Control of Body Freedom Flutter

{ C. P. Moreno, A. Kotikalpudi, H. Pfifer, G. J. Balas } Department of Aerospace Engineering & Mechanics

University of Minnesota
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Motivation

The need for improved performance and reduced operating costs has led modern aircraft designers to adopt lightweight, high-aspect-ratio flexible wings. These modifications are being applied to:

- Commercial planes
- Autonomous aircraft
  - Intelligence
  - Surveillance
  - Reconnaissance missions

These aircraft exhibit high flexibility and significant deformation in flight, leading to increased interaction between rigid and structural dynamics. This phenomenon is called ***Body Freedom Flutter***.

Ground Vibration Test

The University of Minnesota performed an impact hammer test to identify the structural dynamics of the aircraft. Acceleration responses at 34 points were measured using a single input force. The response to a hammer impact is an approximation of the impulse response function. The following frequencies and mode shapes were found from fitted frequency response data:

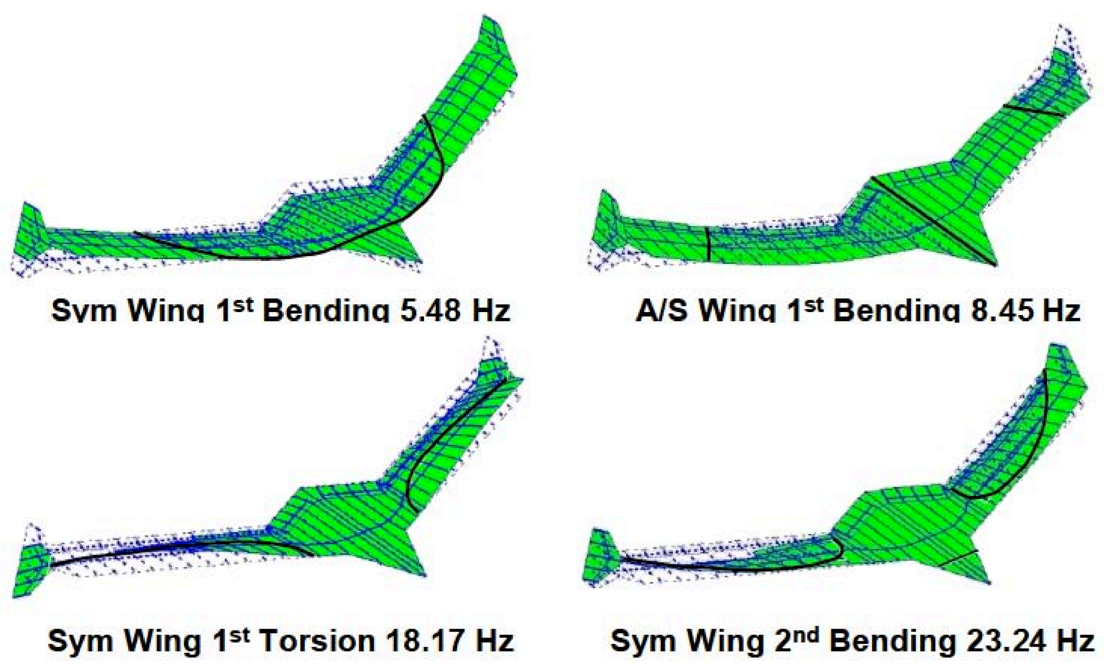

Figure 2: Mode shapes [1]

Aeroelastic Model

Linear, continuous-time, state-space models at constant altitude from 40 KEAS to 90 KEAS describe the aeroelastic behavior of the BFF vehicle. Body freedom flutter is present at 42 KEAS. Additional flutter instabilities are present at 58 and 62 KEAS.

