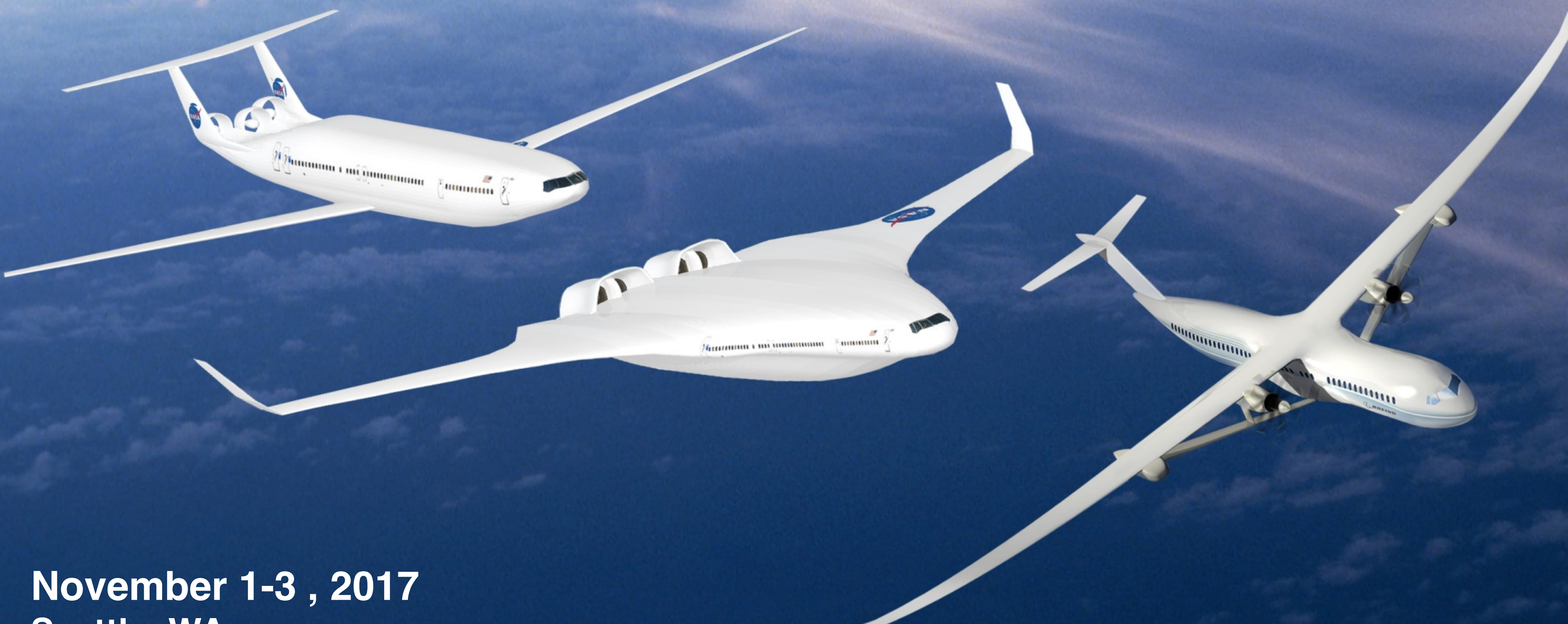
Overview: Performance Adaptive Aeroelastic Wing

