Professional Development Short Course On:

Missile Autopilots

Instructor:

Paul Jackson

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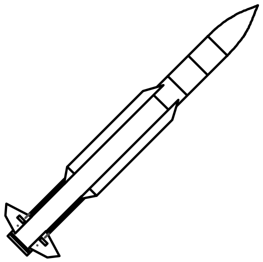
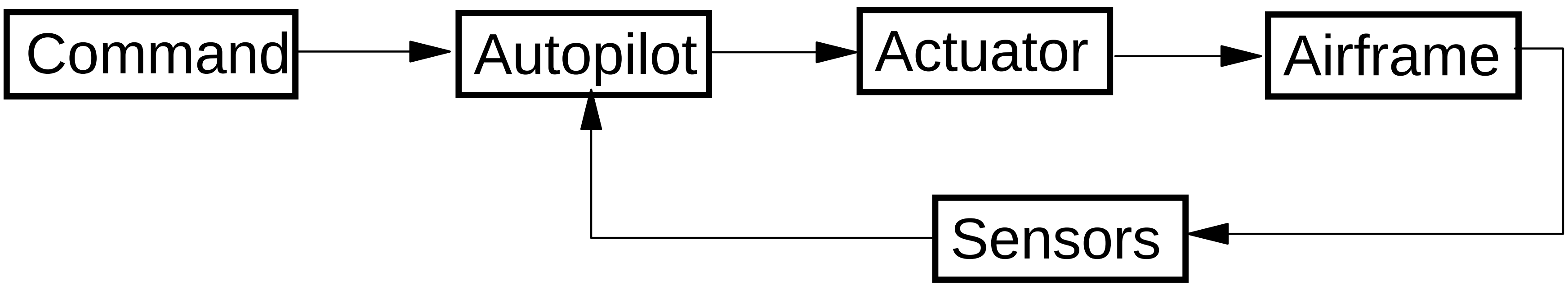
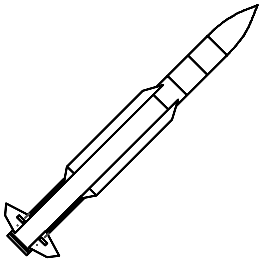


Autopilot Definition

An Autopilot is a System of Equations that Takes Commands and Missile State Measurements as Inputs and Computes a Control Command that Stabilizes the Missile and Forces the Missile State to Track the Command

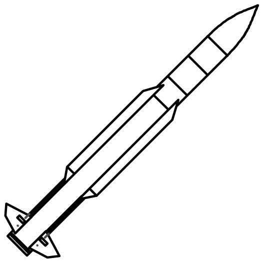


The Combination of Autopilot, Actuator, Airframe, and Sensors is Sometimes Called the "Autopilot." Meaning Should be Clear from Context.



Autopilot Components

- Autopilot
  - Mathematical System of Equations
    - Implemented Digital or Analog
  - External Command and Measurements are Inputs
  - Control Command is Output
- Actuator
  - Mechanical Device that Effects a Variable Force and Moment on Airframe
    - Fin, Nozzle, ...
- Airframe
  - Missile Body Including Fixed Aerodynamic Surfaces
  - Experiences Aerodynamic Lift and Moment
- Sensor
  - Mechanical Device to Sense Missile Motion
    - Accelerometer, Gyroscope, ...



Example Applications

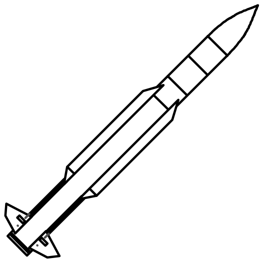
- Acceleration Autopilot
  - Control Missile Acceleration Perpendicular to Airframe
  - Interceptors
- Altitude Autopilot
  - Control Missile Altitude
  - Cruise Missiles
- Terrain Following
  - Control Missile Clearance Relative to Terrain
  - Cruise Missiles
- Pitchover Autopilot
  - Control Missile Attitude
  - Missile Boost Phase
- Others

Day 1

- Equations of Motion
- Linear Systems
- Frequency Response
- Aerodynamics
- Feedback Control

