PID Controller for EASE Pitch Control

Honors Capstone: Matt Foutter

Advisor: Professor Carlos Cesnik

Mateus De Freitas Virgilio Pereira

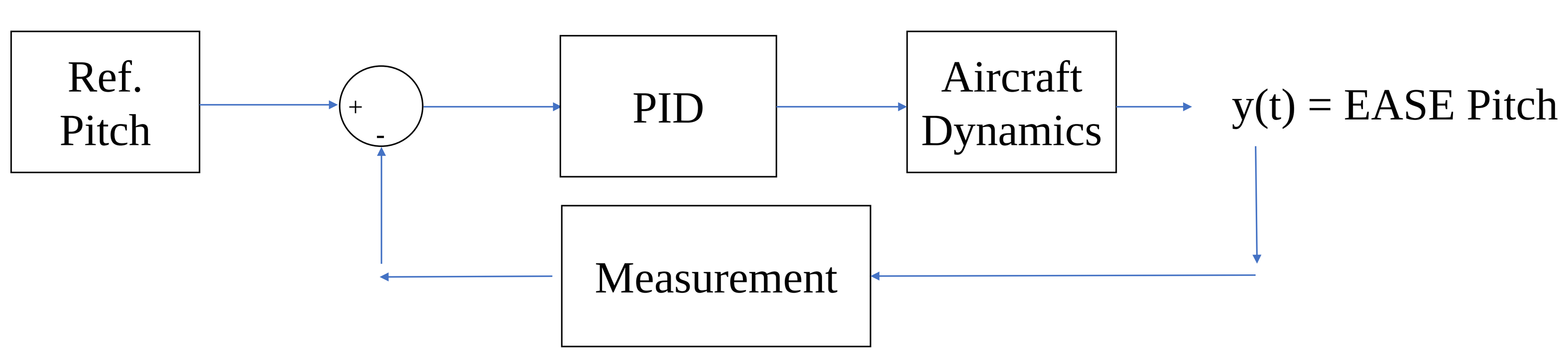
ENGINEERING HONORS PROGRAM
UNIVERSITY OF MICHIGAN

Project Introduction

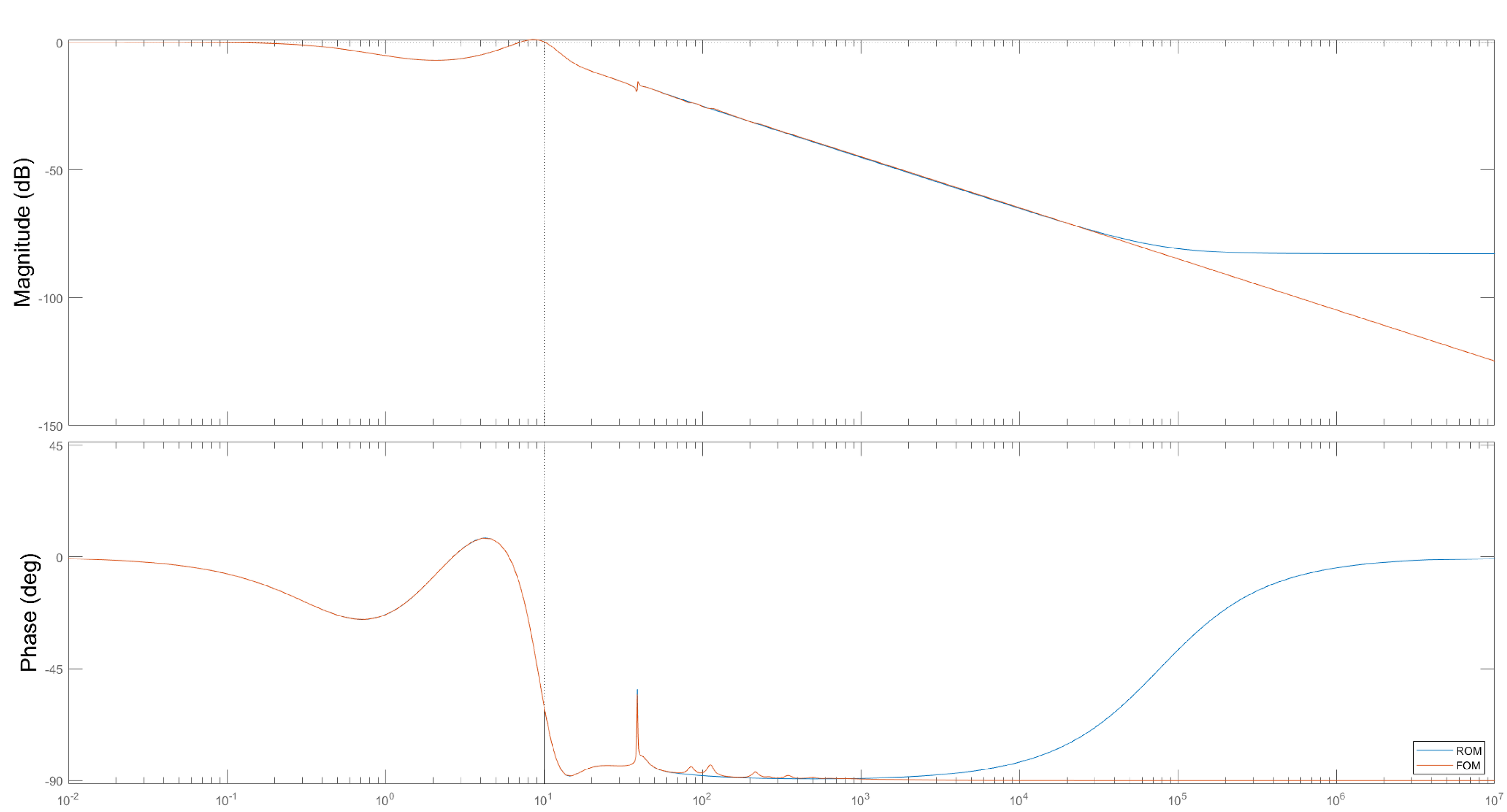
Prof. Cesnik and the Active Aeroelasticity and Structures Research Laboratory require a digital controller to regulate the pitch of the EASE model aircraft in wind tunnel testing. The controller is required to maintain or restore the aircraft's trim pitch value by tracking a constant reference signal using the tail's elevator deflection as an input. The controller is expected to operate in a flight envelope of 20m/s – 30 m/s and initial pitch between -10 deg to +10 deg. The EASE model is pictured belo

