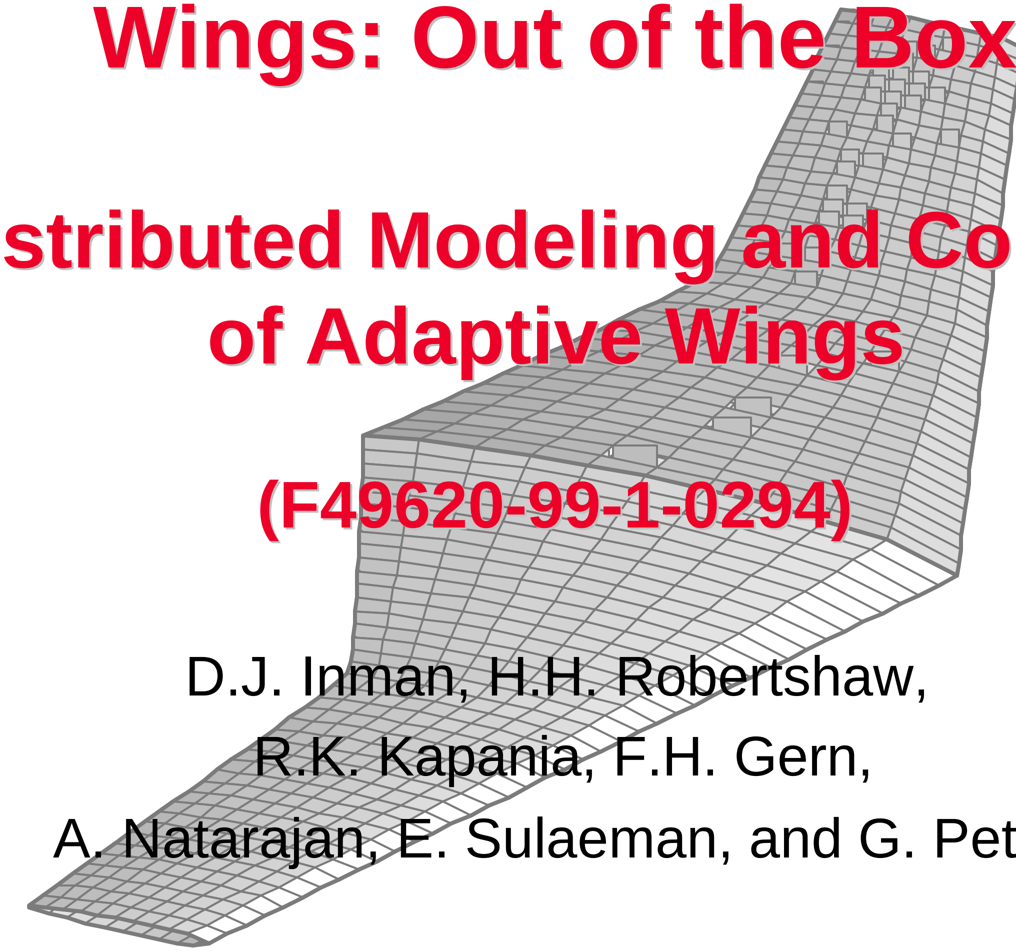
Wings: Out of the Box

Distributed Modeling and Control of Adaptive Wings

(F49620-99-1-0294)



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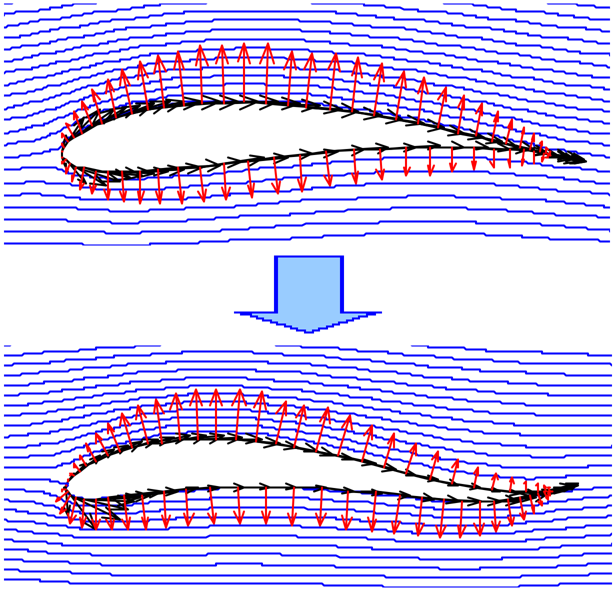
Wings: Out of the Box

Program Goal:

Determination of minimum control energy required to increase maneuverability of an flapless UCAV using smart structures and morphing airfoil technology



Objectives:

- **Mimic the effects of wings with conventional, discrete control surfaces**
- **Determine actuation energy, forces, moments, displacements, and time constants needed for an adaptive wing approach**
- **Investigate performance and maneuverability improvements of a morphing wing vehicle**

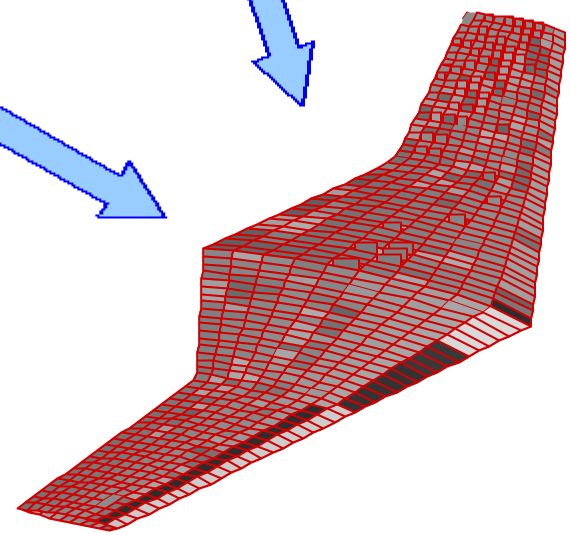
Problem Approach

Determination of force, energy, displacement, and time constant requirements for smart wings

Task 1: Dynamics & Control
Determine control algorithms to maneuver the aircraft using wing morphing.

Task 2: Aeroservoelasticity
Determine the aeroelastic effects of structural changes and use of energy transfer between structure and airflow to facilitate structural morphing.

