Aerodynamic Properties of Avian Flight as a Function of Wing Shape

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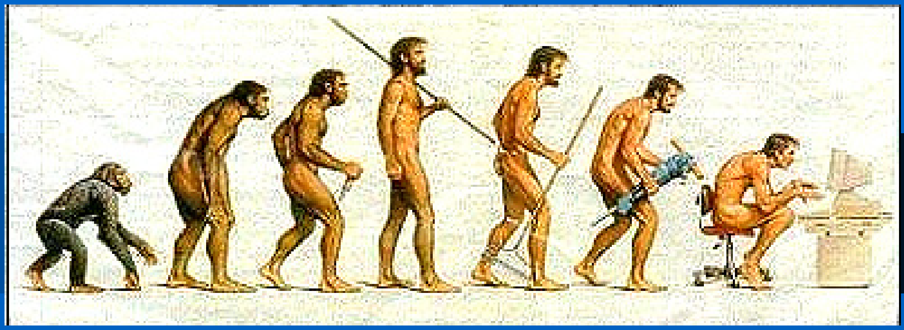
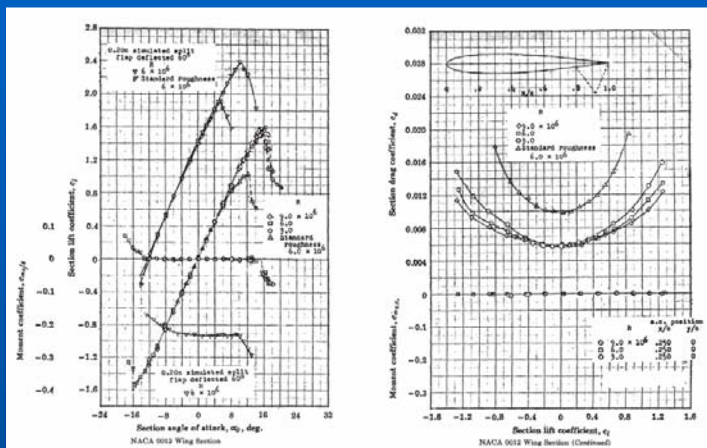
Biomimetics



- The Fusion of Biology and Engineering
  - Natural Selection as an optimization mechanism (Genetic Algorithm)
  - No one’s perfect
- Current Areas of Investigation
  - Neural Networks for Computation
  - Better Kevlar from Spiders
- Advances in Aircraft from Aves
  - Quasi-static aerodynamic measurements of bird wings in a wind tunnel
  - Computer Simulation

Principles of Aerodynamics



(2D-Data)