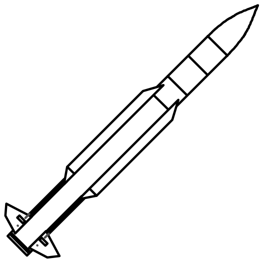
Day 2

- Nyquist Stability Criterion
- Root Locus
- Compensator Design
- Hardware
- Autopilot Design Requirements
- Acceleration Autopilot
- Three Loop Autopilot
- Roll Control



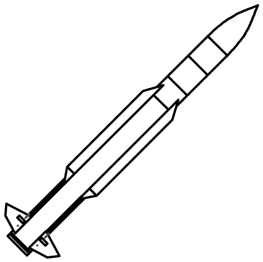
Day 3

- Altitude Control
- Pitch Over Autopilot
- Flexible Modes
- Gain Scheduling
- Discretization
- Hardware Nonlinearities
- Skid-to-Turn Autopilot
- Bank-to-Turn Autopilot



Day 4

- Airframe Design Trade Study
- Linear Quadratic Regulator
- Multivariable Stability
- H-Infinity Control



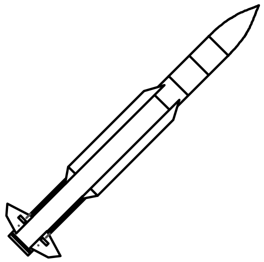
Aerodynamic Stability

Missile is Aerodynamically Stable at a Given Trim Condition if it Tends to Maintain its Trim Condition when Excited by External Disturbances

Consider the Previous Plots. At the Trim Condition a Positive Perturbation to α Results in a Negative Moment on the Airframe that Tends to Restore the Airframe to the Trim Condition

Conclusion: If the M vs. α Curve has a Negative (Positive) Slope at the Trim Condition, the Missile is Aerodynamically Stable (Unstable)

Aerodynamic Stability also called Static Stability

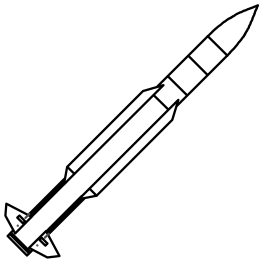


3D Aerodynamic Poles

- 3D Model has Five States
  - Angle-of-Attack, Sideslip, Pitch, Yaw, Roll Rate
- Two (Complex) Poles Associated with Pitch Dynamics are Called "Short Period (Weathercock)"
- Two (Complex) Poles Associated with Yaw Dynamics are Called "Dutch Roll"
- One Pole Associated with Roll Dynamics is Called "Roll Subsidence"
- Aerodynamic Coupling can Sometimes Obscure Relationship Between Poles and States

