

Aeroelastic Control Law Development for the Integrated Adaptive Wing Technology Maturation Wind-Tunnel Test

Josiah Waite, Jared Grauer, Robert Bartels, Bret Stanford

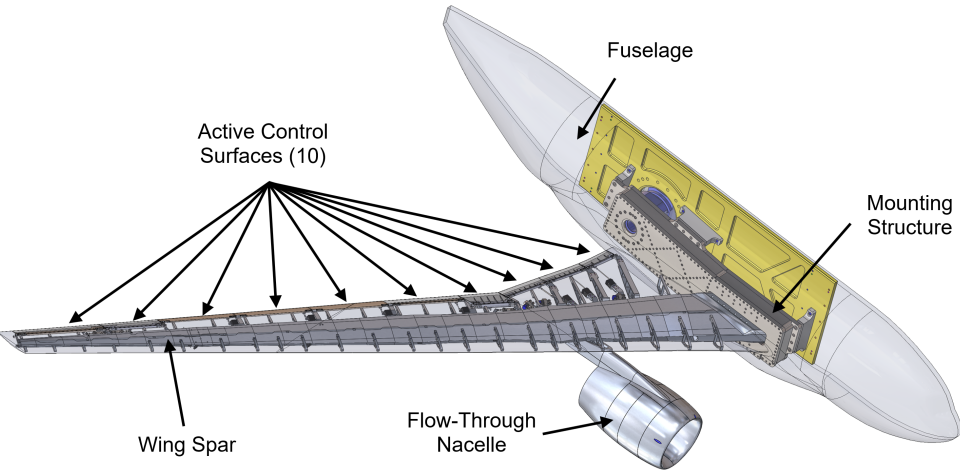
NASA Langley Research Center

2021 AIAA SciTech Forum, 11-15 Jan 2021

Copyright 2021 United States Government as represented by the Administrator of the National Aeronautics and Space Administration.
No copyright is claimed in the United States under Title 17, U.S. Code. All Other Rights Reserved. Published by the American
Institute of Aeronautics and Astronautics, Inc. with permission.



Motivation



Layout of the IAWTM (Integrated Adaptive Wing Technology Maturation) wind-tunnel model (credit: Boeing Research and Technology).

IAWTM research objectives:

- Assess effectiveness of trailing edge control surfaces for:
 - flutter suppression
 - maneuver load alleviation
 - gust load alleviation
 - drag reduction

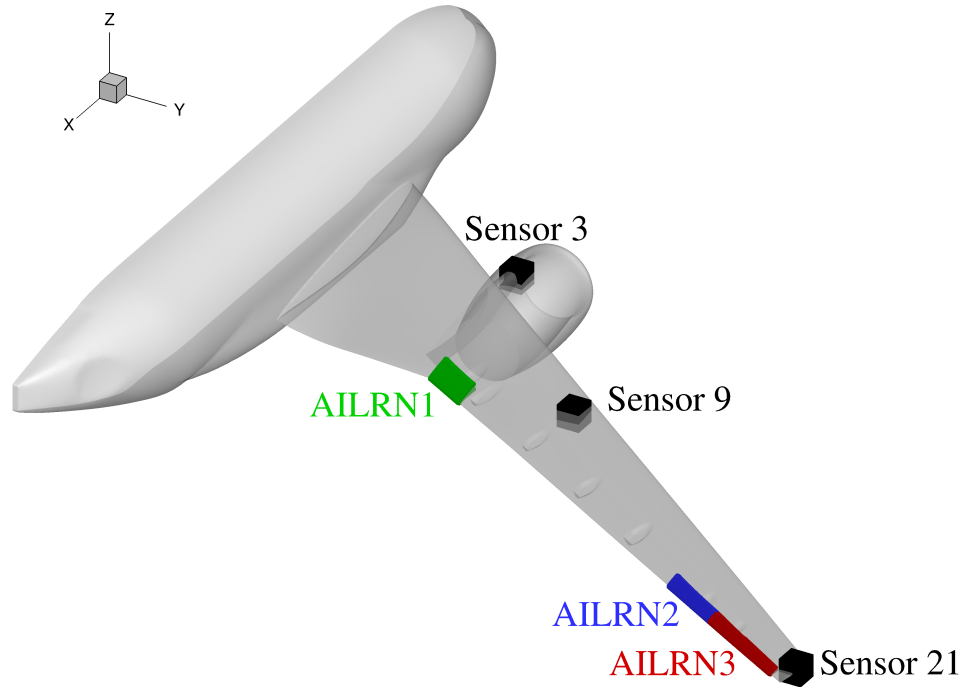
Objective for this work:

- Demonstrate LQG regulator for active flutter suppression.