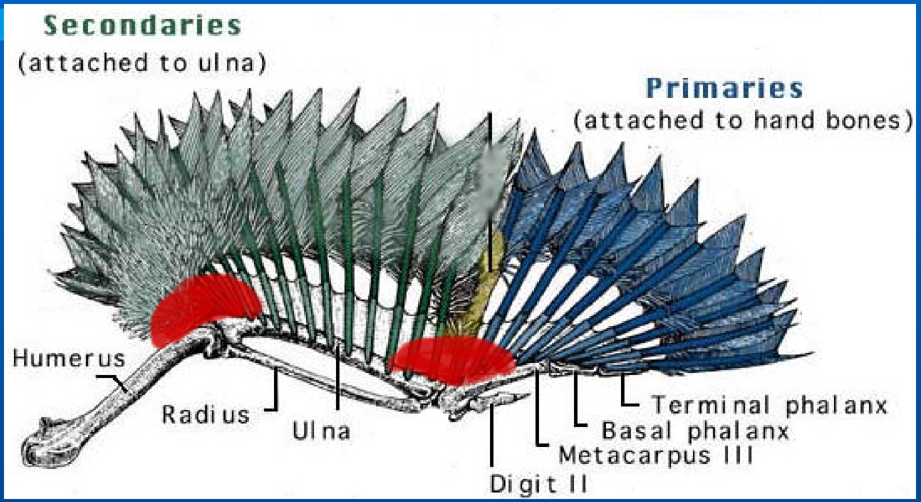
$$C_d = c_d + \frac{C_L^2}{\pi e AR}$$

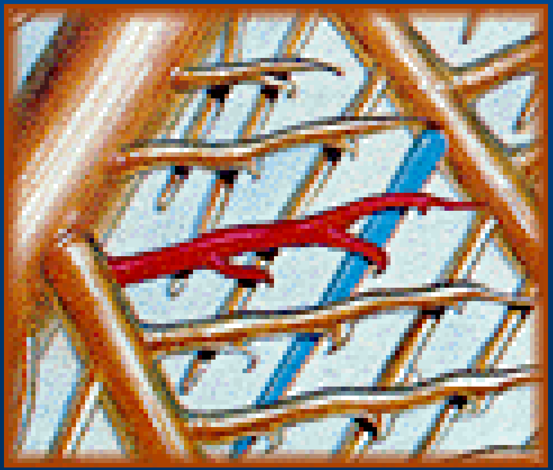
- **Usual lift curve, linear and demonstrates stall**
- **Drag versus Lift is parabolic**
- **Two components of drag: profile and induced**
- **Induced drag and vortex formation**
- **Limits aircraft spacing and cause of adverse yaw**

http://www.engr.utk.edu/~rbond/airfoil.html
http://www.grc.nasa.gov/WWW/K-12/airplane/downwash.html

Background in Birds

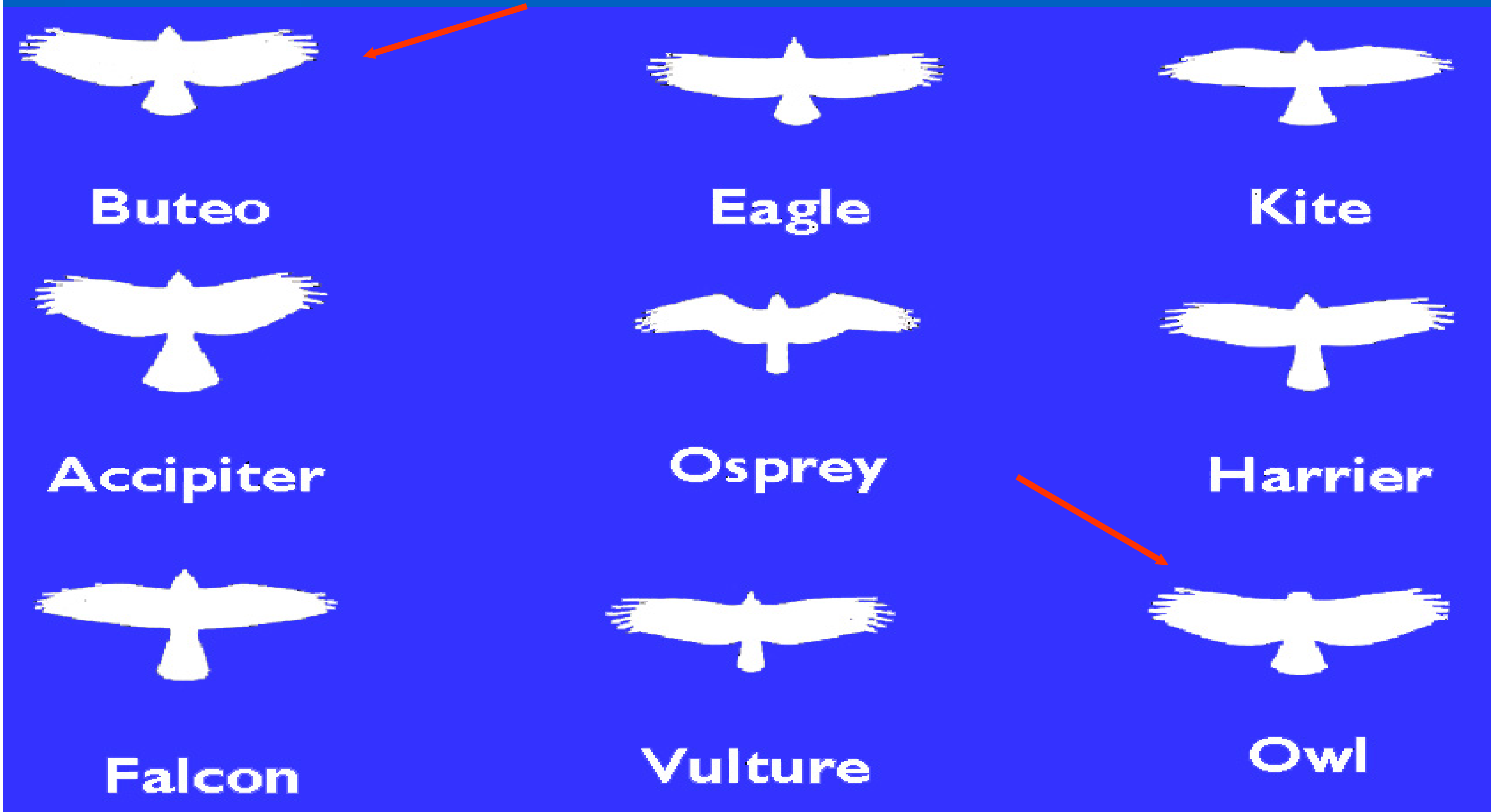
- **Wing Anatomy**
  - **Joints & Angles**
- **Feathering**
  - **Macro**
    - **Primaries**
    - **Secondaries**
    - **Coverts**
  - **Micro**
    - **Barbules**
    - **Owl's Tattered Tips**
- **Flight Strategies**
  - **Gliding**
  - **Flapping**