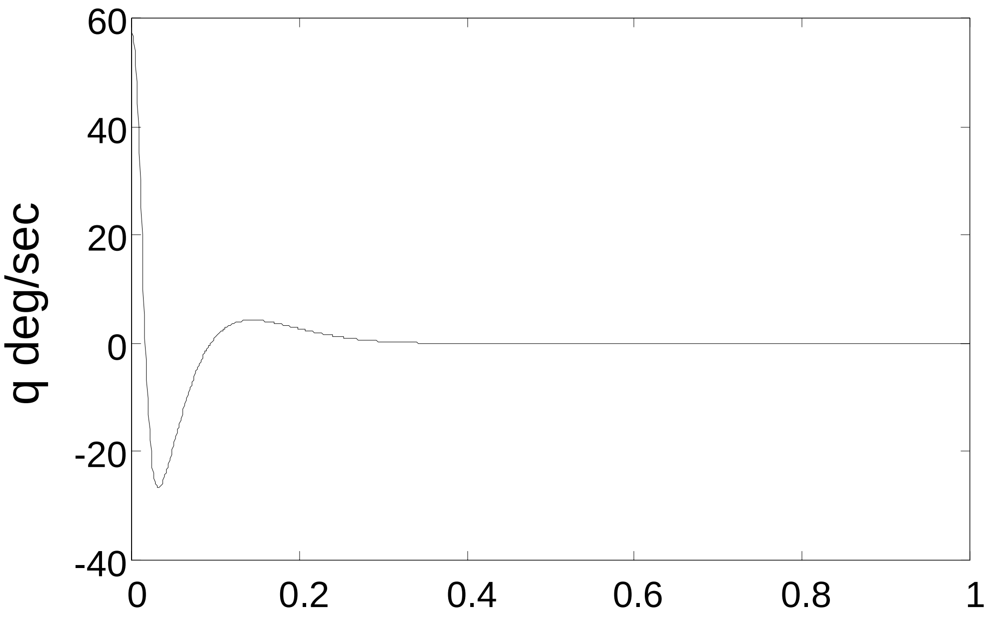
Acceleration Feedback Summary

- Lead Compensation Ineffective Because Compensation Zero is Too Close or Right of Dominant Closed Loop Poles
- Cancellation Ineffective Because of Poor Disturbance Rejection Properties
  - Using Complex Zeros to Pull Airframe Poles to Left (Combination of Above Strategies) Could Still Suffer from Same Problems



Response to Disturbance

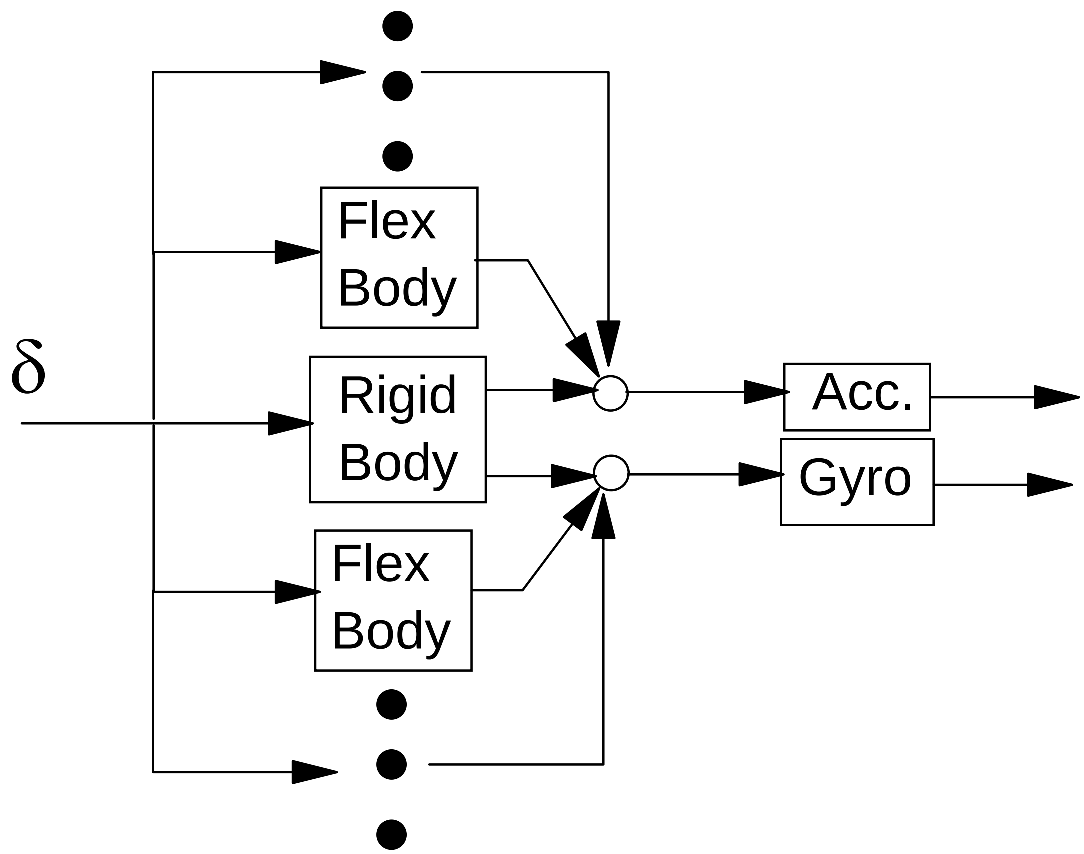
Pitch Rate Response to Angular Acceleration Impulse Disturbance (e.g. Pitch Moment due to Change in Sideslip, Wind Gust)