Design Approach

1. Verify Reduced Order Model (ROM) against Full Order Model (FOM)
2. Determine first iteration PID Definition
   - Determine design requirements
3. Validate Controller in Linear Simulation
4. Validate Controller in Nonlinear Simulation



1) Verify ROM Against FOM



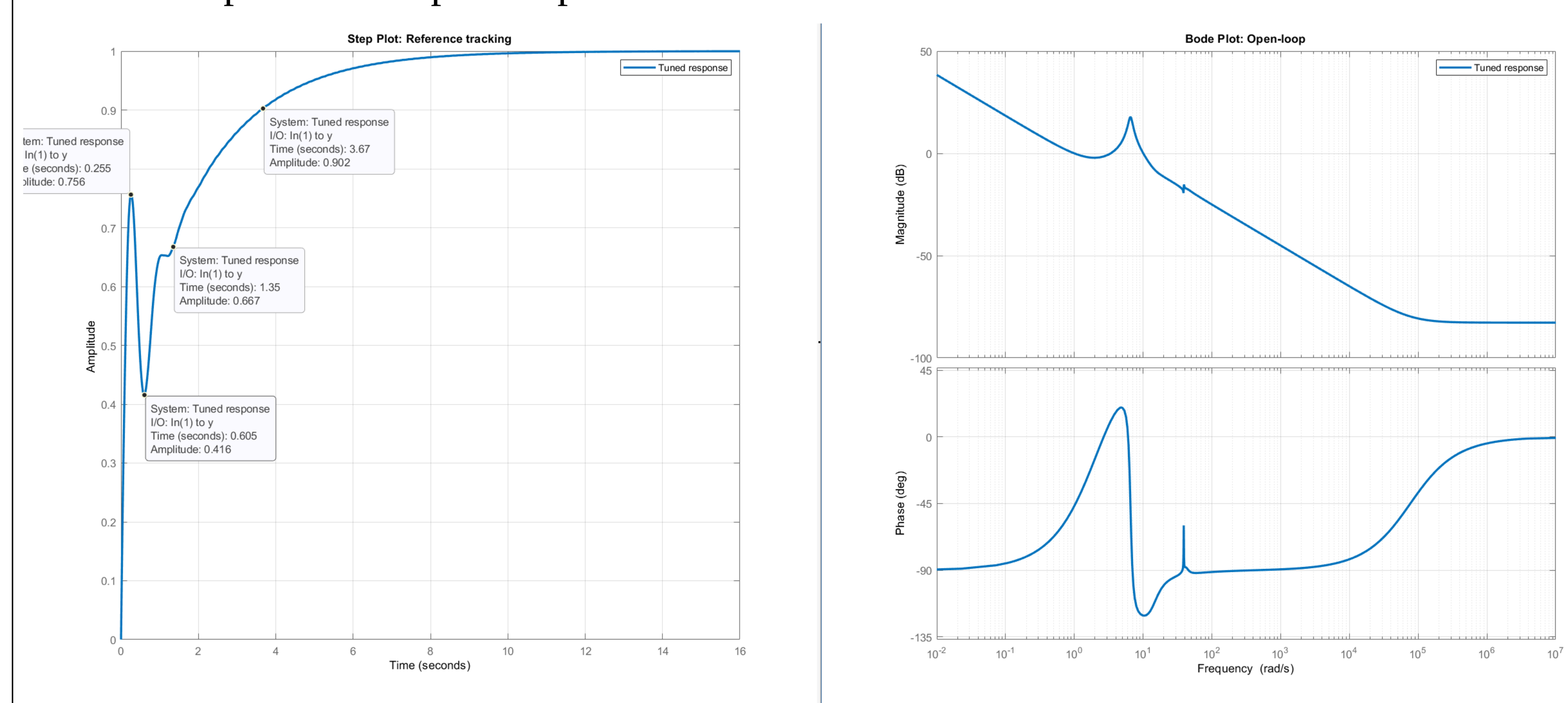
- Actuators bandwidth limited to ~ 10 Hz
- ROM captures FOM magnitude and phase response below 10 Hz ~= 60 rad/s
  - ROM acts as surrogate for FOM for an input below 10 Hz
- This result allows the project to use the ROM in replacement of the FOM in pitch simulation