Task 3: Adaptive Structures
Determine the optimum network of sensors and actuators for a given morphing structure to control vehicle maneuver and cruise performance.

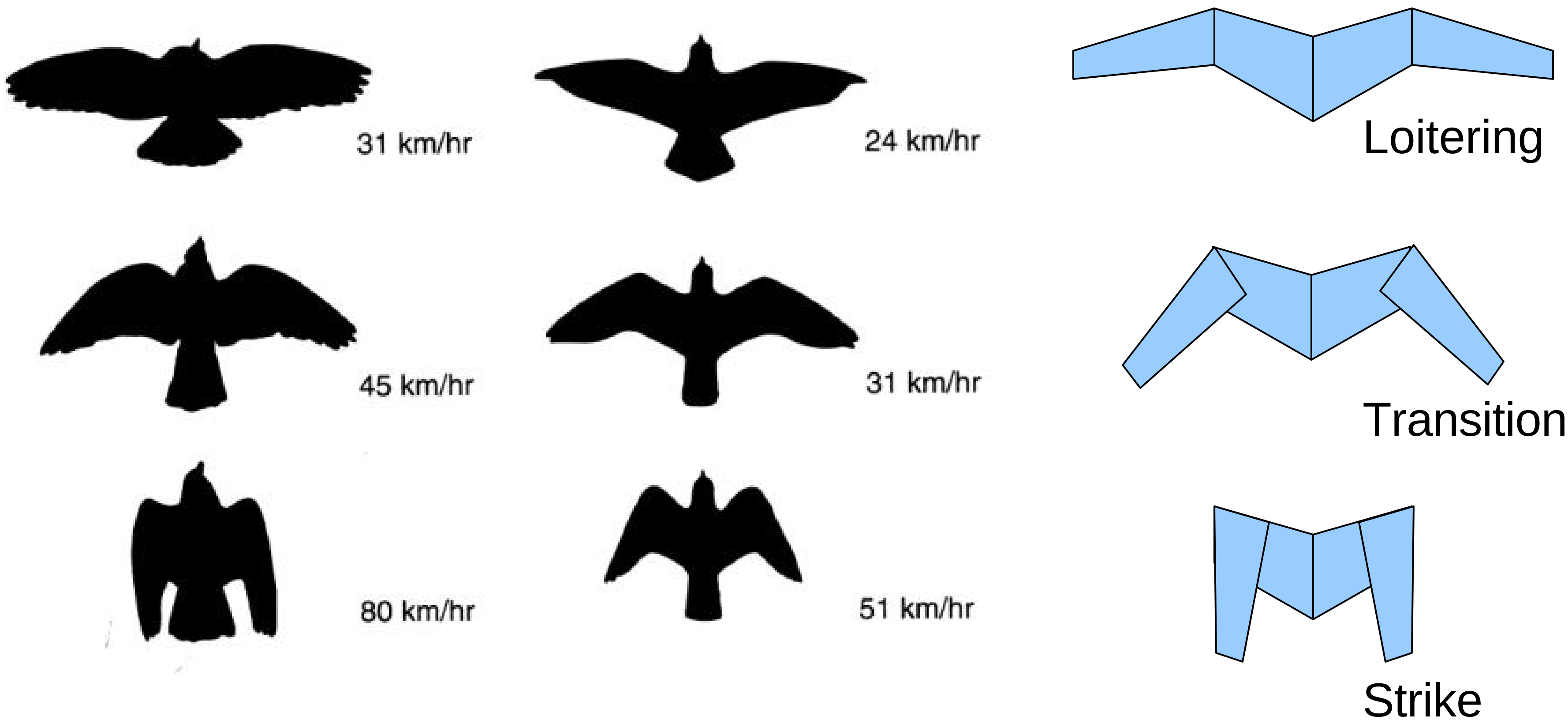


Tools

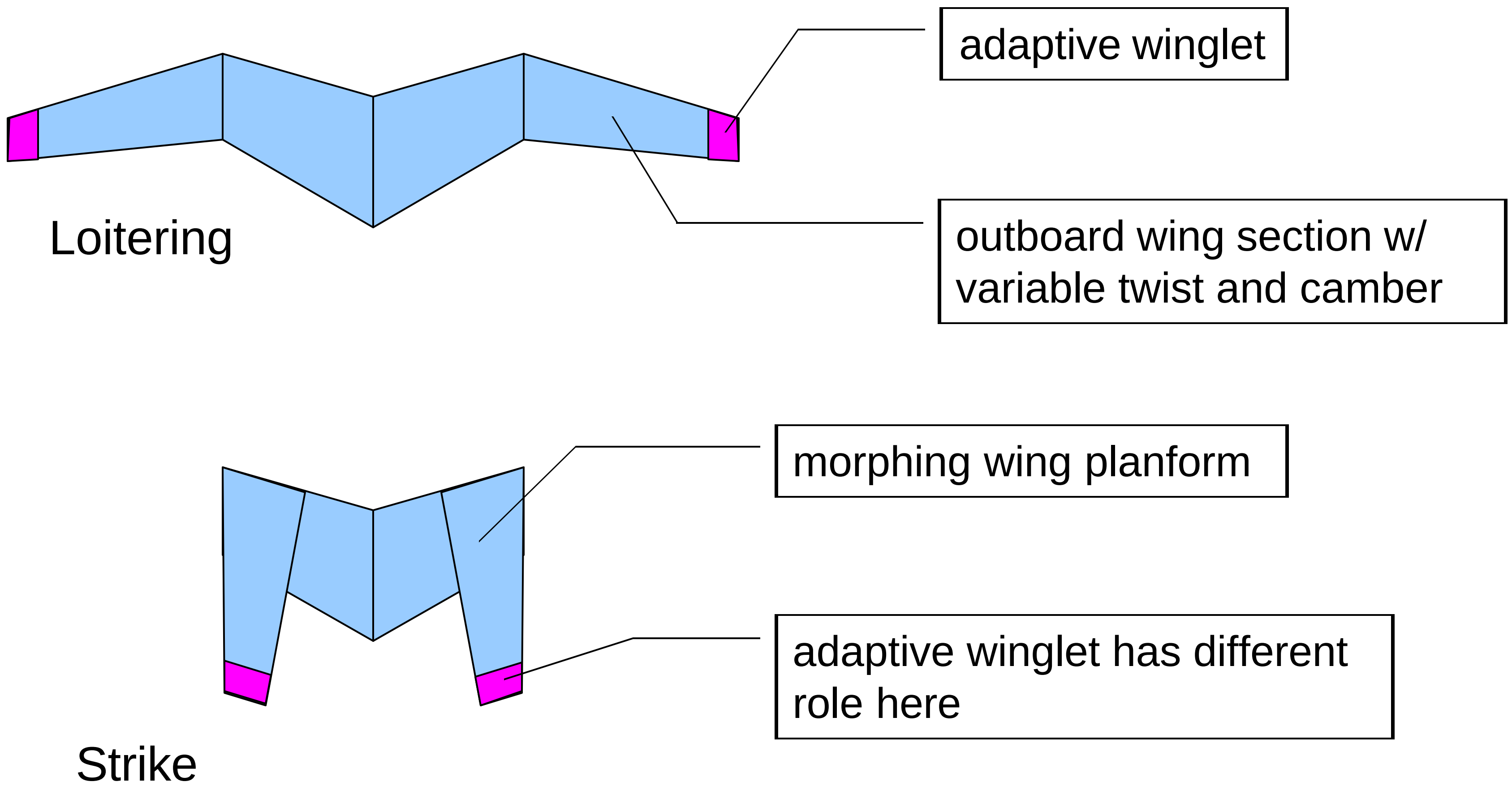
- Matlab / Simulink / Real Time Workshop for dynamic simulations
- Conformal Mapping and B-Spline Methods
- Vortex - Lattice Codes for Quasi-Steady Aerodynamic Load Predictions of Morphing Airfoils
- Doublet-Panel Code for Unsteady Aerodynamic Load Predictions of Morphing Airfoils
- Equivalent Plate Model for Structural Modeling of Arbitrary Planform Wings
- NASTRAN / PATRAN for Validation