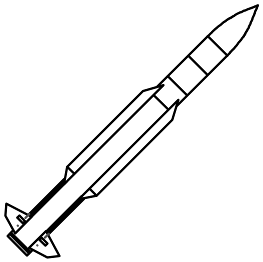


Body Rate Feedback Quickly Damps Out Disturbance Inputs

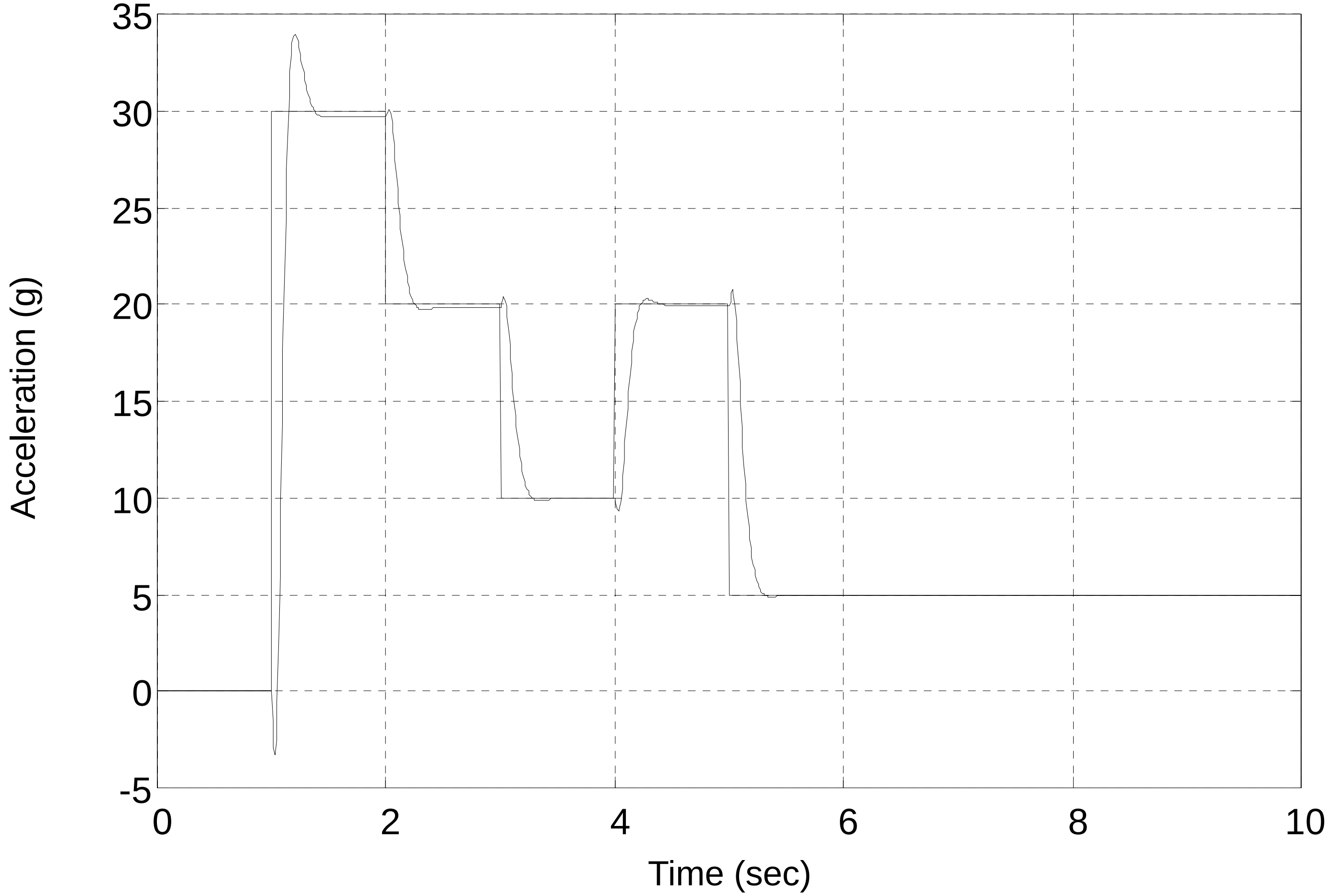
Flexible Mode Modeling

Flexible Mode Dynamics Modeled in Parallel to Rigid Body Dynamics for All Harmonics of Interest





