

# Morphing Aircraft Dynamical Model: Longitudinal Shape Changes



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# What is Morphing

- ✎ It depends on who is asked
  - ✎ A change in sweep
  - ✎ A change in twist
  - ✎ A change in dihedral
- ✎ All of these changes represent some type of shape change

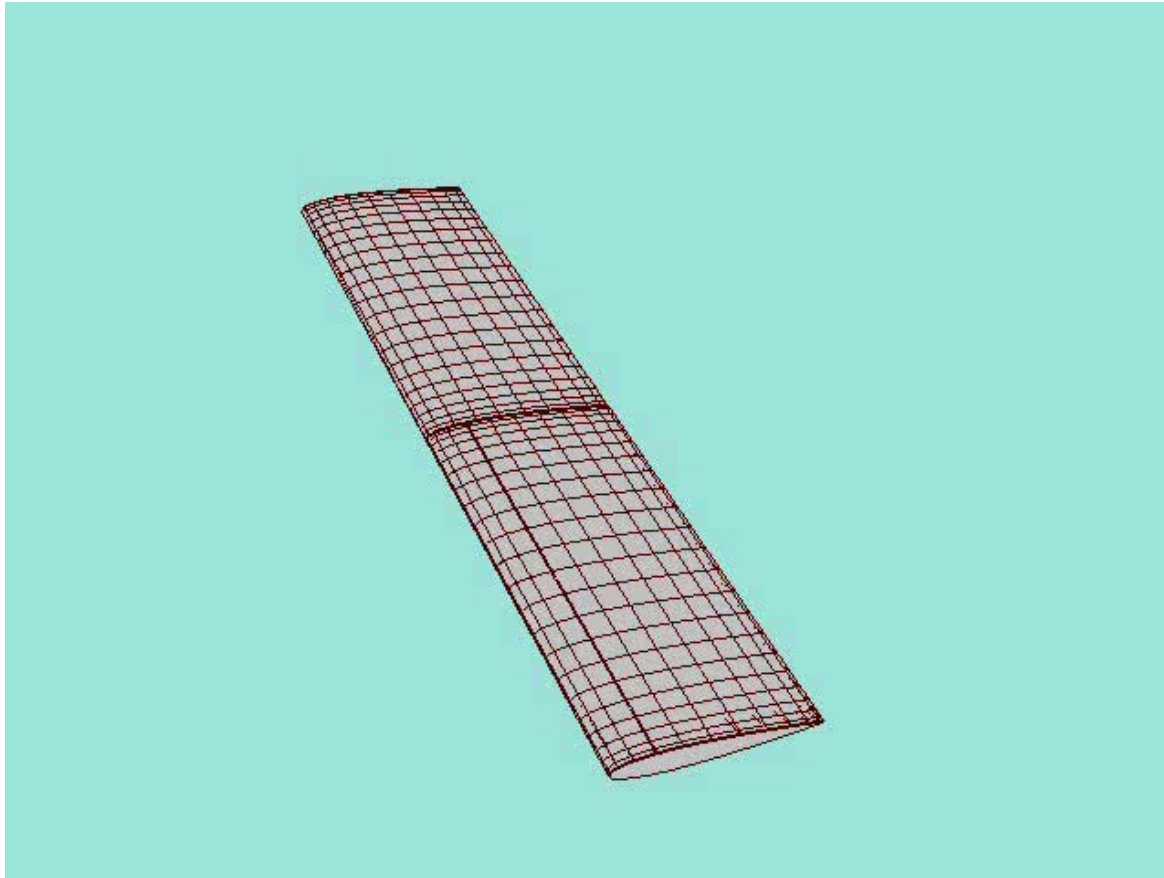


# What is Morphing

- ✎ For this research, morphing will be defined using the DARPA definition
  - ✎ Morphing is defined as a major change in multiple areas of wing geometry



# Morphing Aircraft





# Research Overview

## Approach



-  Develop a model for a morphing aircraft which includes realistic aerodynamics

## Key Issues


-  Making an accurate, computationally efficient aerodynamic model
-  Combining this model with a dynamic model which calculates state information

# Research Overview

## Solution

-  A source-doublet panel method is chosen to model the aerodynamics
-  The standard 6 DoF aircraft equations of motion are used to model the dynamics