Outline

- Aeroservoelastic (ASE) Model
- Linear Quadratic Gaussian (LQG) Regulator
- Results

ASE Model



Visualization of the 3 control surfaces (AILRN1, AILRN2, & AILRN3), and locations of the 3 sensors.

ASE Model

Structural Dynamic Model

- linear modal representation
- 24 modes from MSC.NASTRAN

Control Surface Model

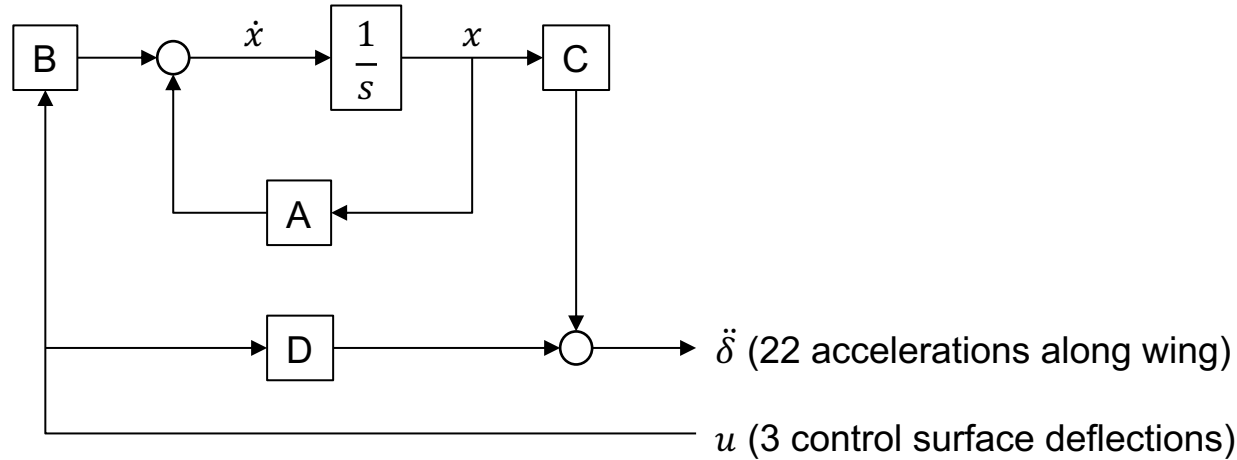
- linear modal representation
- 3 modes represent unit deflections for each control surface

Aerodynamic Model

- reduced-order model
- generated using system identification methods from CFD data (FUN3D)
- linearized about a nonlinear static aeroelastic CFD solution