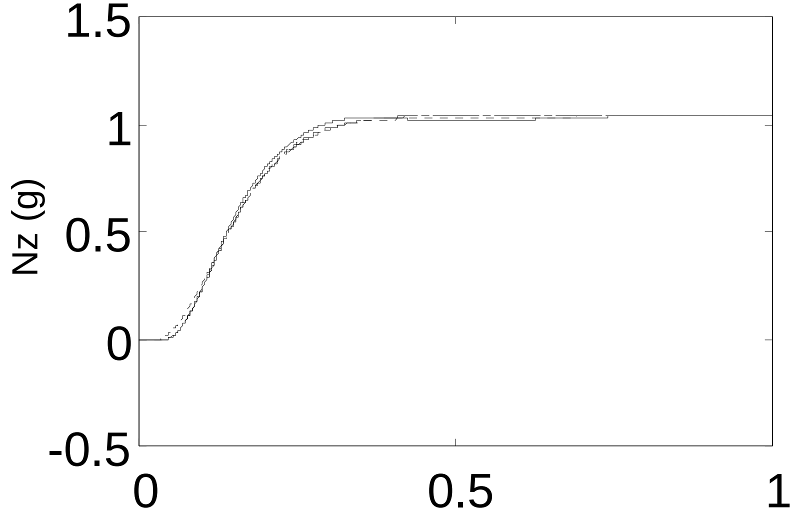
Acceleration Command Following

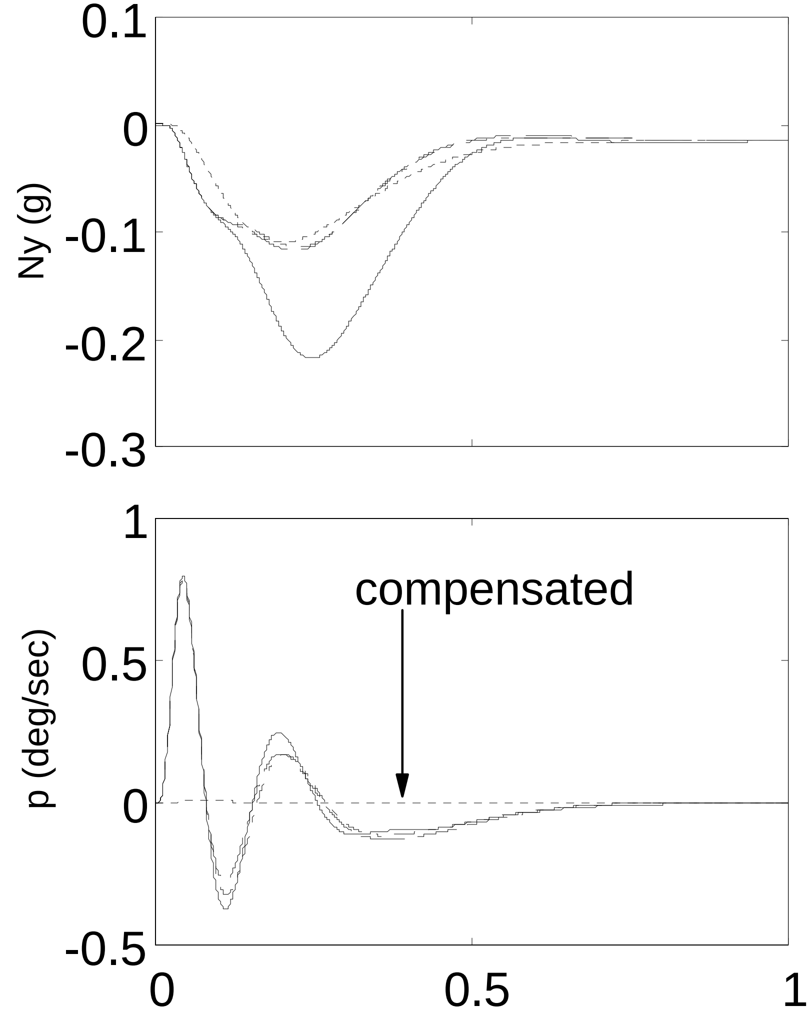


Gain Scheduled Autopilot Tracks the Command

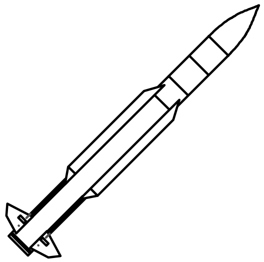
Delp/Dely Compensated Response

in addition to pitch/yaw, alpha/beta compensation

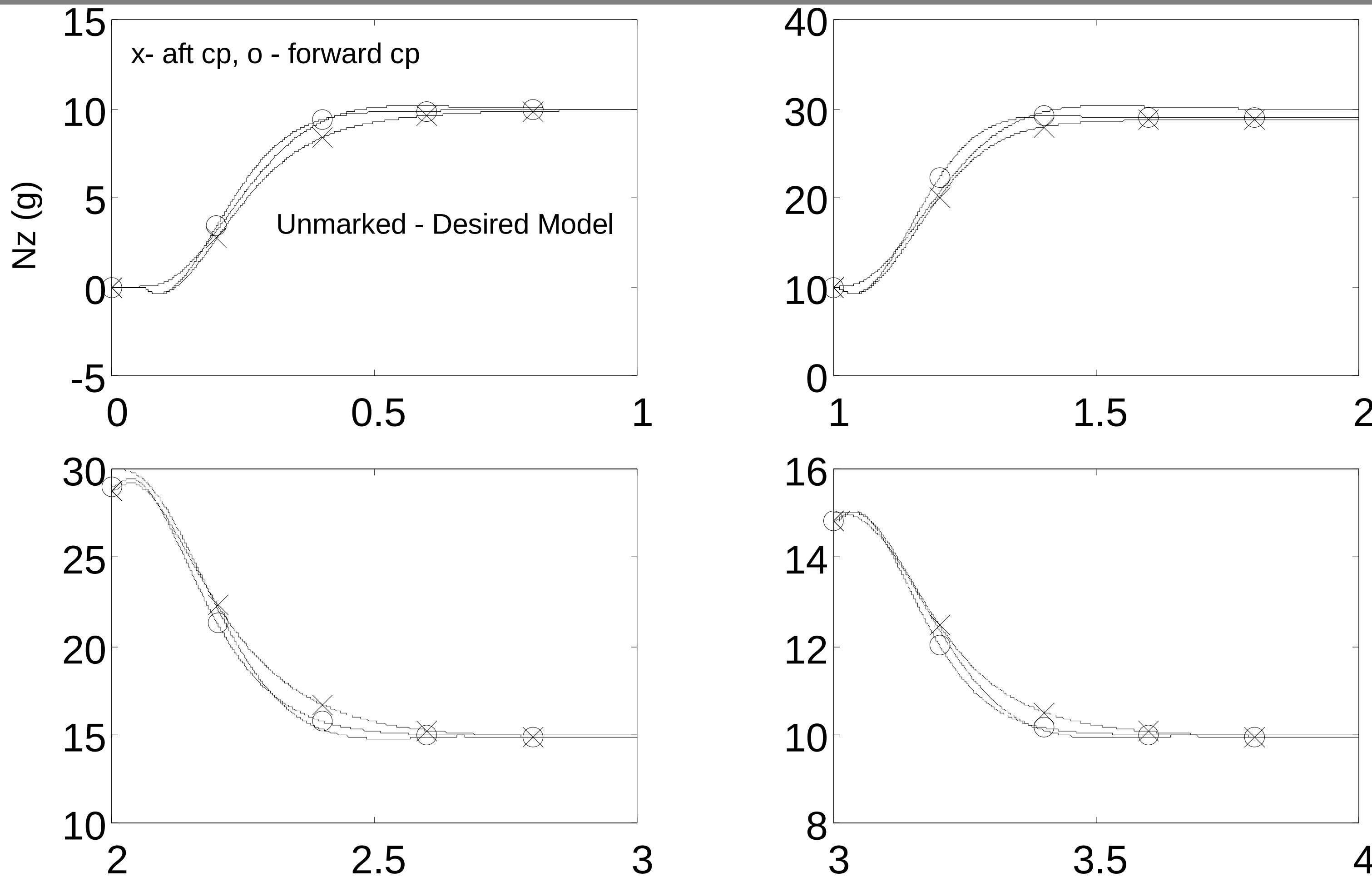