## Benefit

-  The panel method is able to handle large scale shape changes




# The Aerodynamic Model

- ✎ A constant strength source-doublet method was chosen for the aerodynamic model
  - ✎ The sources provide a model for thickness while the doublets provide a model for lift
  - ✎ Utilizes cosine spacing for the grid
- ✎ Uses NACA 4 Digit airfoil sections
  - ✎ Have equations to describe the surface
  - ✎ Can perform well at low speeds
- ✎ Shape changing degrees of freedom are thickness, camber, location of maximum camber, wing span, root chord, tip chord, sweep angle, and dihedral angle




# Aerodynamic Assumptions

## Incompressible flow

 A valid assumption because the vehicle will fly at very low speeds


## Inviscid flow

 This is a good starting point for this simulation. However, if micro-air-vehicles are going to be considered, a viscous analysis will become necessary in the future

# Aerodynamic Development

 Start with basic potential flow theory

$$\nabla^2 \phi = 0$$

 By assuming the velocity potential can be represented as a combination of sources and doublets, this equation becomes

$$\phi = \frac{1}{4\pi} \int_{\text{Body+Wake}} \mu \mathbf{m} \cdot \nabla \left( \frac{1}{r} \right) dS - \frac{1}{4\pi} \int_{\text{Body}} \sigma \left( \frac{1}{r} \right) dS + \phi_\infty$$

# Aerodynamic Development

- ✎ The integrals are a function of the panel geometry and can be evaluated
- ✎ The wake shed from the trailing edge can be modeled as

$$\mu_U - \mu_L = \mu_{Wake}$$

- ✎ A system of N equations with N unknown doublets now exists and can be solved

# Aerodynamic Development

✍ Once the doublet strengths have been calculated, the velocity at each panel can be calculated

$$q_l = -\frac{\partial\mu}{\partial l}, q_m = -\frac{\partial\mu}{\partial m}, q_n = \sigma$$

✍ From this, the total velocity can be written as

$$Q_k = (Q_{\infty l} + Q_{\infty m} + Q_{\infty n})_k + (q_l, q_m, q_n)_k$$

# Aerodynamic Development

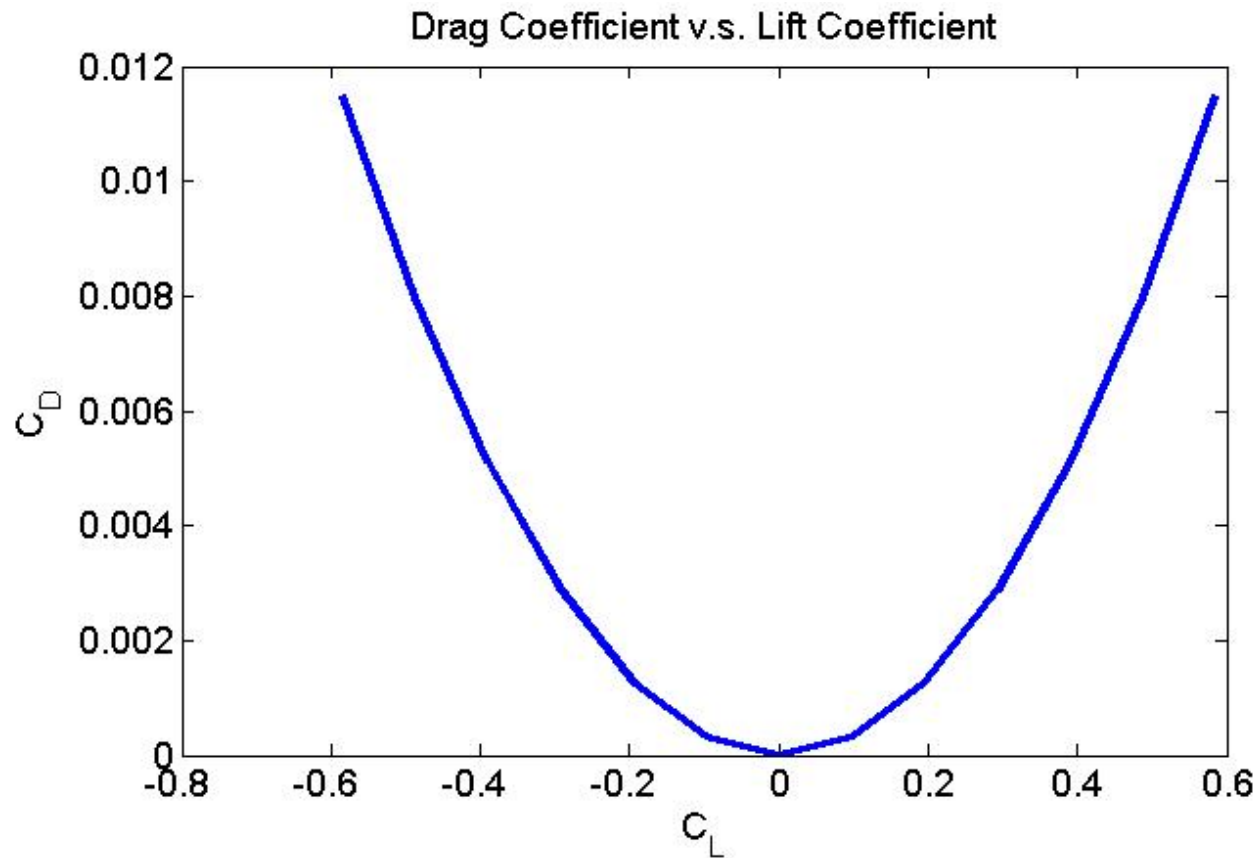
- ✎ Once the velocities have been calculated, the pressure coefficient is found using Bernoulli's Equation