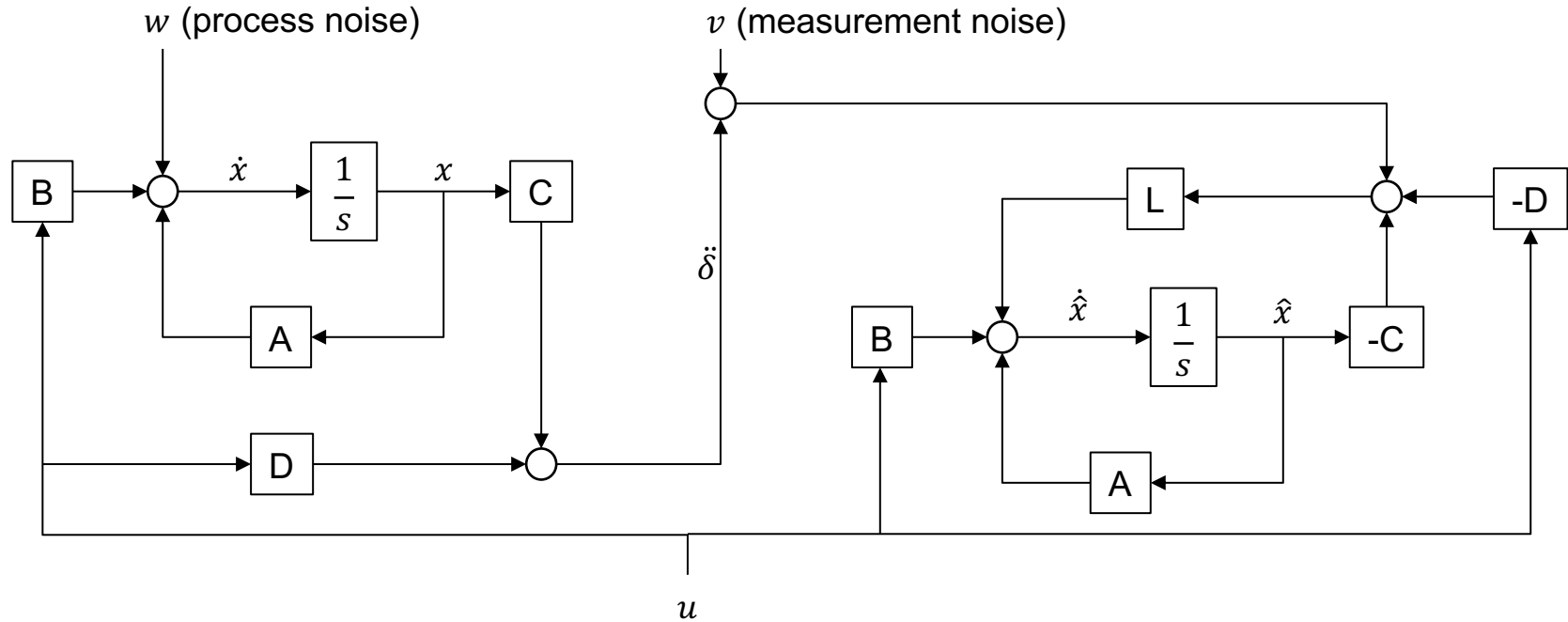
State Space
ASE Model
(A, B, C, D)

LQG Regulator



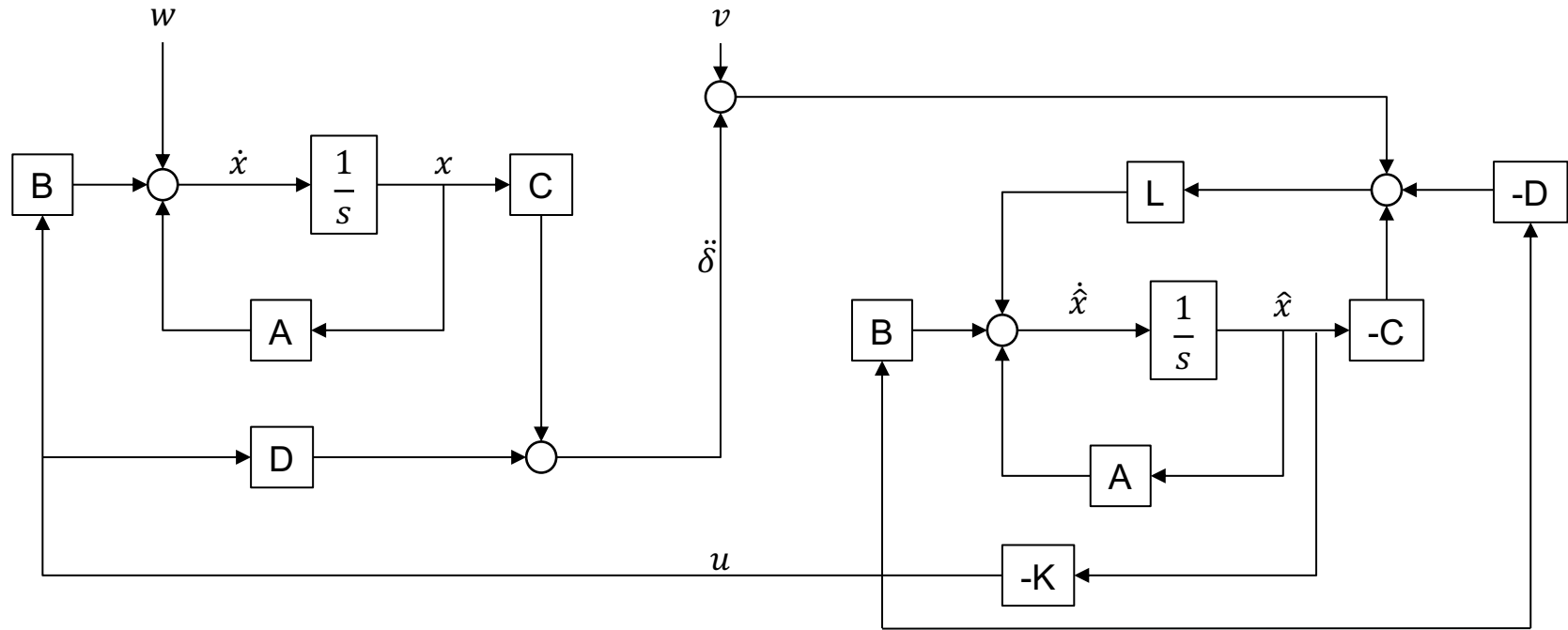
For flutter suppression, we want to use a state feedback controller: $u = -Kx$.