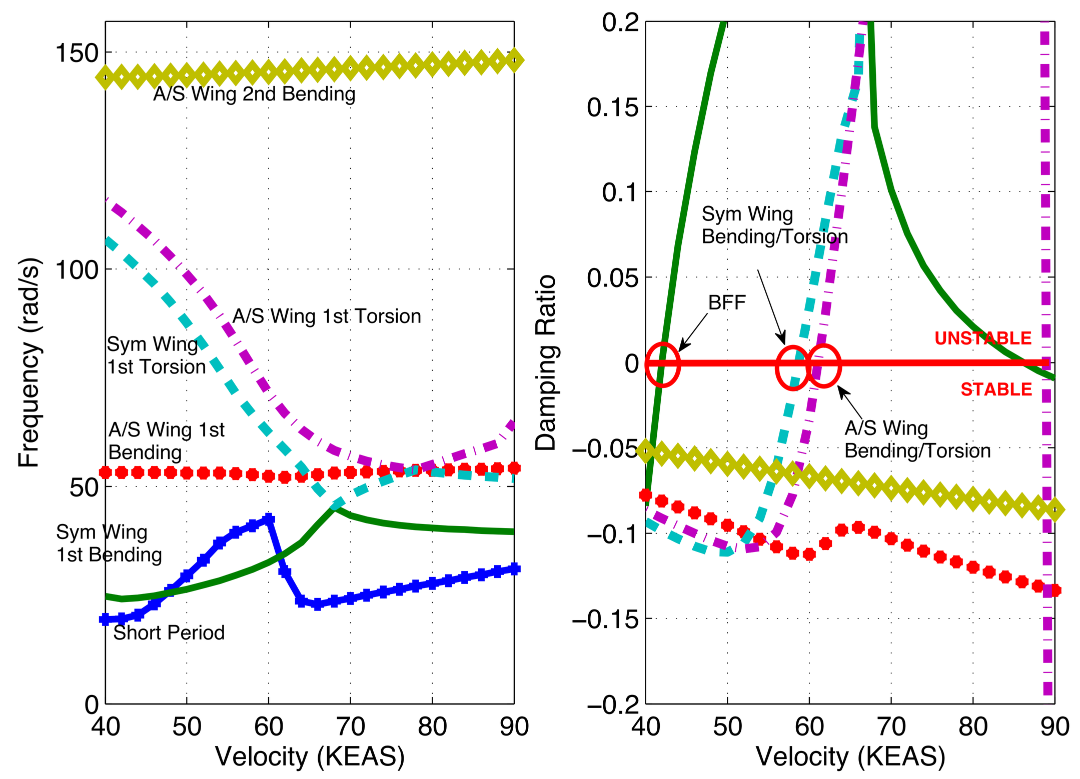

Figure 3: Velocity/frequency/damping plot

Body Freedom Flutter Vehicle

The U.S. Air Force Research Laboratory contracted with Lockheed Martin Aeronautics Company to develop a body freedom flutter (BFF) vehicle for demonstration of active aeroelastic control. The vehicle is a high-aspect-ratio flying with light weight airfoil made from a rigid center body and foam core flexible wings. The aircraft has eight control surfaces, four used for flutter suppression, six vertical accelerometers distributed along the vehicle and rate sensors.

The airfoil cross-section is positively cambered for good lifting characteristics at low angles of attack. The center of gravity is ahead of the aerodynamic center, providing static stability in the longitudinal axis. Lateral stability is provided by the winglets.