http://www.indiana.edu/~bradwood/eagles/wingsfeathers.htm
http://www.ummz.lsa.umich.edu/birds/Anatomy/anatomyhome.html

Raptors


Buteo
Eagle
Kite
Accipiter
Osprey
Harrier
Falcon
Vulture
Owl

Species Used in Data Collection

- **Red-tailed Hawk (*Buteo jamaicensis*)**

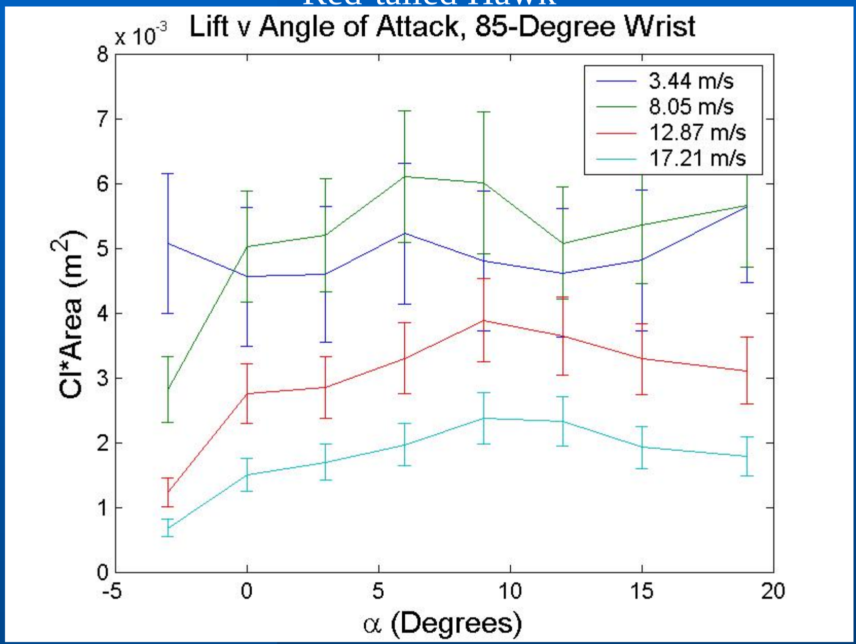
- **Great Horned Owl (*Bubo virginianus*)**