Multimission Vehicle Inspired by Nature

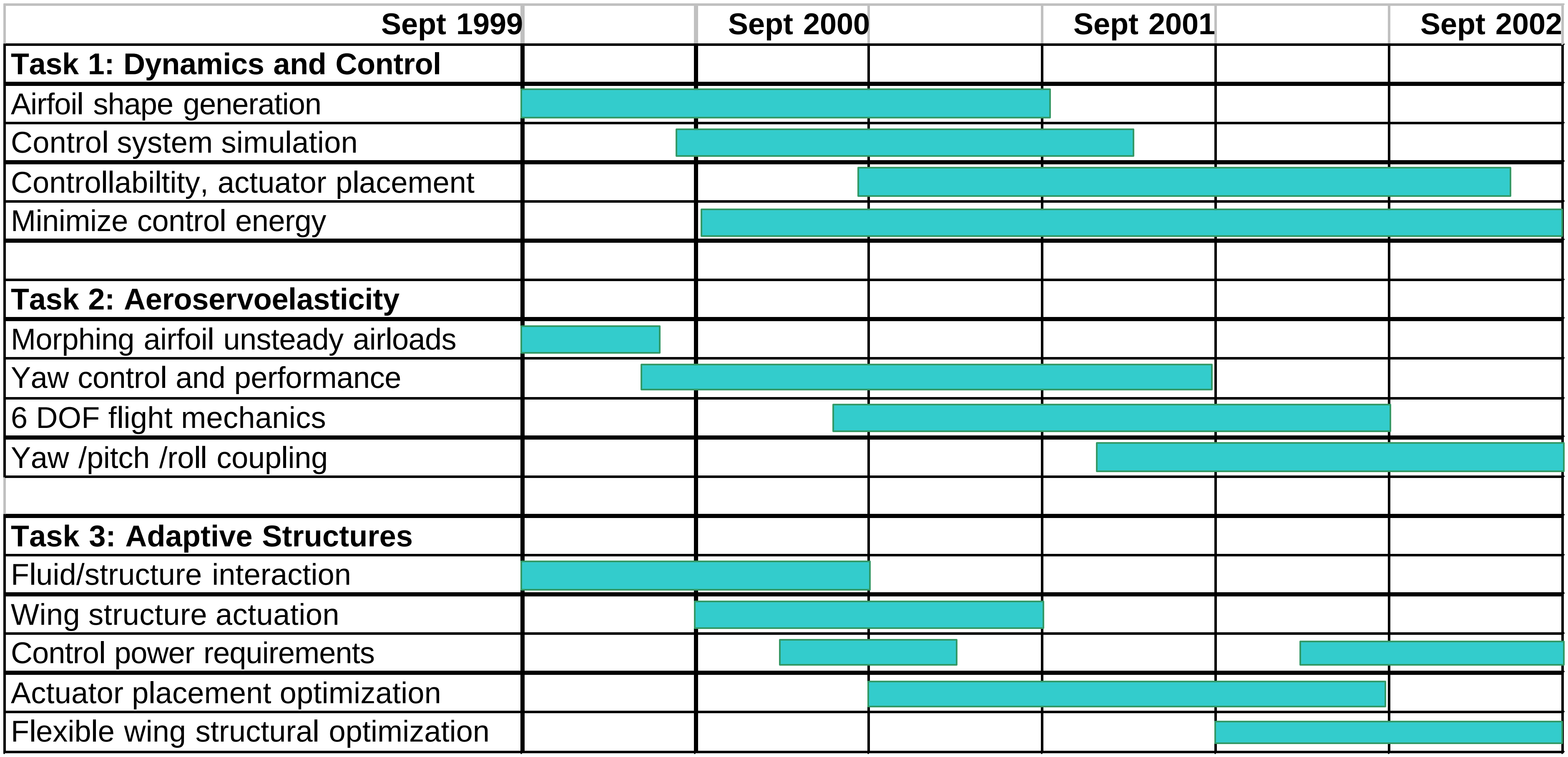
Pigeon | Falcon | Morph-Eagle



Multimission Vehicle

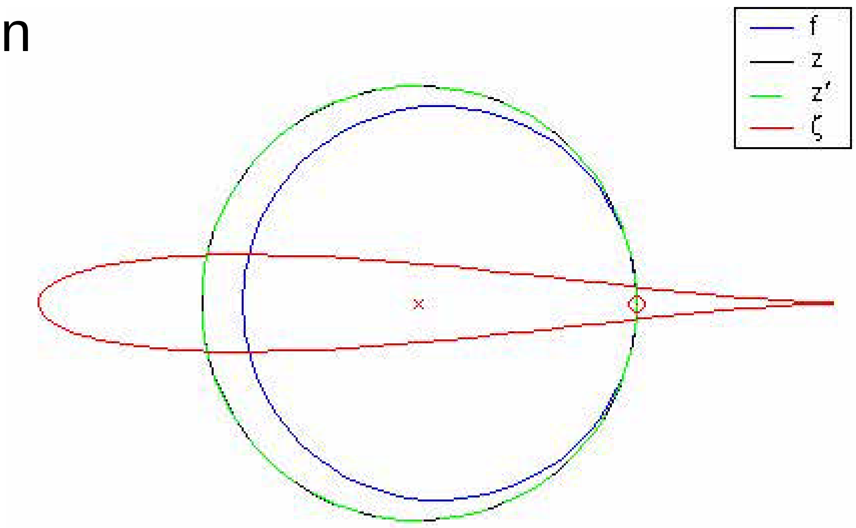


Program Plan/Progress



Creating Airfoil Sections

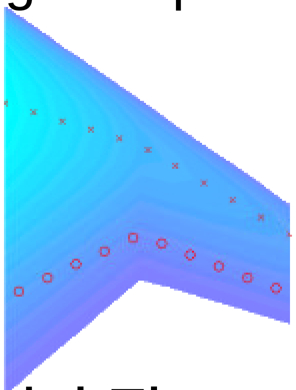
- Why conformal mapping?
  - Easy way of creating complex geometry.
  - Fast and easy to solve for flow when used with potential flow theory.
- Conformal mapping
  - f is mapped into the z-plane
  - z-plane circle offset by xc, yc and goes through point xt, yt
  - z'-plane, morphed circle
  - ζ-plane, airfoil



- 6 shape parameters