Kelley Hashemi
Universities Space Research Association
NASA Ames Research Center

ACGSC Meeting

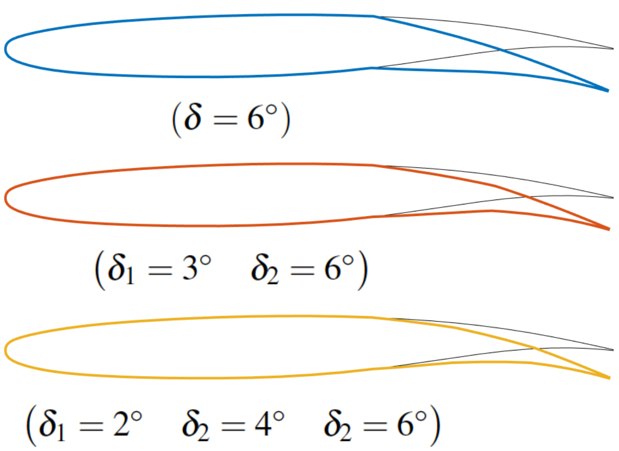


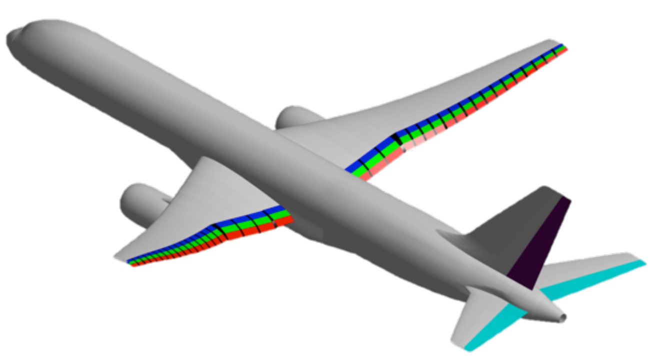
November 1-3 , 2017
Seattle, WA

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



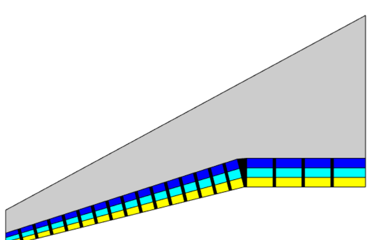


Configuration optimization for drag reduction

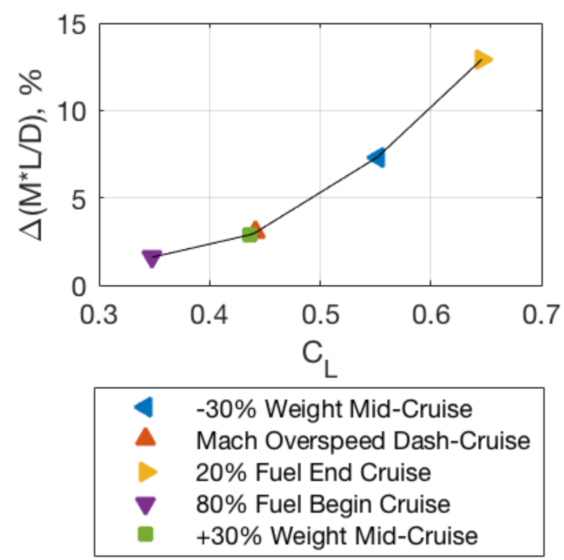
- Analyzed VCCTEF configuration to determine an optimal drag-reducing arrangement and deflection profile
- High fidelity CFD is impractical, rapid aero-structural solver with reasonable accuracy needed to help narrow the design space
- Developed a vortex lattice method with transonic and boundary layer 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

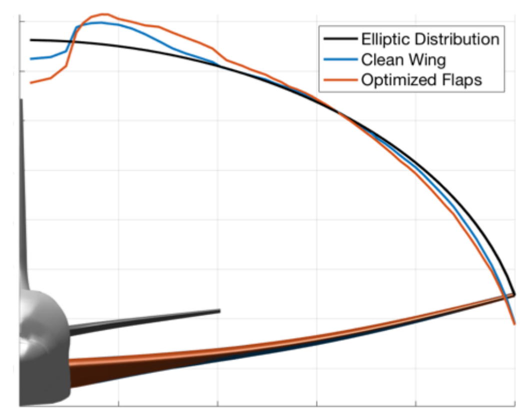
Parabolic-3 configuration

$$\left(\delta_1 = 1^\circ \quad \delta_2 = 3^\circ \quad \delta_2 = 6^\circ\right)$$