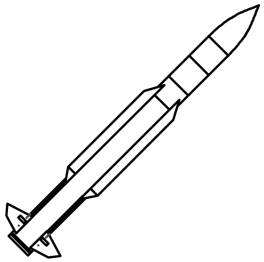
Control Cross Coupling
Compensation Effectively
Eliminates Roll Transient



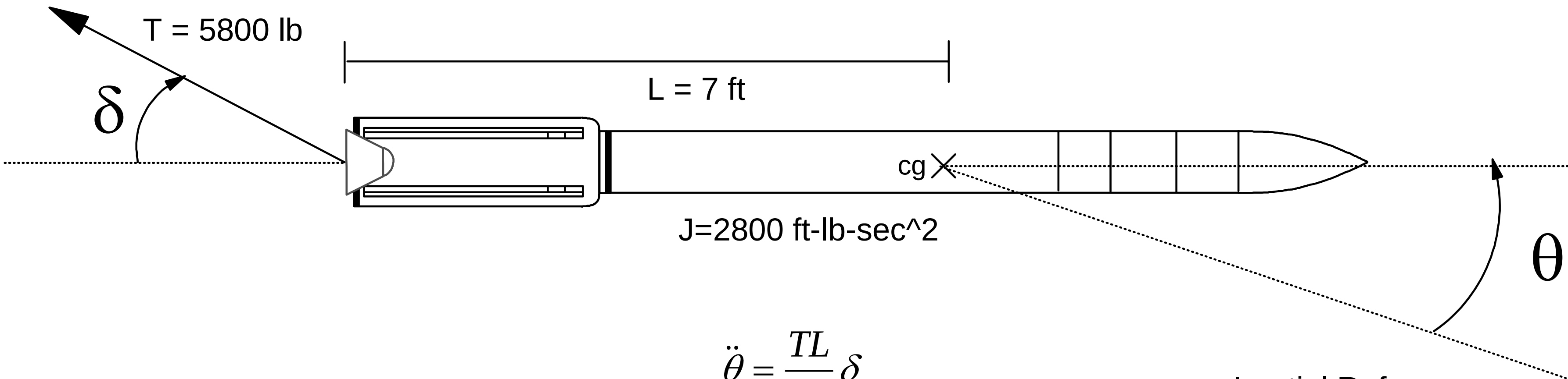
Acceleration Response



- Acceleration Response Nearly Matches Desired Model
- Stable Airframe Slightly Slower



Dynamics Model



$$\ddot{\theta} = \frac{TL}{J}\delta$$

- Assumes Small Angle for TVC Deflection
- No Aerodynamic Induced Moment
  - Subsonic, Slender Body
- Assume Fixed CG
  - Typically Shifts as Rocket Motor Burns
  - Might Have to Gain Schedule

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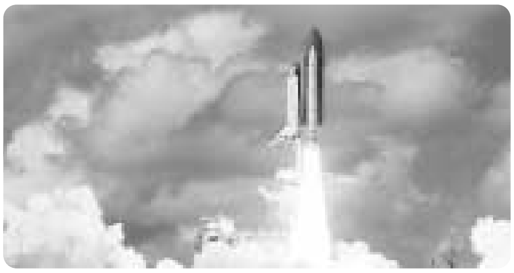

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