LQG Regulator



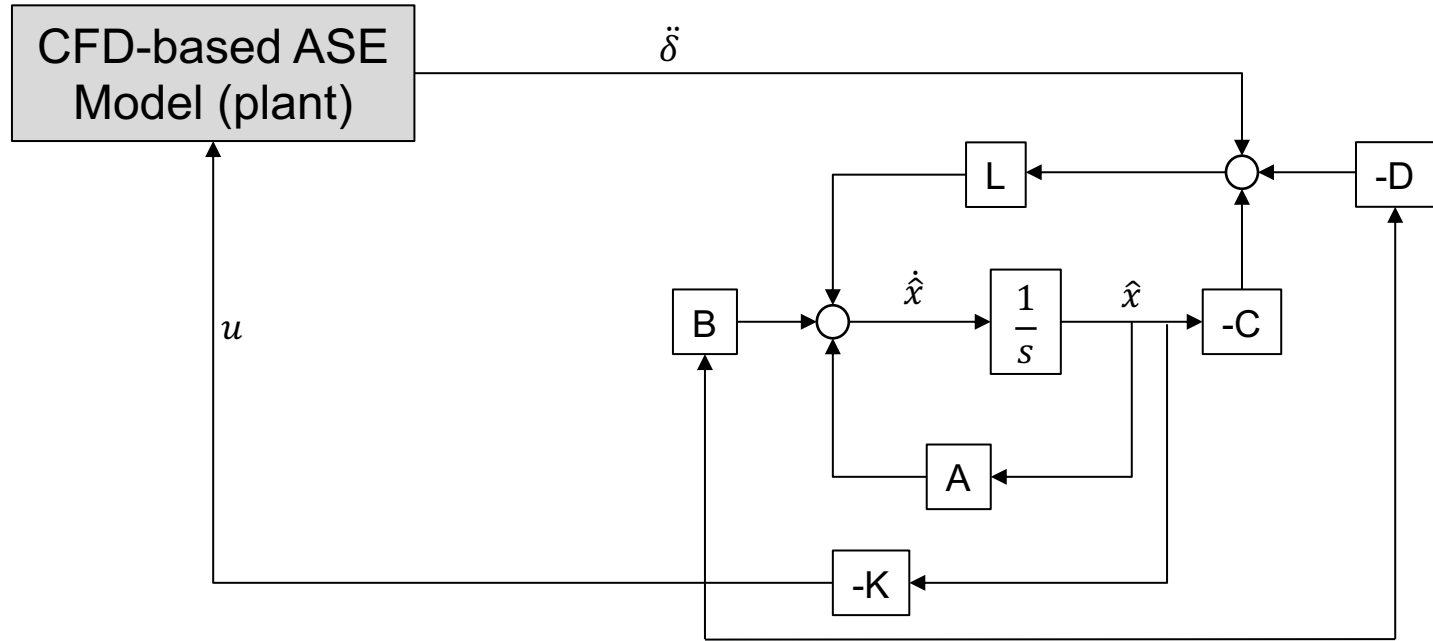
Use a Kalman filter to estimate the state vector, x .