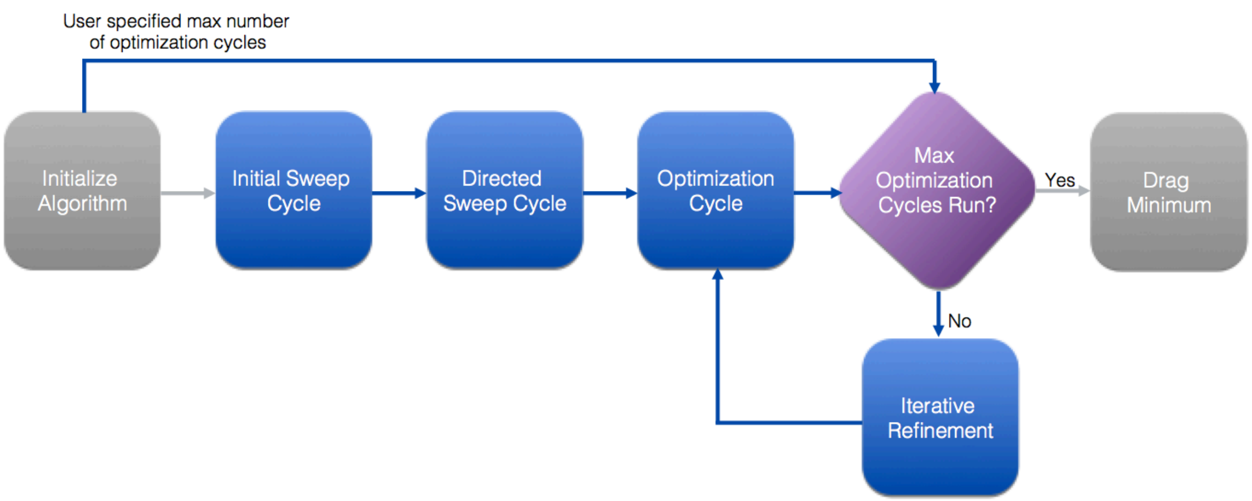
-4-16 configuration





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

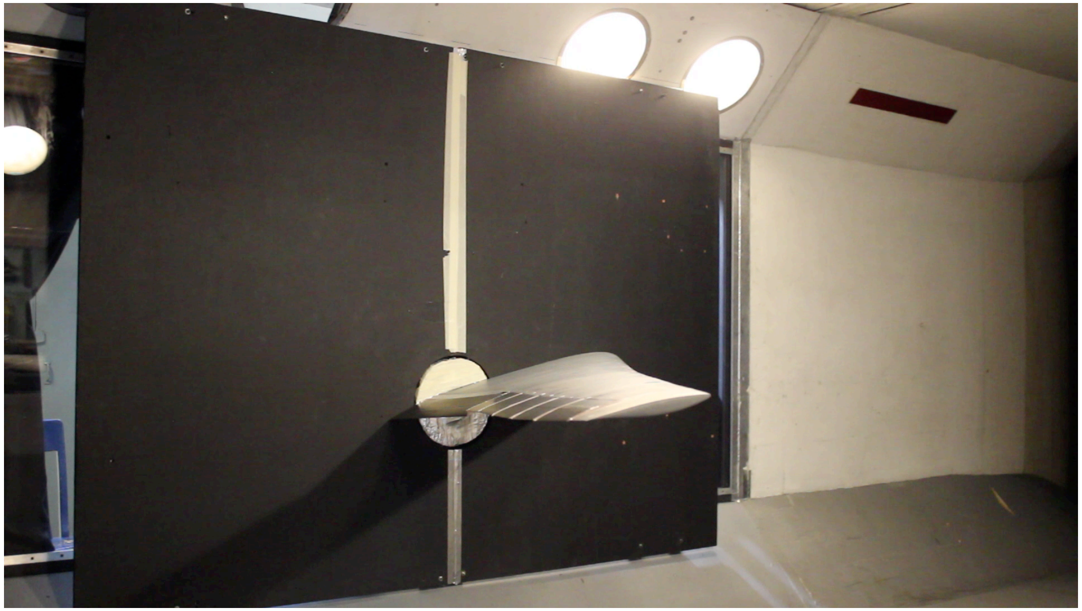
Directed sweep: Drag approximation model estimated for design lift

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):

$$J = \lim_{t\to\infty} \frac{1}{2} \int_0^t \Big(\overbrace{q_f \hat{x}^T G_x^T Q G_x \hat{x}}^{\textbf{\textit{Modal suppression}}} + u_a^T R u_a + \overbrace{q_M \widehat{M}_y^T \widehat{M}_y}^{\textbf{\textit{Load alleviation}}} \Big)\, dt$$