  - xc, thickness towards leading edge
  - yc, camber of airfoil
  - xt, thickness towards trailing edge
  - yt, trailing edge camber
  - Δ, trailing edge thickness
  - chord

Finite Span Aerodynamics

- Vortex Line
  - Used to determine the amount of circulation, Γ, along the span.

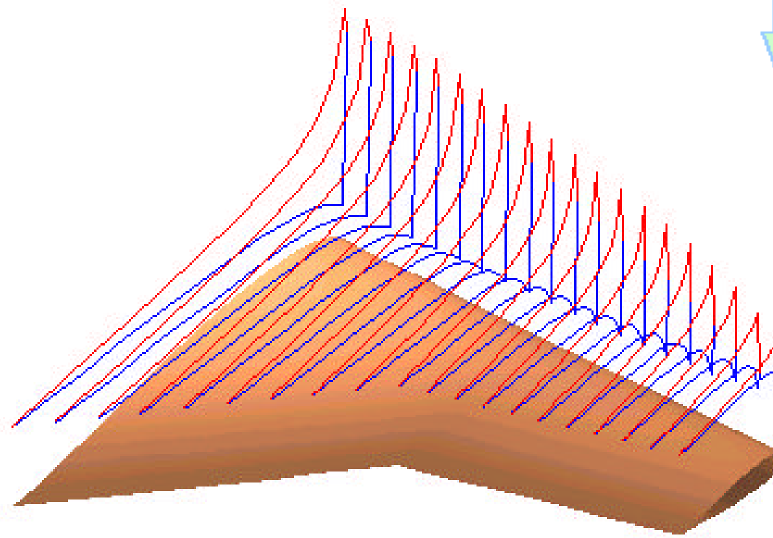


- Potential Flow
  - Used to determine flow around the unit circle(f-plane) with circulation.

$$\frac{dw}{df} = V_{\infty}\left(e^{-ja} - \frac{e^{ja}}{f^{2}}\right) + \frac{j\Gamma}{2\,fp}$$

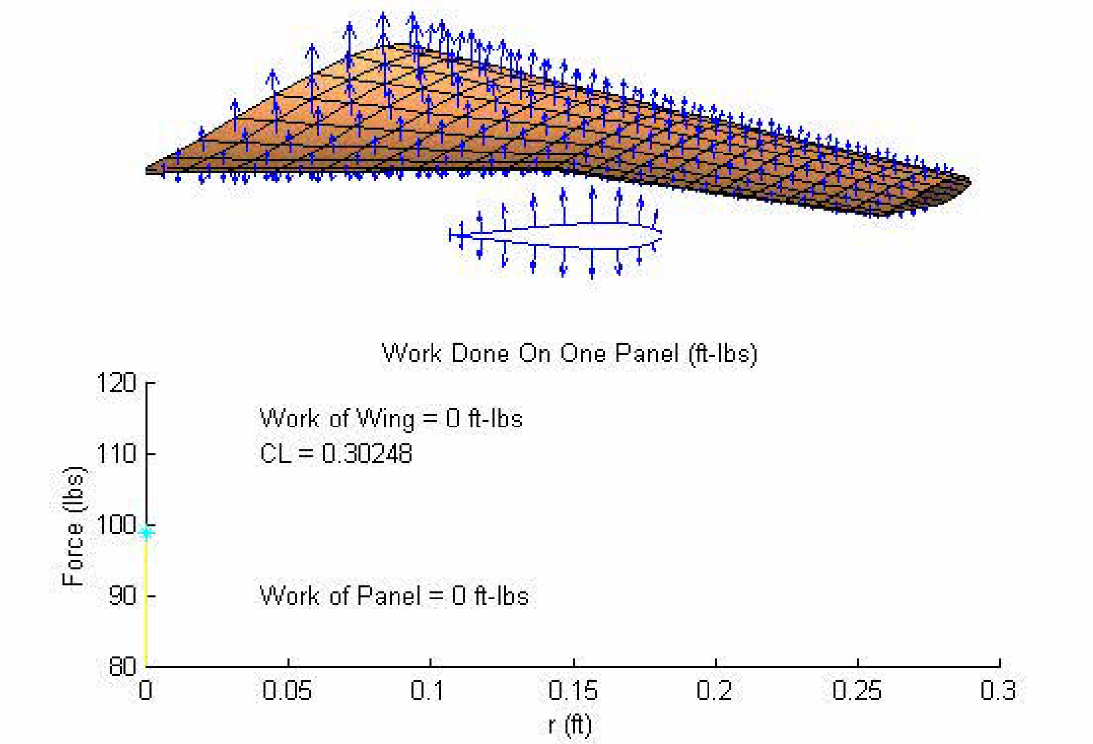
- Conformal mapping
  - Used to determine the flow around the airfoil.