LQG Regulator



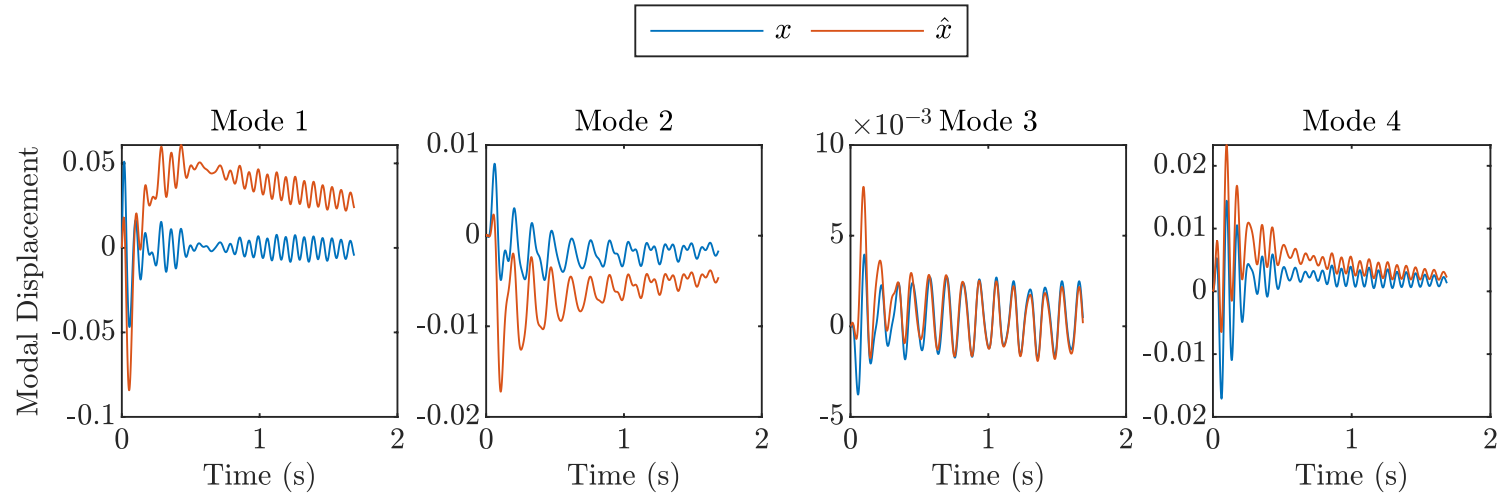
Implement state feedback controller using state estimates, $\hat{x}$.

Results



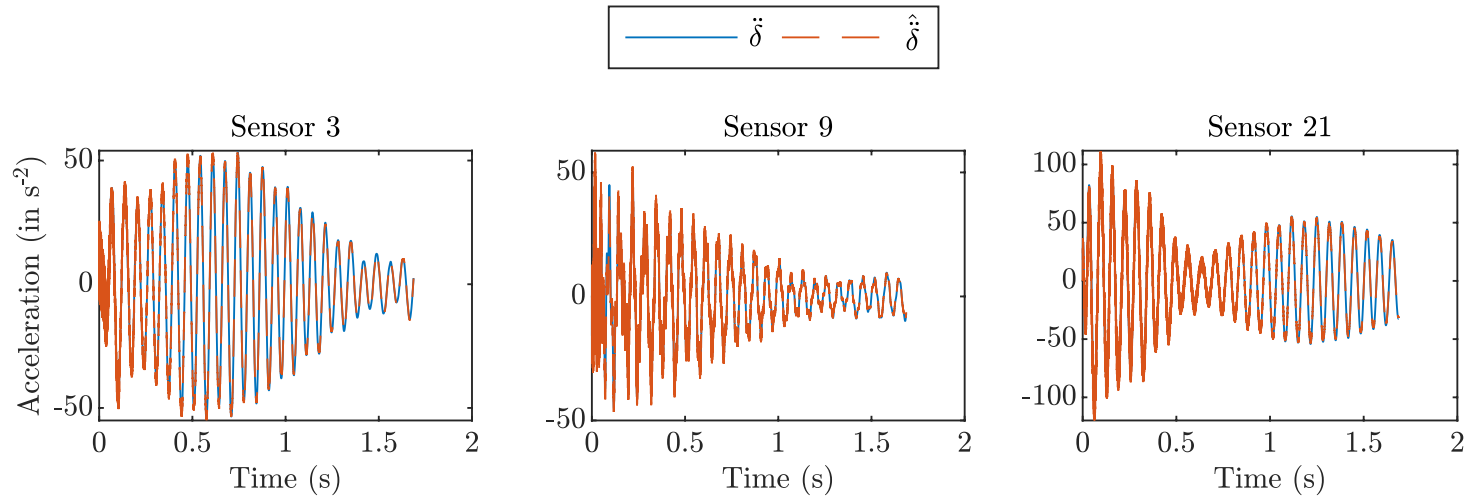
Replace plant with CFD-based simulation and see how LQG regulator does...