$$C_{pk} = 1 - \frac{Q_k^2}{Q_\infty^2}$$

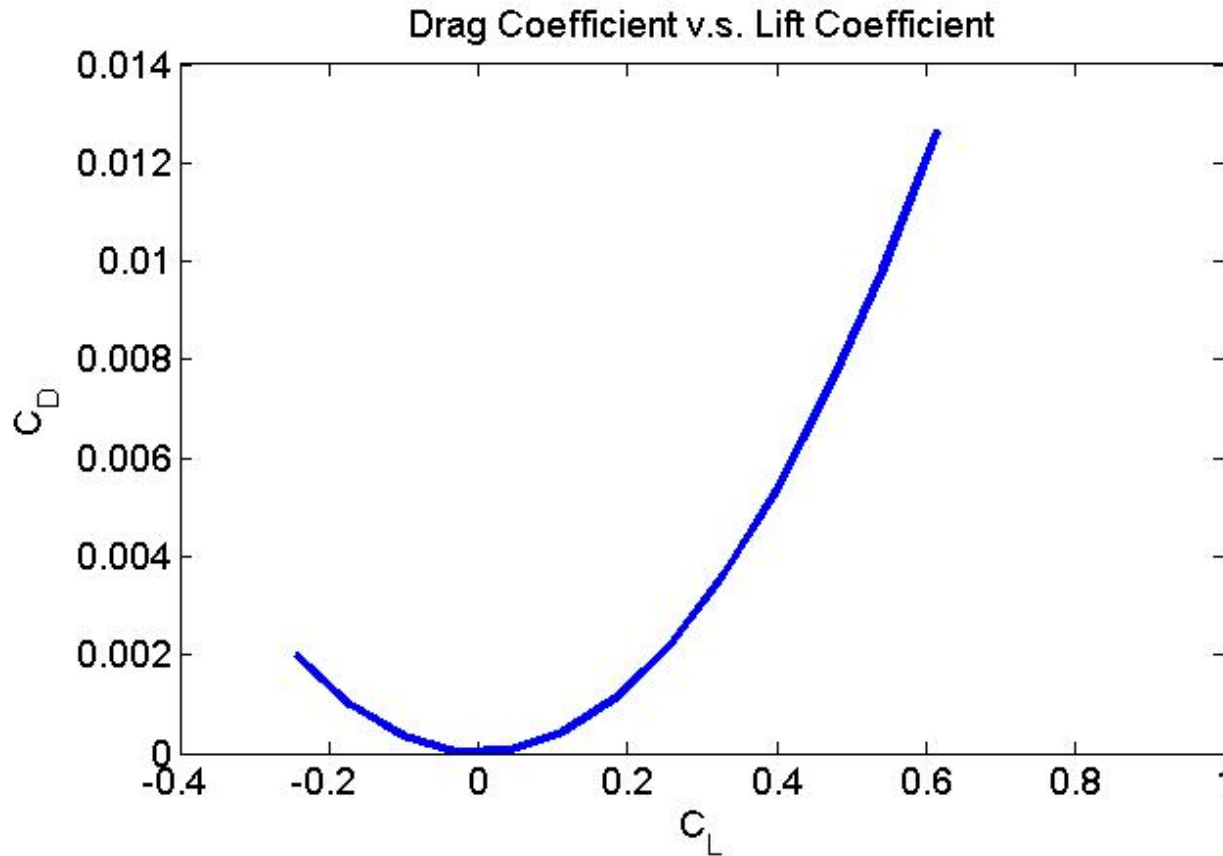
- ✎ The aerodynamic force at each panel is calculated from the pressure coefficient