$$\frac{dw}{dz} = \frac{dw}{df}\frac{df}{dz}\frac{dz}{dz'}\frac{dz'}{dz}$$



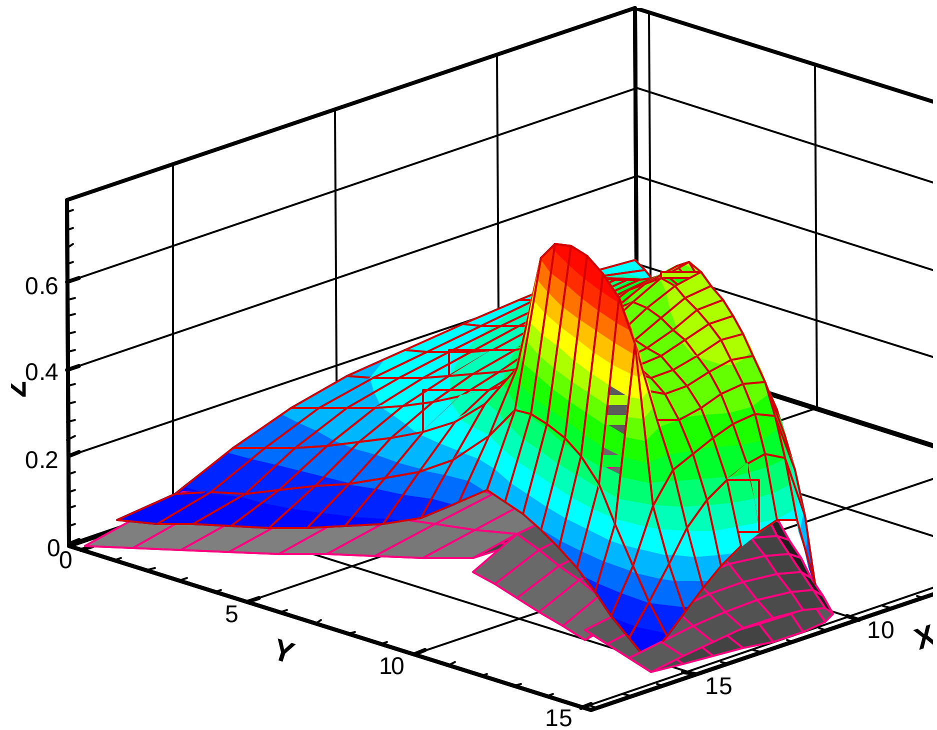
Work of Morphing Wing Against Aerodynamic Forces

- Forces
  - Forces can be determined from the pressure distribution.
- Work
  - $W = \int F \bullet dr$
  - $CL_1 = 0.30 \rightarrow CL_2 = 0.47$
  - $q_{ref} = 1.04\, psi$
  - $W \approx 616\ ft \cdot lbs$