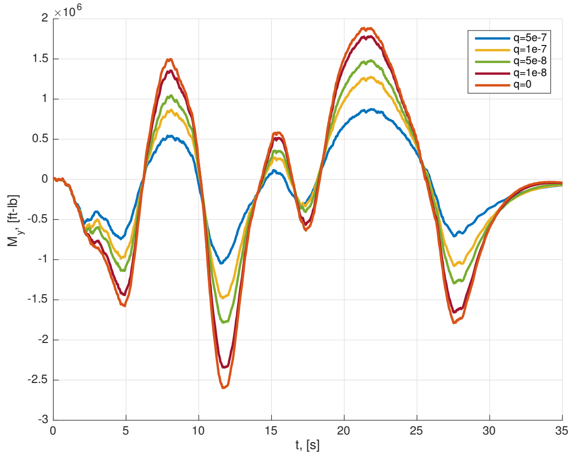
Tracking

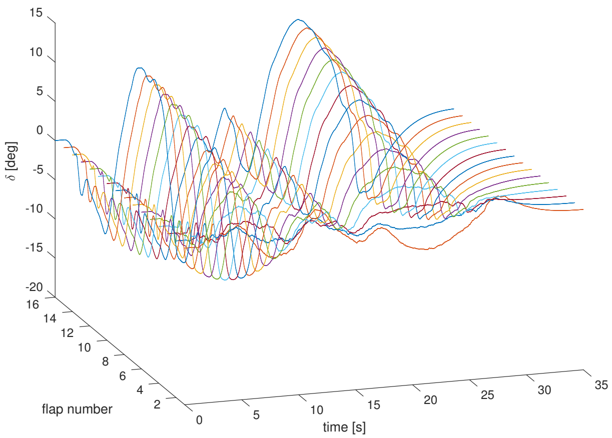
$$\widehat{M}_y = \widehat{M}_x \hat{x} + \widehat{M}_{\boldsymbol{u_n}} u_n + \widehat{M}_{\boldsymbol{u_a}} u_a + \widehat{M}_w \widehat{w}$$

- 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





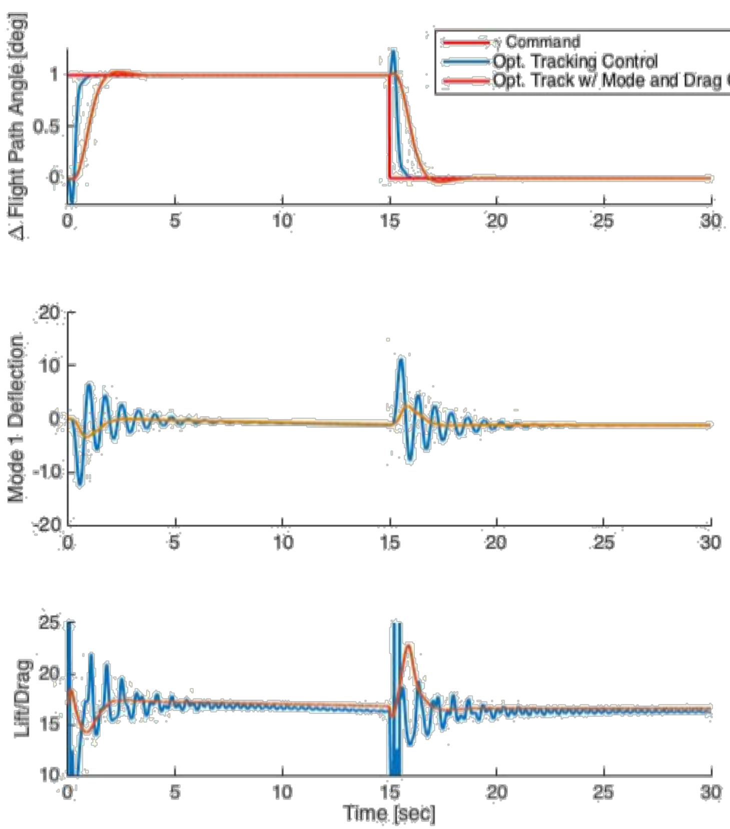
- Maneuver load alleviation

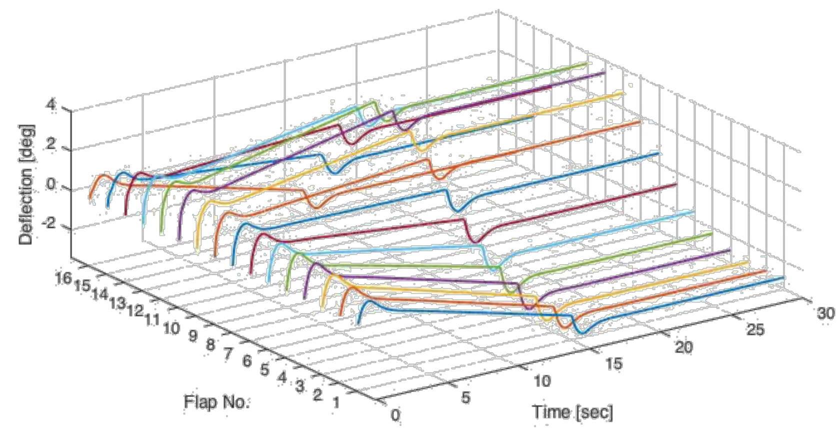
Baseline Pitch Rate Control

Drag-cognizant control

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

$$J = \lim_{t\to\infty} \frac{1}{2}\int_0^t (q_f \hat{x}^T G_x^T Q G_x \hat{x} + u_a^T R u_a + q_D \Delta C_D)\, dt$$





Baseline Flight Path Control

Questions?