Results



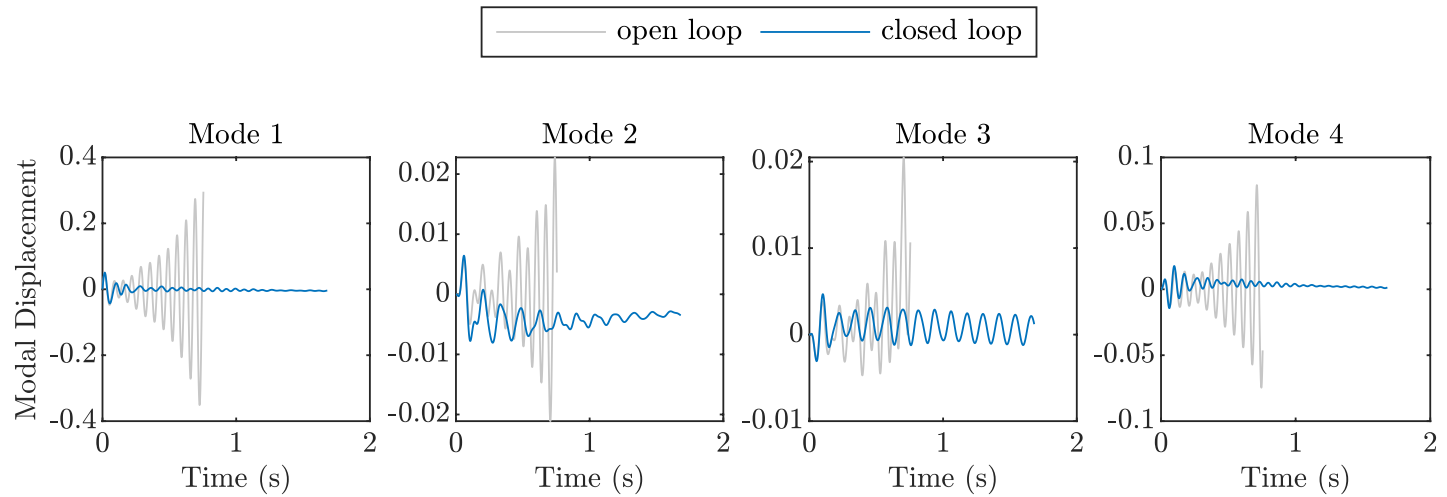
Kalman filter state estimates versus the actual value from the plant.

Results



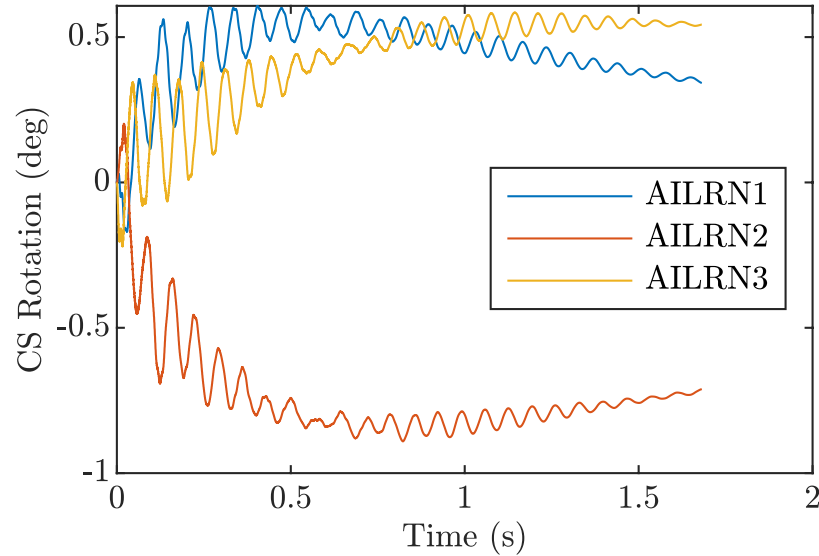
Kalman filter acceleration estimates versus the actual value from the plant.