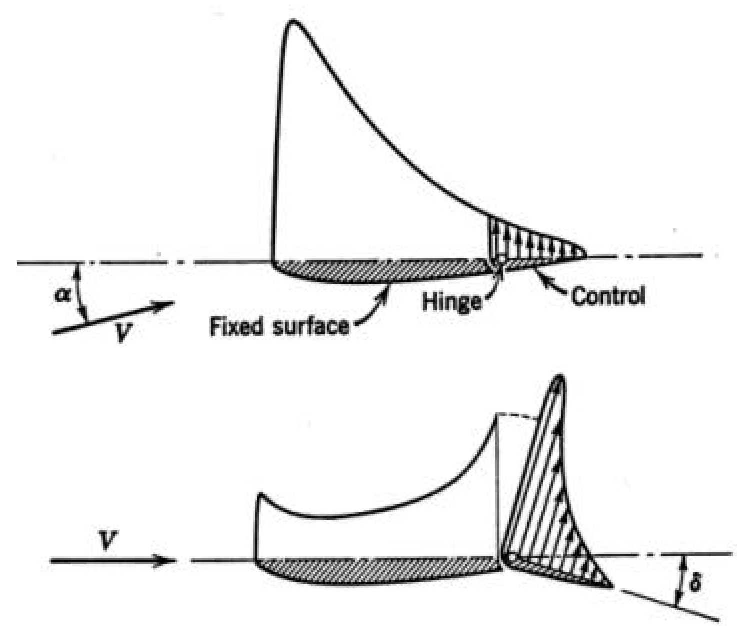


Trailing Edge Flap Performance Evaluation

3d Pressure distribution



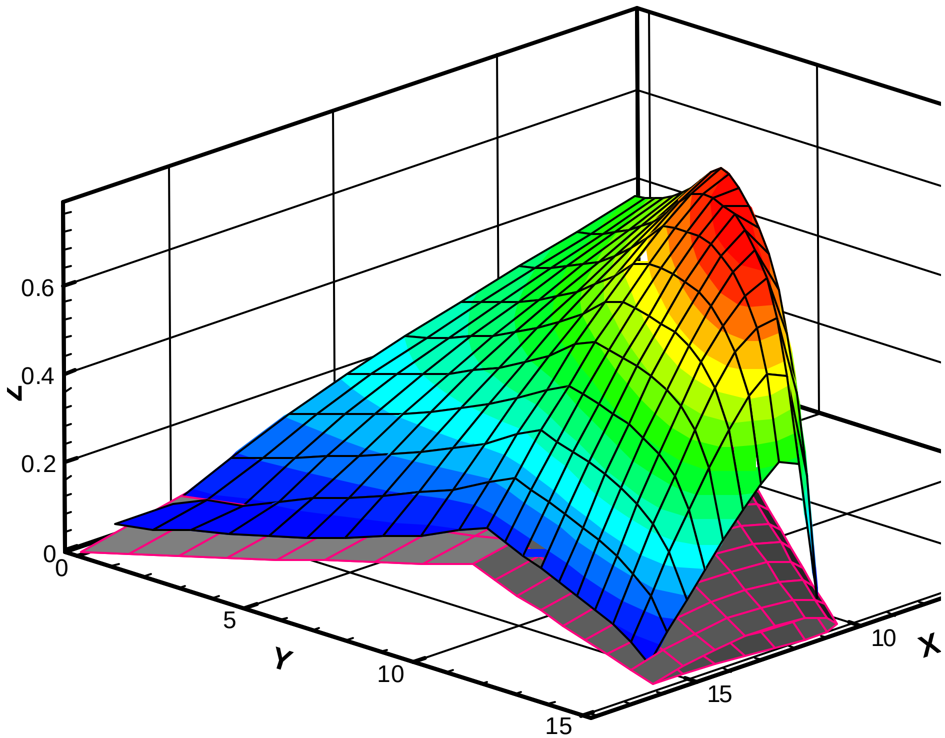
Hinge moment



Actuation energy: $\Delta W_{flap} = \int_0^d M_{flap}(d)dd = \sum_{flap\ panels} \int_0^d \Delta S_{flap\ panel} q \Delta c_p(d) x_{flap\ panel} dd$

Morphing Wing Performance Evaluation

3d Pressure distribution

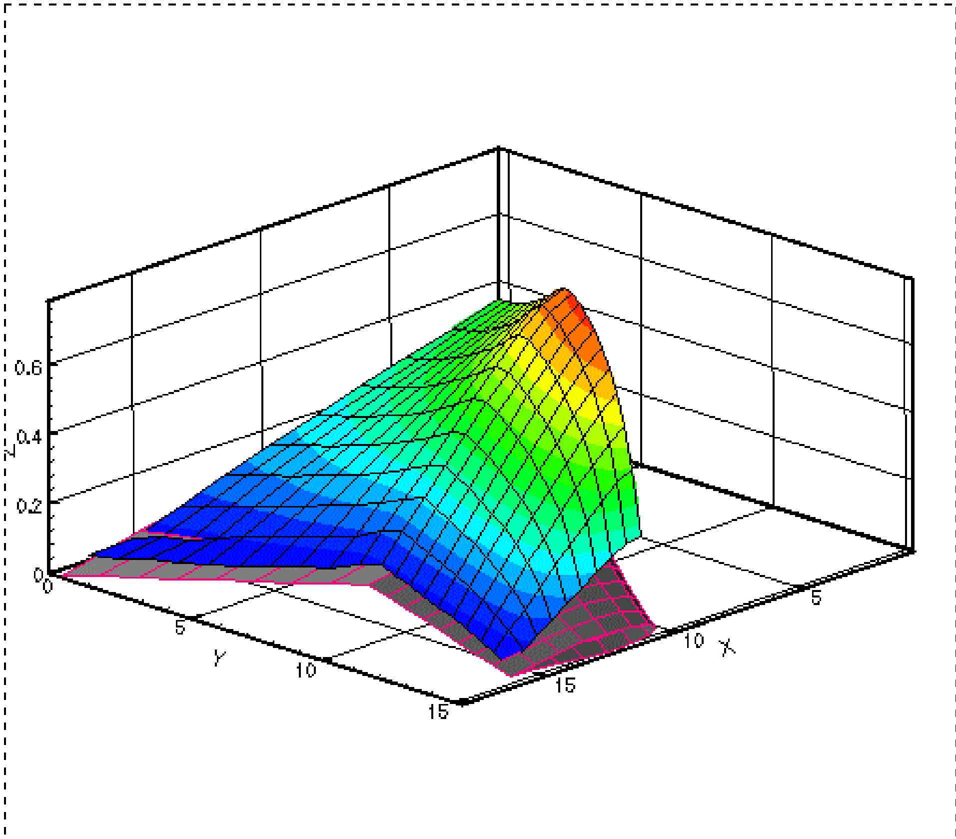


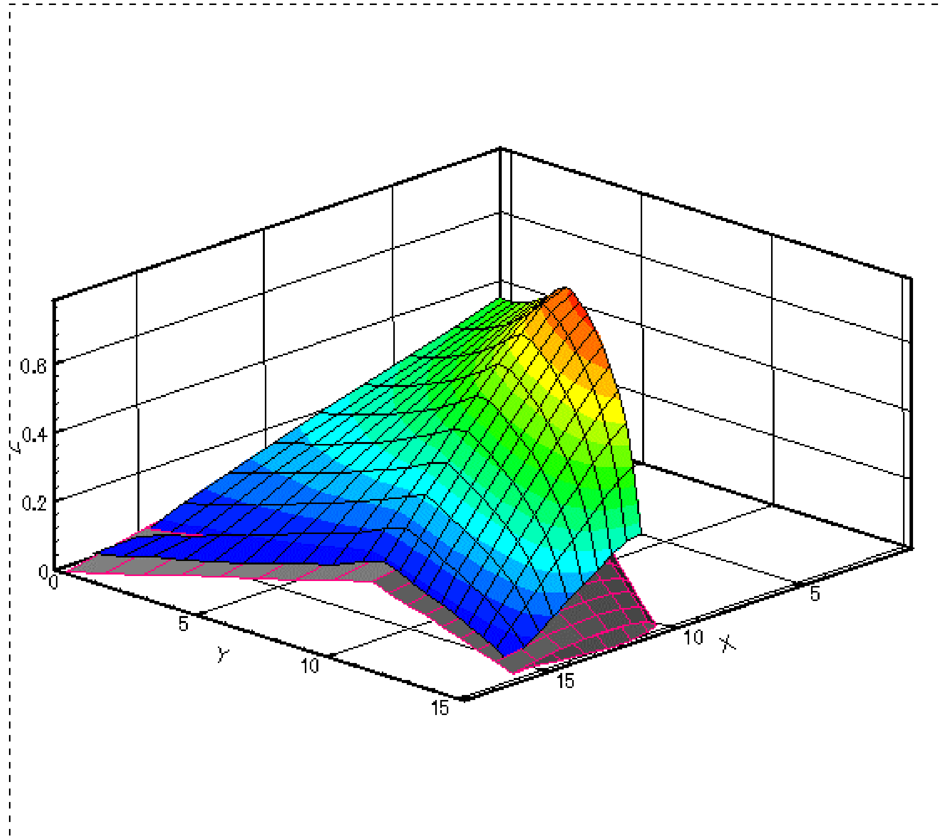
Wing morphing

- Linear increase of outboard wing camber
- Constant strain actuation of upper and lower skins
- Increase of wing c_L from 0.3 to 0.47
- Equivalent to TE flap 10° down

