Autopilot board

Host PC

XPC Target

Via Ethernet

Visualization PC

NAL Autopilot

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. Ramesh G, Head, MAV unit.
References


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6. Kamali C, Pranshu Basaniwal, Shikha Jain, Vijeesh T ,”Processor In the Loop Simulation (PILS) for NAL’s Class 1/Similar class MAV”, OT 04-07, July 2014.


Thank You