Results



Unstable, open-loop response compared to the stabilized, closed-loop response.

Results



Control surface deflections during the closed-loop simulation.

Conclusions

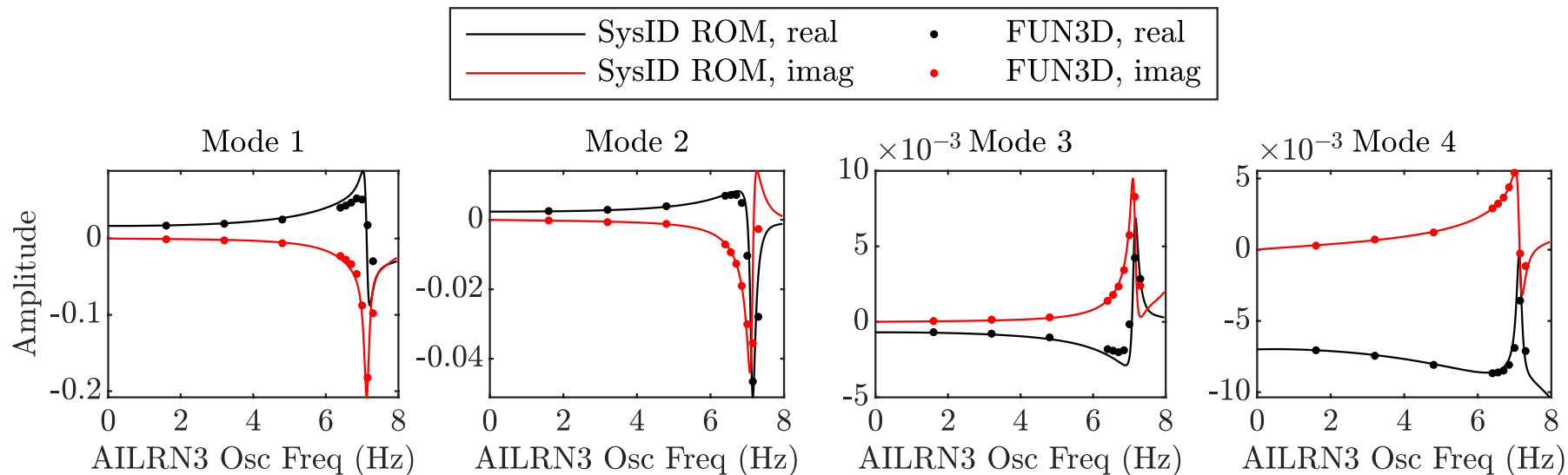
- Kalman filter estimates were adequate for feedback control.
- Feedback controller successfully stabilized an unstable plant.
- Active flutter suppression using a LQG regulator successfully demonstrated.