2) Determine First Iteration PID Definition

PID Design Requirements

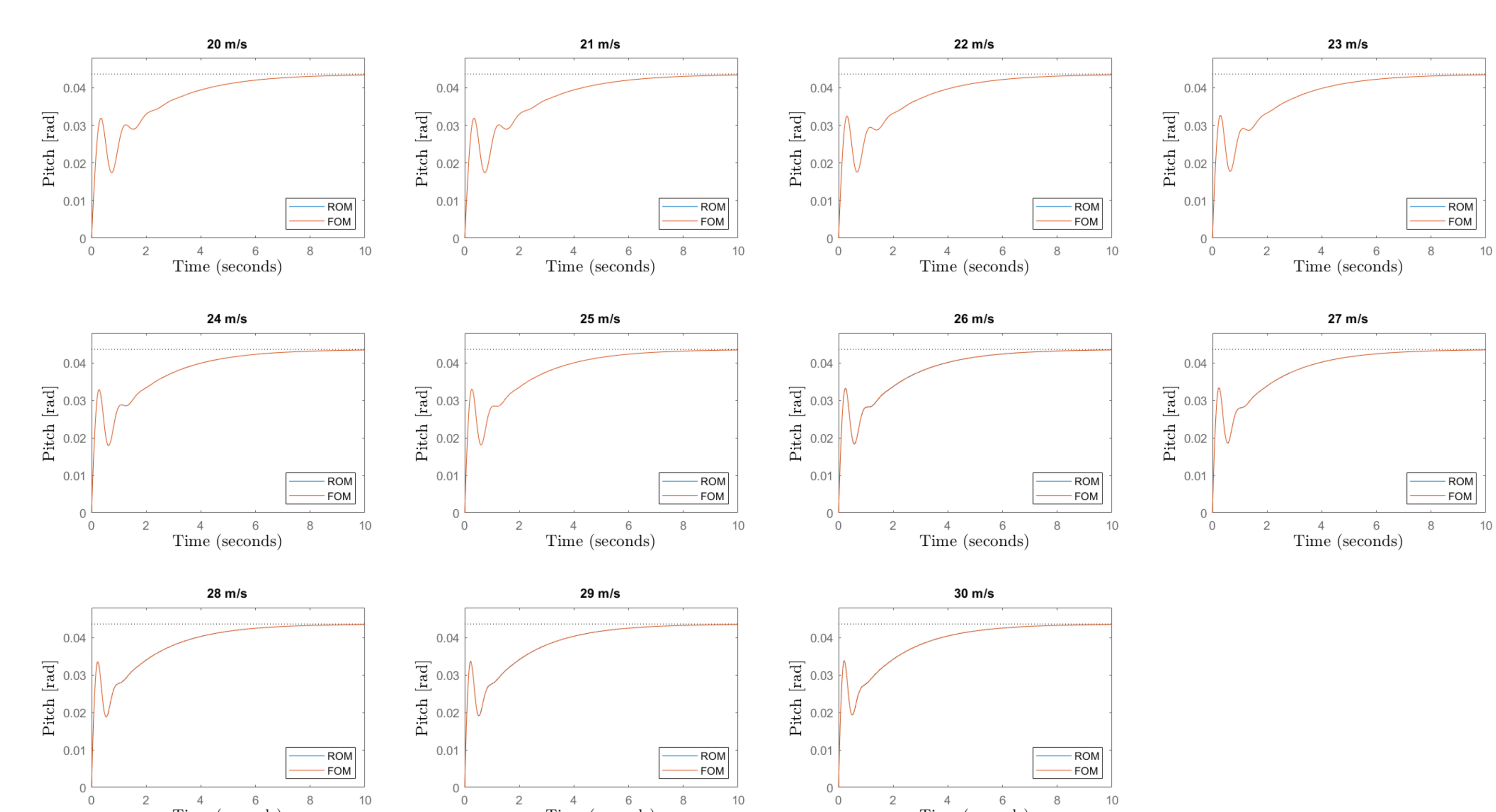
1. Demonstrate an overdamped step response with little oscillation, if any
2. Demonstrate a rise rime to 90% the steady state value less than roughly two sec.
3. Demonstrate a 5% band settling time in the range of four to six seconds
4. Demonstrate a gain margin greater than 6 dB
5. Demonstrate a phase margin greater than 30 deg