$$\Delta F_k = -C_{pk} \left( \frac{1}{2} \rho Q_\infty^2 \right) \Delta S_k n_k$$

# Results- Rectangular Wing



# Results-A More Complex Wing



# Dynamic Model

- ✎ The dynamic model is based on the forces and moments calculated by the aerodynamic model
- ✎ Only longitudinal motion is considered
  - ✎ Aerodynamic model currently calculates longitudinal forces and moments only



# Dynamic Development

✎ Let the velocity vector and angular velocity vector for the morphing aircraft be given by


$$\mathbf{v} = \begin{bmatrix} u \\ 0 \\ w \end{bmatrix} \quad \boldsymbol{\omega} = \begin{bmatrix} 0 \\ q \\ 0 \end{bmatrix}$$

✎ Taking the inertial derivative of the velocity vector and setting it equal to the forces yields


$$m\dot{u} = -mqw - mg \sin(\theta) - D \cos(\alpha) + L \sin(\alpha) + T$$

$$m\dot{w} = mqu + mg \cos(\theta) - D \sin(\alpha) - L \cos(\alpha) + T$$

# Dynamic Development


 Assume the angular momentum vector for the morphing aircraft to be

$$\mathbf{h} = \mathbf{I}\boldsymbol{\omega}$$


 Taking the inertial derivative of the angular momentum vector and equating this to the pitching moment yields