Actuation energy: $$\Delta W = \sum_{panels} \Delta W_{aero} = \sum_{panels} \int_{r_1}^{r_2} \Delta S_{panel}\; q\; \Delta c_p(r) dr$$

Nondimensional Pressure Distribution Morphing Wing vs. TE Flap





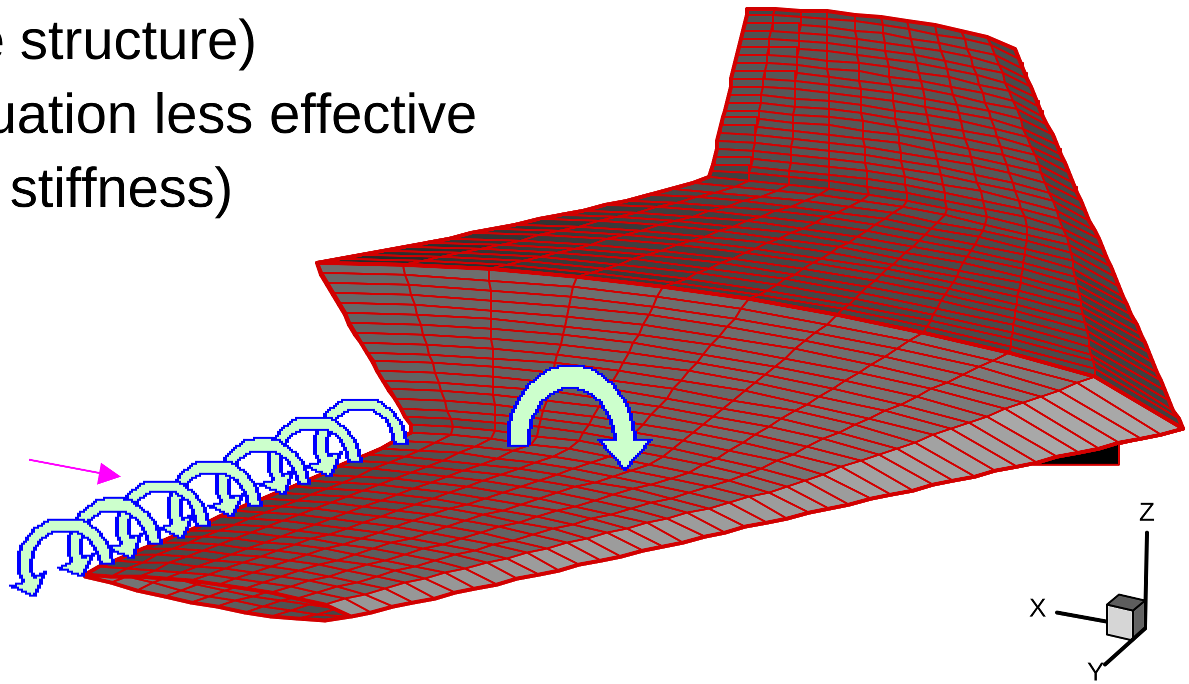
Actuation Energy and Peak Power Draft Calculations

	Trailing edge flap	**Morphing wing**
Δc_L	0.17 (0.3 to 0.47)	0.17 (0.3 to 0.47)
Actuation	Flap10º down	Increased outboard wing camber (eq. flap10º down)
Actuation energy	136.99 *ft-lbf* (185.732 *J*)	423.13 *ft-lbf* (573.687 *J*)
Peak power (based on 90º/sec flap rotation)	1232.90 *ft-lbf/sec* (2.24 *HP*)	3808.17 *ft-lbf/sec* (6.92 *HP*)
Hinge moment	1302.7 *ft-lbf* (15632 *in-lbf*)	N/A

Wing Actuation

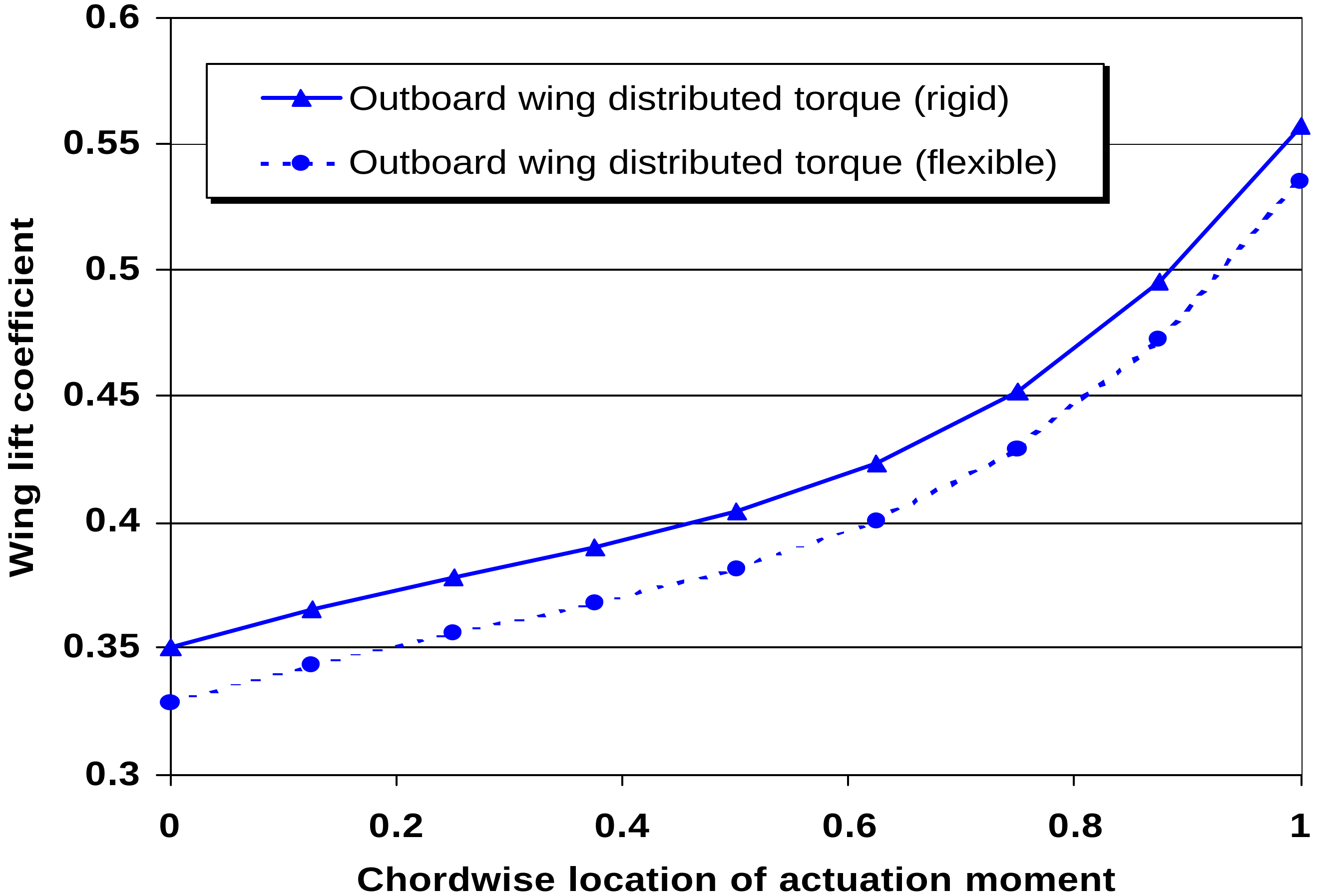
- Constant torque actuation of outboard wing section
  - torque applied close to trailing edge (relatively flexible structure)
  - leading edge actuation less effective (higher structural stiffness)