With the above design requirements, MATLAB's pidTuner function was utilized to size each gain term for a candidate PID controller, returning the closed loop step response and bode plot of the open loop controller.



- Knobs available to design controller: controller bandwidth, controller phase margin
- Three candidate controllers developed to meet quantitative reqs. 2-5
  - With varying levels of oscillation to assess qualitatively against req. 1
- Maximum EASE pitch excursion -10 deg to 2.5 deg => 12.5 deg
- While oscillation above is large (20 deg!) this would scale to ~ 4 deg peak to peak for on the EASE aircraft's excursion
- Controller bandwidth balances fastest response time and oscillation magnitude
  - 1.4s rise time and 3.7s 90% band settling time
  - 0.16 Hz controller used for remainder of project

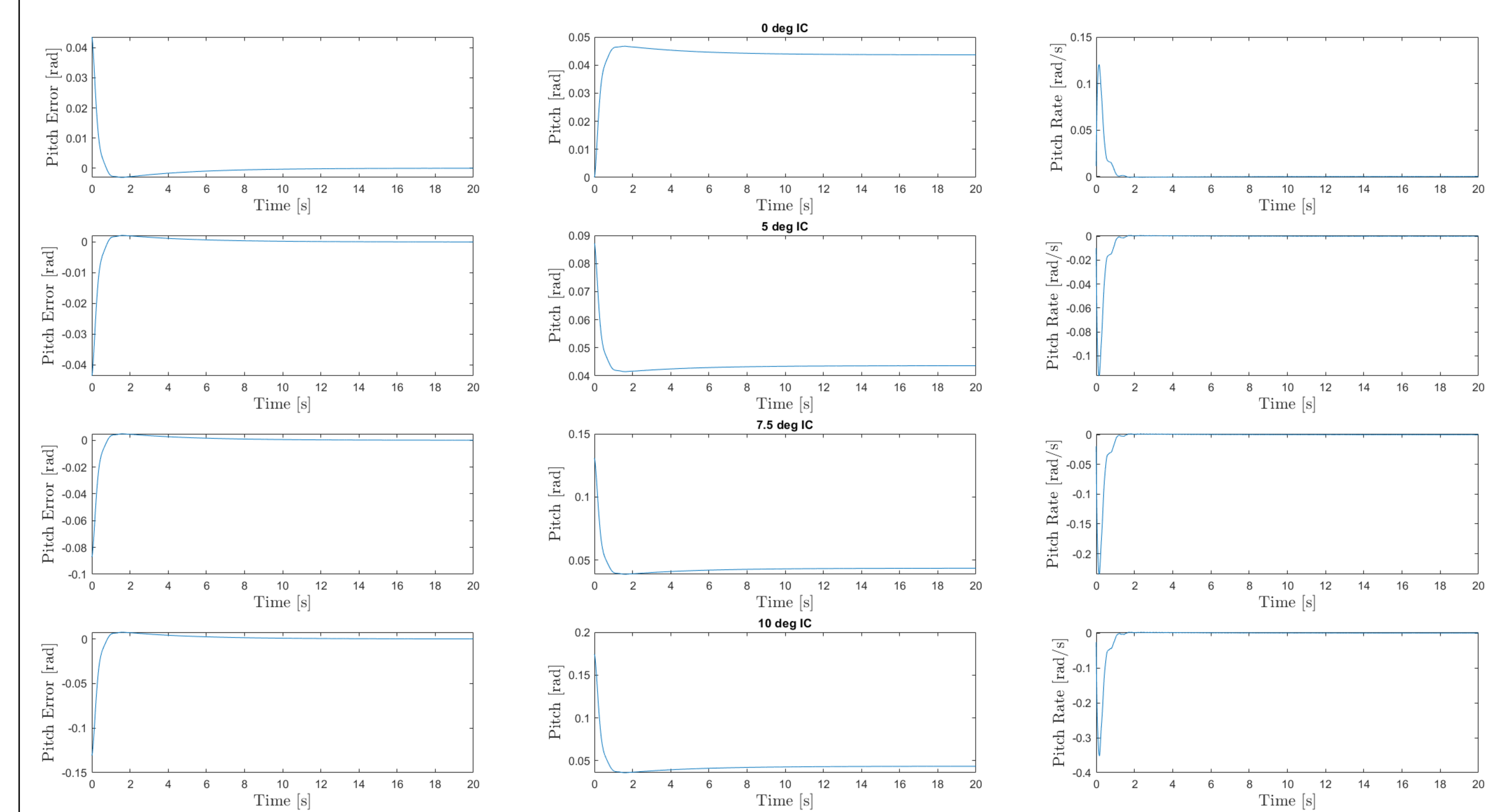
3) Validate Controller in Linear Simulation



- 2.5 deg step response simulated within speed range 20 m/s to 30 m/s using FOM and ROM closed loop with controller
- Pitch trajectory follows design prediction
  - Controller stable at all speeds within flight envelope
- Pitch trajectory indistinguishable with ROM and FOM
- These results suggest the controller is stable within 20-30m/s under a linear approximation

4) Validate Controller in Non-linear Simulation

In the scope of this project, evaluating a candidate controller in non-linear simulation represents the final step in controller design before an implementation can be developed in software to test in a wind tunnel. Non-linear simulation is also the most rigorous evaluation step, as the controller is simulated in the absence of the linear model assumption used in the controller's original design. In simulation, this project uses a full speed sweep of 20 m/s – 30 m/s and initial pitch sweep of -10 deg – 10 deg. Only results at 20 m/s and positive, non-trim, initial conditions are presented for the brevity of this poster.



- Step response simulated within speed range 20 m/s to 30 m/s for initial pitch between -10 deg and 10 deg
- Pitch trajectory does not follow design prediction
  - However, controller stable at all initial pitches within flight envelope
- These results suggest the controller is stable within 20-30m/s under a nonlinear analysis

Conclusion

This poster presents a PID architecture to meet the task of pitch control for the EASE aircraft. First, to facilitate the design of each controller, a ROM was developed for the aircraft's dynamics using a residualization based on structural modal frequencies and actuator bandwidth limitations. This project selected five design requirements to guide PID controller development. A PID controller of 0.16 Hz was selected to balance controller speed and stability, after which the controller's ROM closed loop response was verified in linear simulation against the FOM. Then, through nonlinear simulation, the controller's ability to control pitch to trim was evaluated in a sweep of initial conditions and flight speeds. Nonlinear simulations results show that the controller can sufficiently control the aircraft's pitch to equilibrium within a pitch regime of [-10 deg, 10 deg] and a flight speed regime [20 m/s, 30 m/s].

Future Work

For future work, this project suggests translating this PID controller definition in MATLAB to a C++ definition. This C++ software will physically interact with the EASE aircraft and enable controller validation in wind tunnel testing.

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