$$I_{yy}\dot{q} = M_A - \dot{I}_{yy}q$$

# Dynamic Development

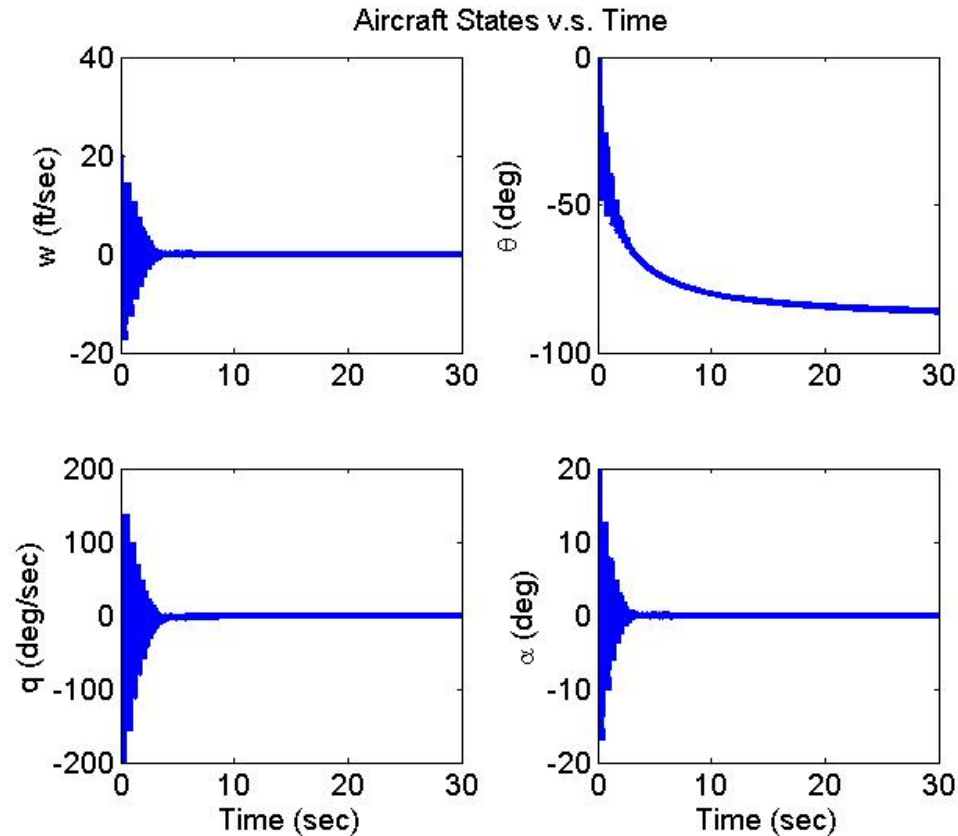
 Let the angle-of-attack be given by

$$\tan(\alpha) = \frac{u}{w}$$

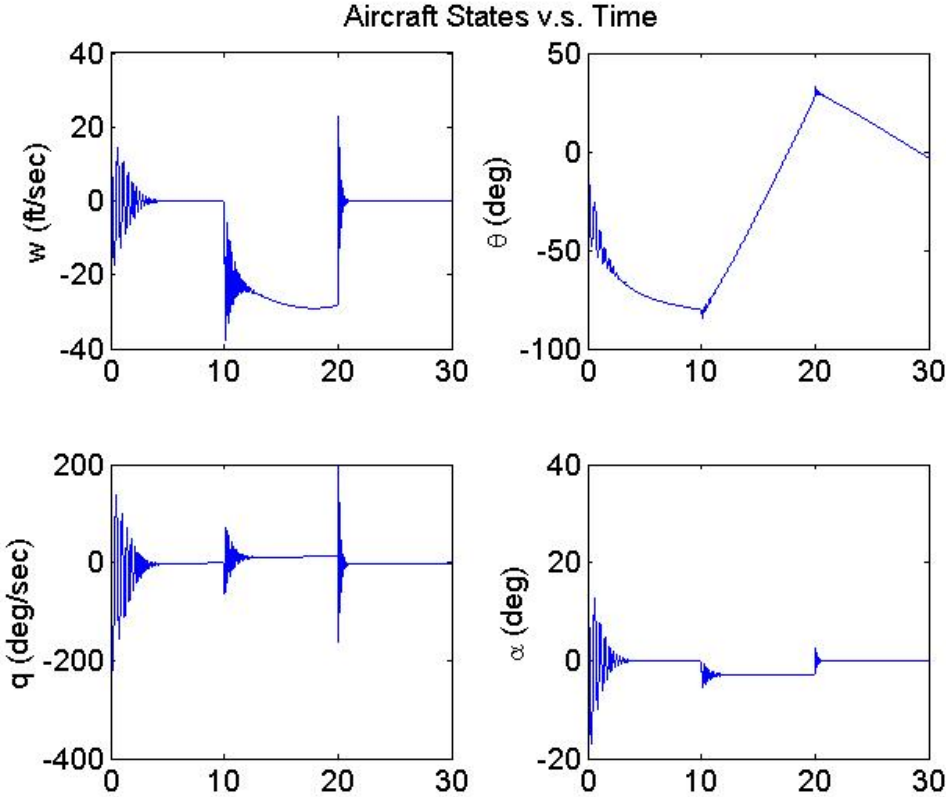
 Taking a time derivative of this expression and rearranging terms gives an expression for angle-of-attack rate

$$\dot{\alpha} = \frac{1}{V} (\dot{w} \cos(\alpha) - \dot{u} \sin(\alpha))$$

# Aircraft States: No Shape Change



# Aircraft States: Shape Change



# Conclusions

- ✎ The aerodynamic model is able to handle large scale shape changes
- ✎ The dynamic model shows that a wing with a symmetric airfoil section trims in a non-lifting configuration
- ✎ The dynamic model shows that a wing with asymmetric airfoil sections trims in a lifting configuration

# Challenges and Open Problems

- ✎ Both the aerodynamic model and dynamic model should eventually include the lateral-directional forces and moments
- ✎ Improve the computational efficiency of the aerodynamic model
- ✎ Add a profile drag calculation to the aerodynamic model
- ✎ Adding a capability to control forces and moments on the aircraft

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# Questions?