Experimental Setup

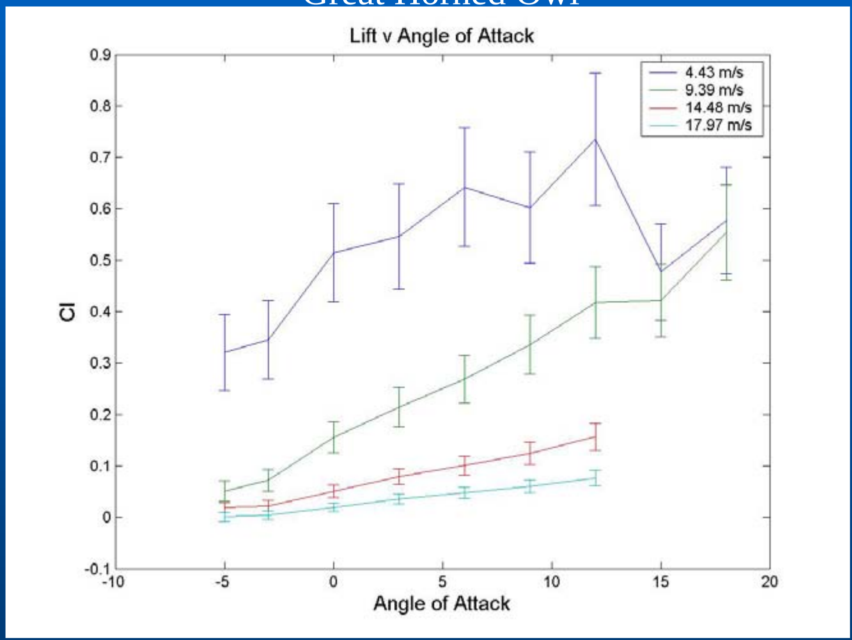
- Bio Kinetic Specimens
  - Rigidity and Flexibility
    - Original Goal
    - Steel Wire for Joint Actuation and Stability
    - No Airfoil Impact
- Force Measurements
  - 6 DOF, Foil Strain Gauge, Force Balance
- Wind tunnel
  - 4’x4’ Cross Section
  - Suction Driven, 50’ Flow Development
- Speeds
  - 7.7, 18.0, 28.8, 38.5 mph
  - [3.4, 8.05,12.9, 17.21 m/s]
  - Davis Instruments Wind Speed Meter 0271
- Visualization
  - He Bubbles and Smoke