Need to understand **where** to actuate



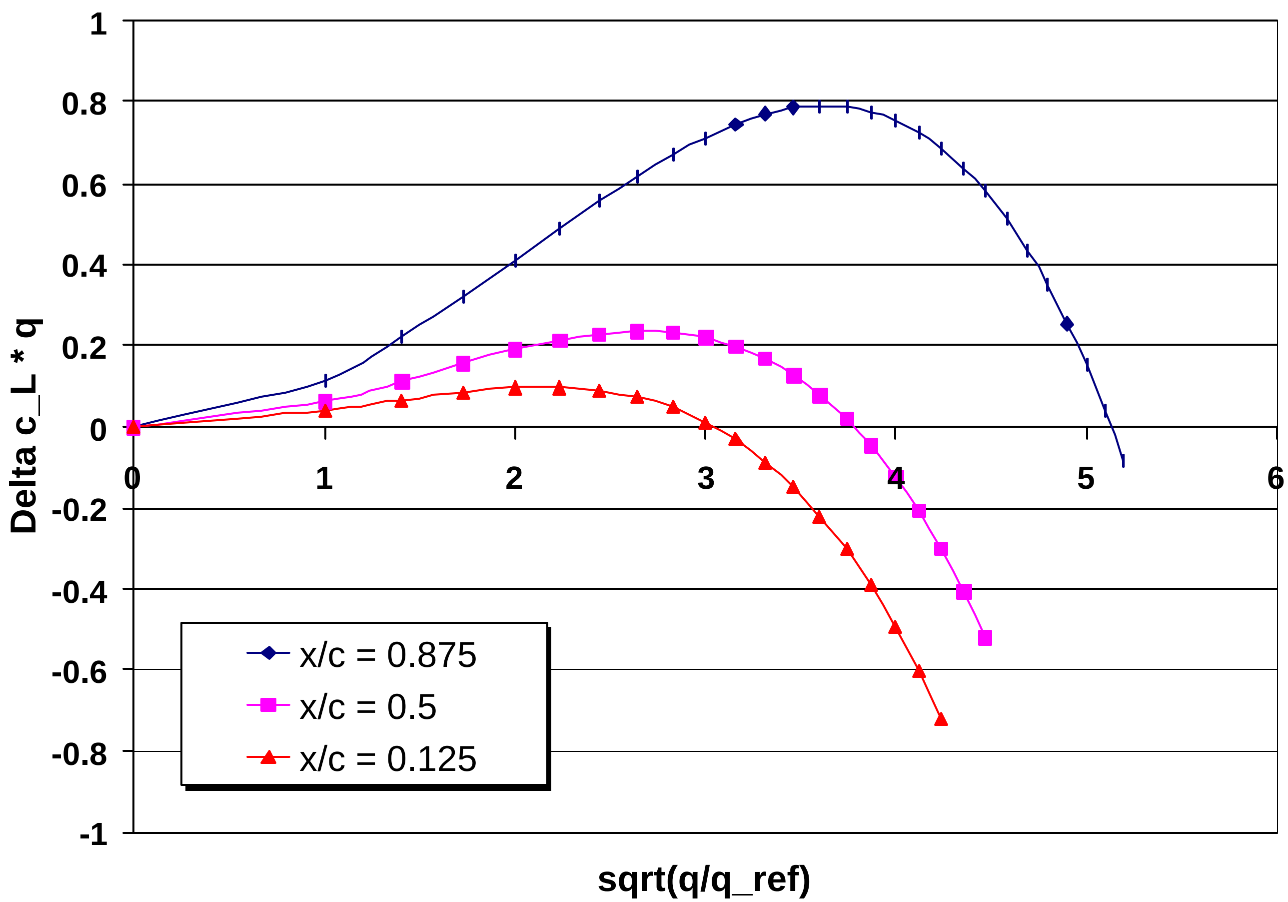
Wing Actuation

- Influence of chordwise moment location on actuation effectiveness



Wing Actuation

- Influence of chordwise moment location on roll performance



Accomplishments

- Modified conformal mapping methods to produce possible morphed wing shapes.
- Developed and verified appropriate design aerodynamic model for evaluating effects of wing morphing.
- Developed design tools for flexible wings with general planform.
- Developed model to include unsteady effects of morphing wings
- Integrated these modules for energy tracking and performance evaluation

Gained / Learned

- Can fly a plane in longitudinal dynamics with a morphing wing
- Demonstrated the applicability of our chosen / developed tools for investigating morphing wing control.
- The actuation approach for adaptive wings depends heavily on the structure chosen.
- Unsteady effects are not primary