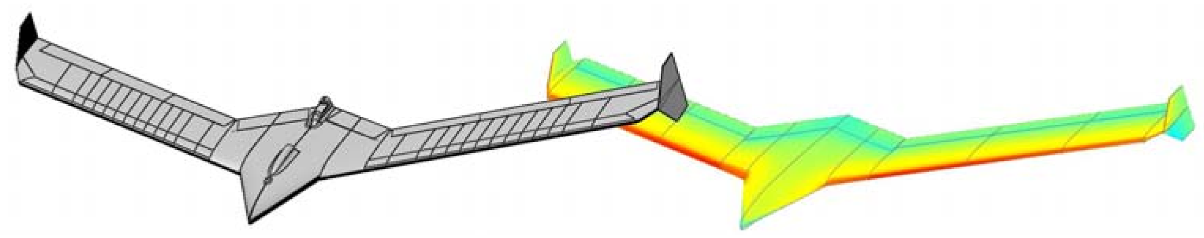

Figure 1: Aircraft model

Robust Aeroservoelastic Control

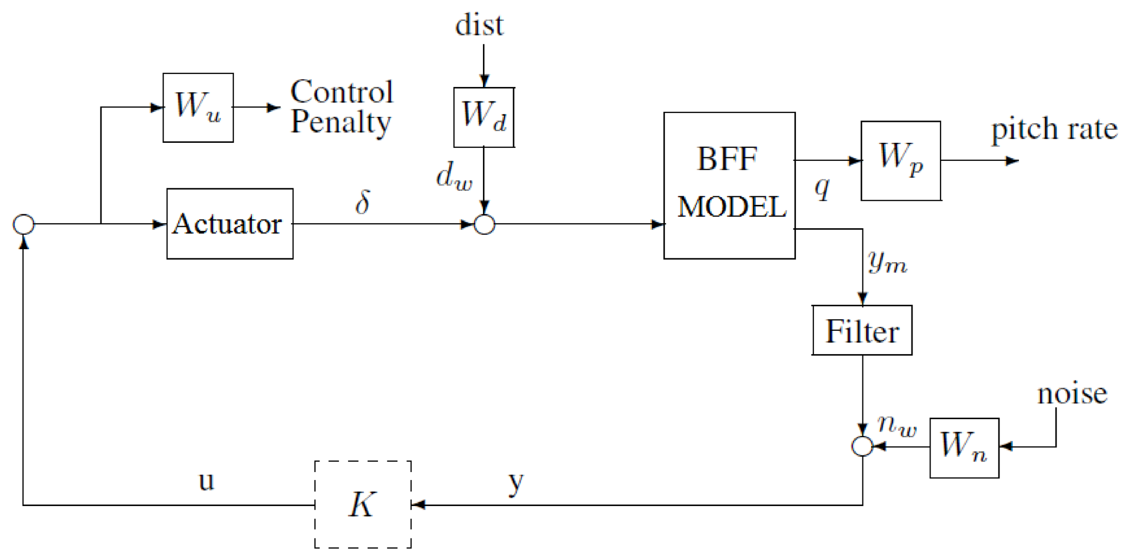

Figure 4: Interconnection for controller synthesis

Performance objectives are stabilization of the aircraft across the flight envelope and attenuation of the flexible modes observed in the pitch rate.

H -controllers are designed at individual flight conditions.

Stabilization of the system is achieved until 82 KEAS.

Future work looks to integrate flutter suppression for flight control and gust load alleviation.

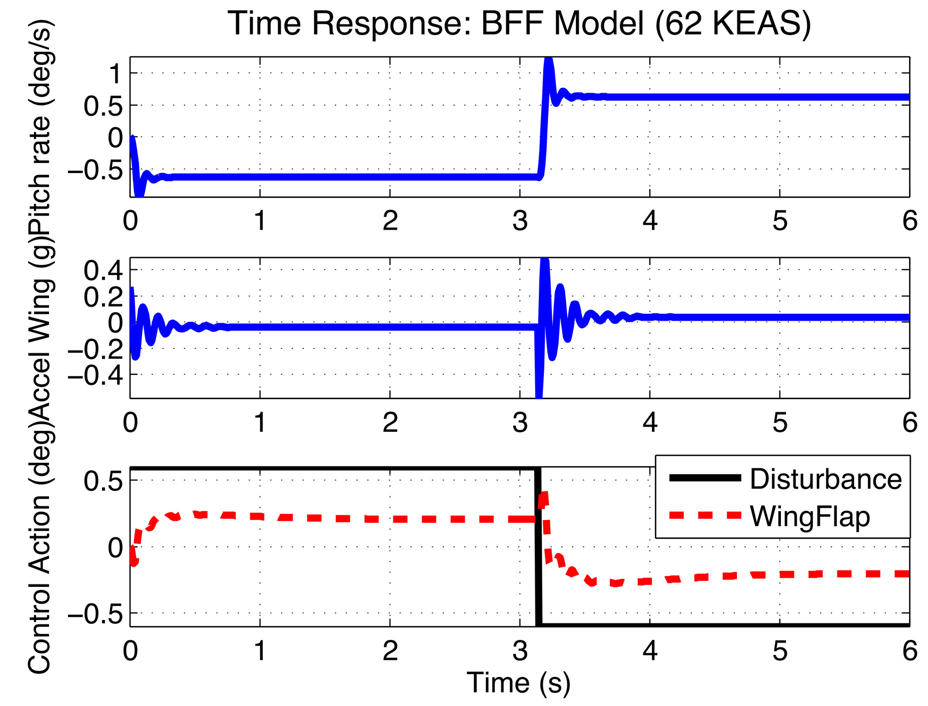

Figure 5: Flutter suppression time response

References

[1] Holm-Hansen, B., Atkinson, C., Benarek, J., Burnett, E., Nicolai, L., and Youssef, H., "Envelope expansion of a flexible flying wing by active flutter suppression.", *AUVSI*, Vol. 1, Denver, CO, 2010.

Future Research

Currently, robustness and performance of the linear controllers is being assessed. The system will be evaluated in presences of uncertainties and simulations of the nominal flight condition and worst-case uncertainty will be performed.

Design of linear, parameter-varying (LPV) controllers based on the linear time invariant controllers is the final objective for this project.

Contact Information

Web www.uav.aem.umn.edu
Name Claudia Moreno
Email moren148@aem.umn.edu