Results, Lift

Red-tailed Hawk

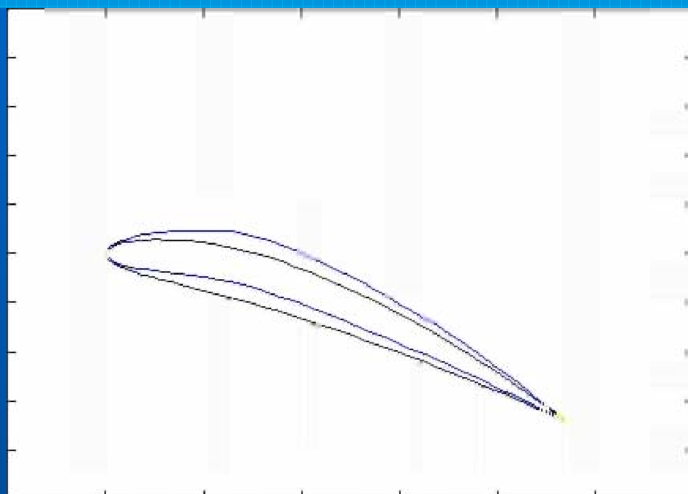


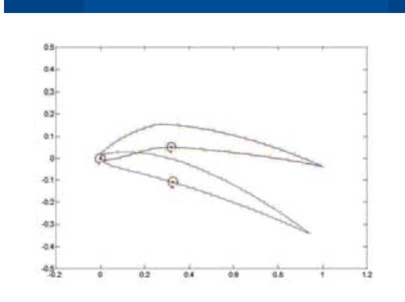
Great Horned Owl



- **Non-conventional lifting curve**
- **No distinct stall, lift levels off**
- **Demonstrates Aeroelasticity of the wing, and twisting into the flow**

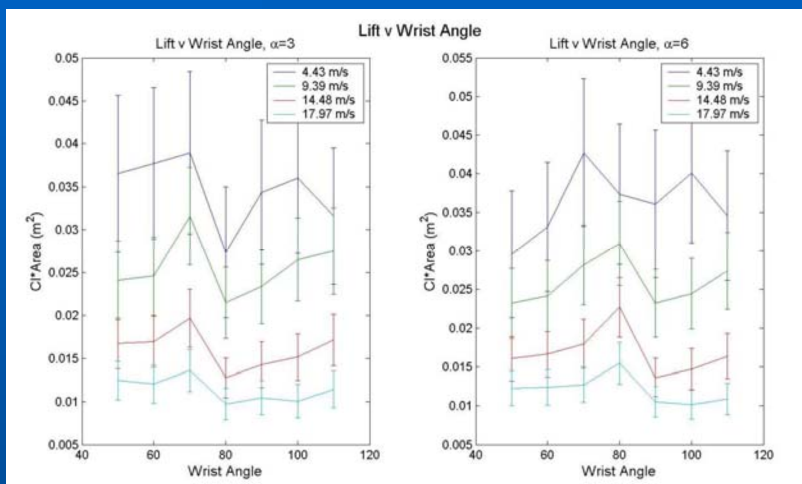
Simulation Comparison: Aeroelasticity

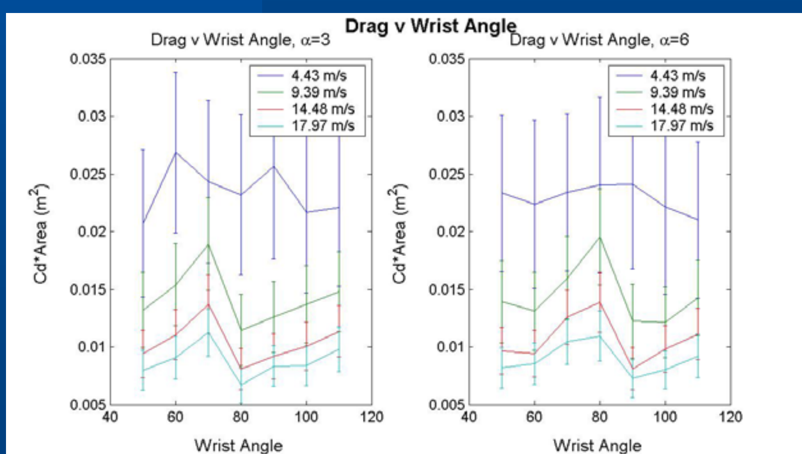




- Comparison of owl wing to an airfoil with two torsional springs in Potential Flow
- The model predicts a coefficient of lift decrease similar to that observed with wing
- Potential Flow is an okay model because moment from drag is small, compared to moment from lift

