Overview: Performance Adaptive Aeroelastic Wing

Kelley Hashemi
Universities Space Research Association
NASA Ames Research Center

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Overview

Applications for the Performance Adaptive Aeroelastic Wing equipped with the Variable Camber Continuous Trailing Edge Flap (VCCTEF)

- Configuration optimization for drag reduction
  - Rapid aero-structural solver
  - Optimal configuration study

- Real-time drag minimization
  - Algorithm development
  - Wind tunnel demonstration

- Multi-objective control
  - Gust load alleviation
  - Maneuver load alleviation
  - Drag-cognizant control
Configuration optimization for drag reduction

- Analyzed VCCTEF configuration to determine an optimal drag-reducing arrangement and deflection profile
- High fidelity CFD is impractical, rapid aero-structural solver with reasonable accuracy needed to help narrow the design space
- Developed a vortex lattice method with transonic and boundary layer corrections
  - 3% error when compared to CFD
  - 26x faster than Euler-based model
- Optimization results identify “best” configuration that provides 8% drag benefit
  - parabolic deflection
  - 3 camber segments
  - 4-16 outboard flaps

Parabolic-3 configuration
\( \delta_1 = 1^\circ, \delta_2 = 3^\circ, \delta_2 = 6^\circ \)

-4-16 configuration
Real-time drag minimization

- Developed a real-time drag optimization algorithm for aeroelastic wings with wing-shaping control
  - Recursive least-squares system identification of aerodynamic lift and drag model
  - Optimization based on Newton-Raphson nonlinear solve of quadratic drag surrogate model

**Initial sweep**: Aerodynamic lift model estimated

**Directed sweep**: Drag approximation model estimated for design lift

**Optimization**: Nonlinear solve to identify flap solution corresponding to drag minimum

**Iterative Refinement**: Random perturbations about flap solution to refine surrogate model
Real-time drag minimization

- Subscale wind tunnel test of VCCTEF-equipped flexible wing conducted
  - SBIR Phase 2 agreement with Scientific Systems Company, Inc. and University of Washington Aeronautical Laboratory
  - Follow-on test planned to address actuator failures
Gust and maneuver load alleviation

• Designed controller for flexible wings utilizing the VCCTEF to mitigate gust and maneuver loads as measured through wing root bending moment $M_y$

• Gust and some quantities poorly known
  – Generate adaptive estimates
  – Results in time-varying control gains, solve Riccati equation online

• Multi-objective control formulation addresses several goals simultaneously
  – Cost function and weights used to combine potentially competing objectives
  – Can combine with use of nominal controller

• Cost function for gust load alleviation (GLA):

$$J = \lim_{t \to \infty} \frac{1}{2} \int_0^t \left( q_f \hat{x}^T G_x^T Q G_x \hat{x} + u_a^T R u_a + q_M \tilde{M}_y^T \tilde{M}_y \right) dt$$

\[ \tilde{M}_y = \tilde{M}_x \hat{x} + \tilde{M}_{u_n} u_n + \tilde{M}_{u_a} u_a + \tilde{M}_w \tilde{w} \]

• Wind tunnel test for GLA planned as part of SBIR Phase 2x agreement with Scientific Systems Company, Inc., University of Washington Aeronautical Laboratory, and Boeing
Gust and maneuver load alleviation

- Gust load alleviation applied to Generic Transport Model

- Maneuver load alleviation

Baseline Pitch Rate Control
Drag-cognizant control

- Multi-objective formulation easily accommodates other goals, such as drag reduction

\[ J = \lim_{t \to \infty} \frac{1}{2} \int_0^t \left( q_f \dot{x}^T G_x^T Q G_x \dot{x} + u_a^T R u_a + q_D \Delta C_D \right) dt \]
Questions?