Thank you



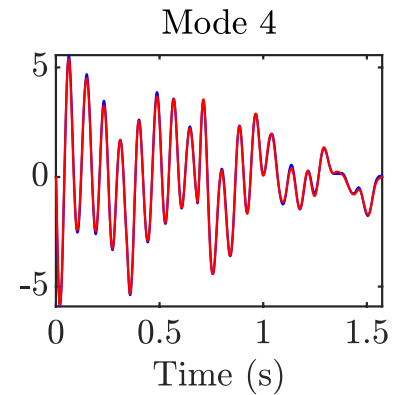
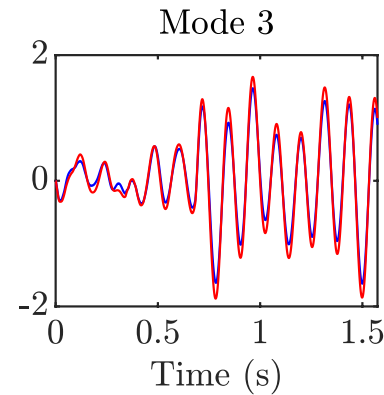
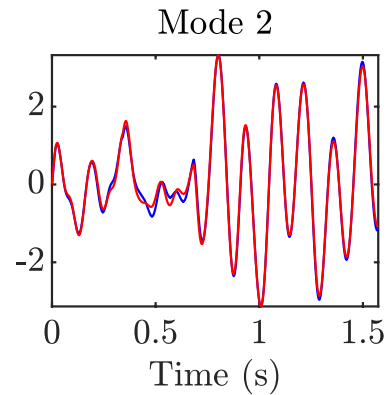
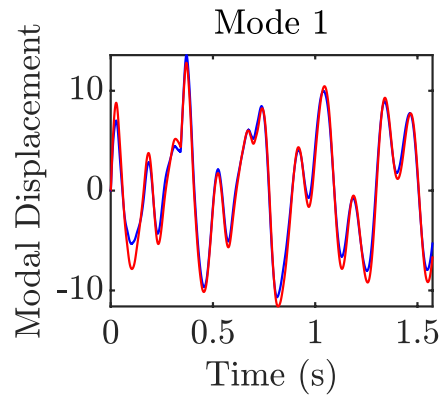
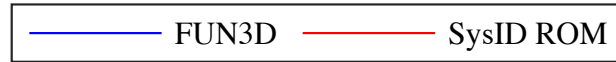
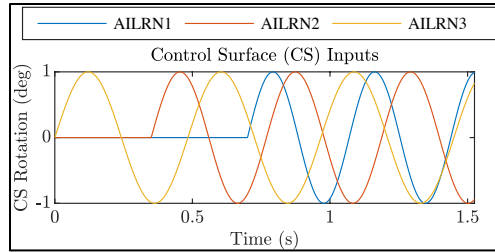
backup slides

ASE Model



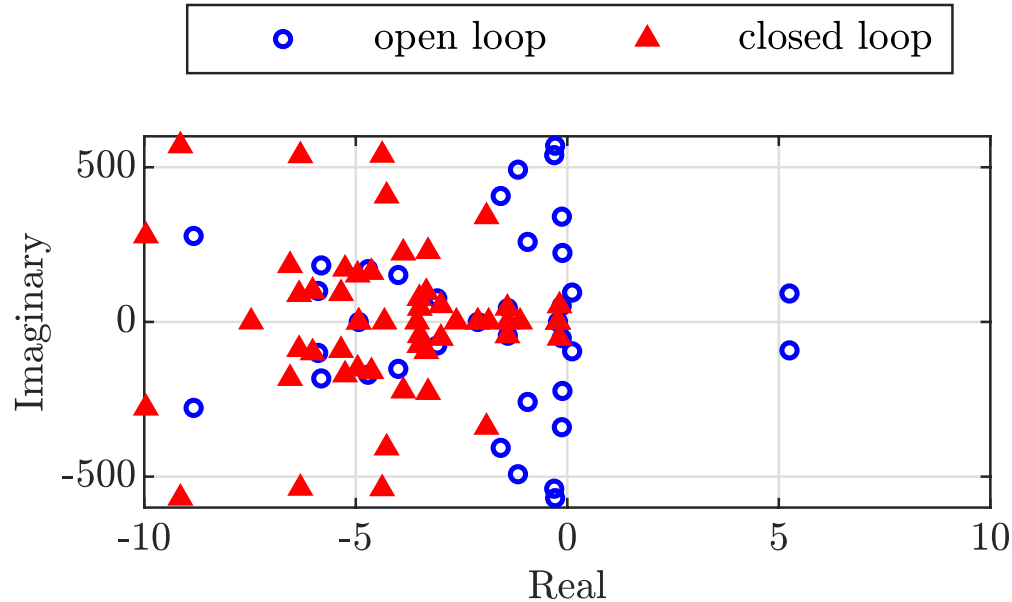
Real and imaginary components of responses in modal displacement due to a sinusoidal input to AILRN3 as a function of oscillation frequency.

ASE Model



Responses of the first four structural modes to prescribed control surface inputs.

LQG Regulator



Open- and closed-loop poles of the combined system.