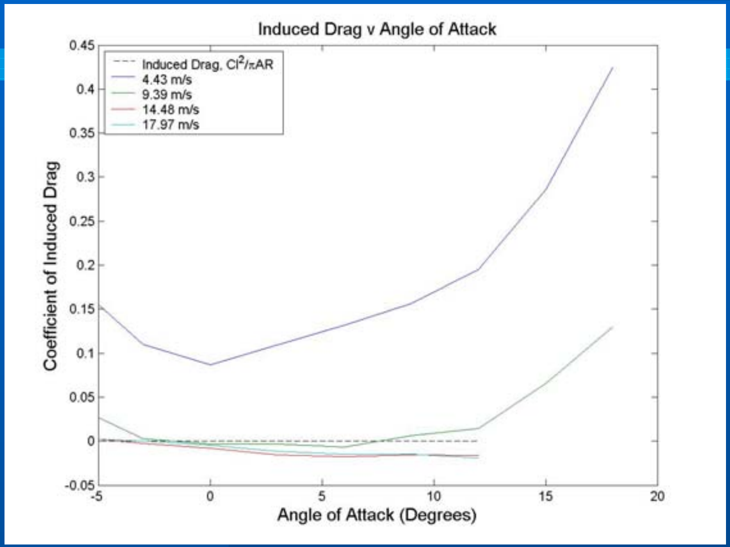
Results, Wrist Angle

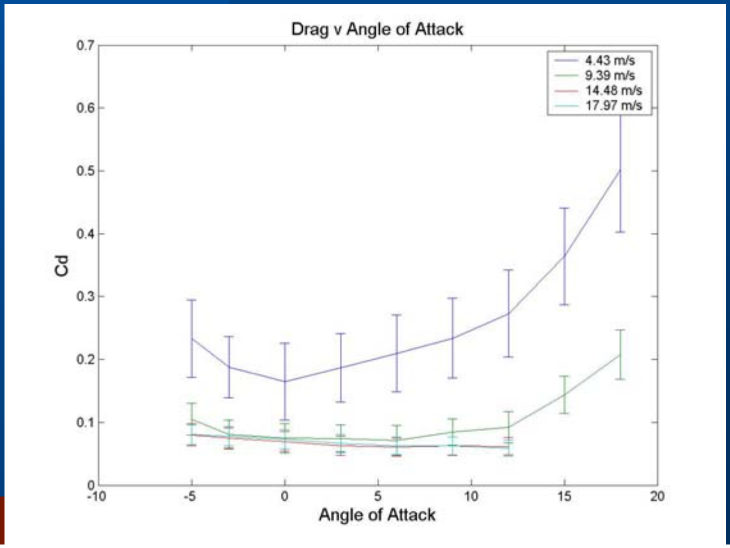




- **Red-tailed Hawk**
- **Minimal effect**
- **Jumps are due to exposure of covert feathers**
- **Two trends because of aeroelasticity**
- **Low airspeeds lift/drag decreases**
- **Higher airspeeds lift/drag has a maximum**

Results, Induced Drag





- Induced drag on Great Horned Owl is below theoretical!
- Net drag still positive
- Great Horned Owl has primaries fanned at wingtips
- Flow vortex around primaries generates thrust.

Applications

- In 1987, J.J. Spillman showed wingtip sails (like primary feathers on bird wings) could reduce the drag substantially on aircraft
- "Provided the sail is small it will experience a thrust offsetting the lift-dependent drag on the wing,"
- He estimated a fuel savings of $200,000 per commercial jet per year
- Approximately $700,000 today!
- The sails were a detriment at flight regimes other than they were designed for
- Passive shape change and aeroelasticity could be the solution needed to minimize induced drag on modern aircraft

Spillman, J.J; 1987, Wing Tip Sails, Progress to Date and Future Developments. Aeronautical Journal, vol 91, pp 445-453, December 1987.

Conclusion

- **Current aircraft are only optimized for one flight regime**
- **Birds can completely alter their form to be in an optimum configuration in any regime**
- **The measurement of the forces on bird wings in different configurations is the first step towards morphing aircraft**
- **Passive shape change may play an essential role in mitigating induced drag and vortex formation**

NASA concept of morphing aircraft

http://oea.larc.nasa.gov/PAIS/21stcentury.html

Questions?

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