Morphing of aircraft configurations

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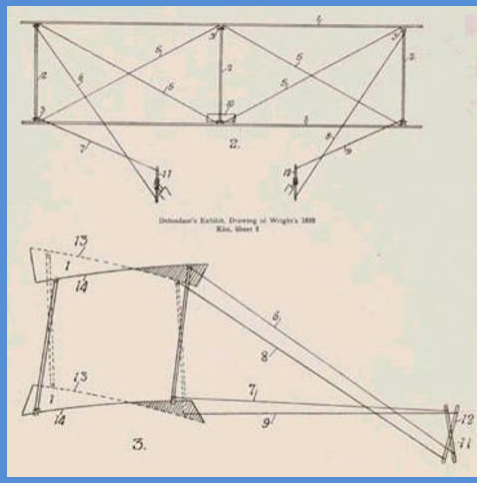
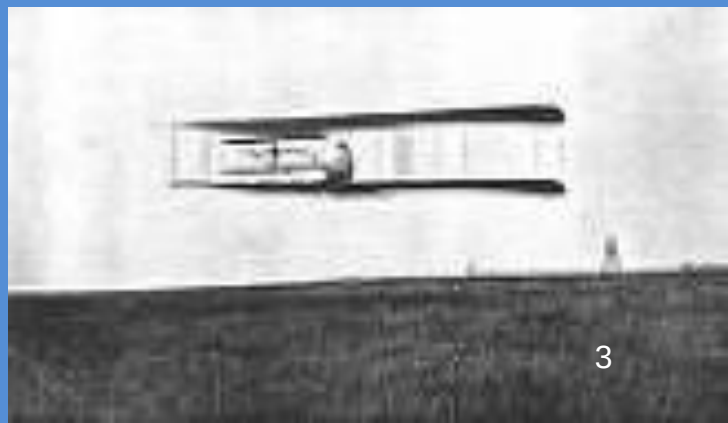
NASA's Film on Morphing aircraft

Introduction

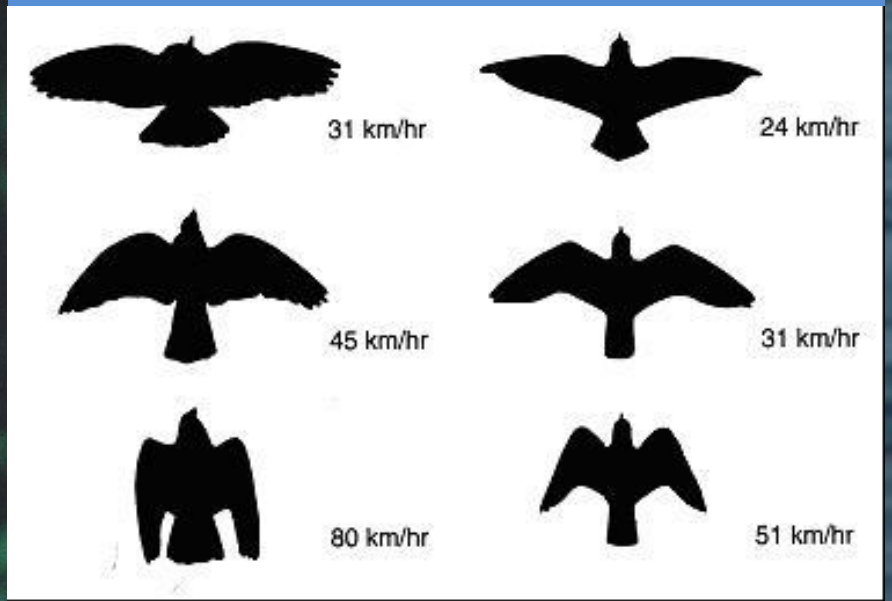
- Morphing= Metamorphosis = *to cause to change shape*
- Morphing aircraft
  - Aircraft that changes its shape during flight for improved
- Biological Inspiration
  - Honey Bees, Bumble Bees, Butterflies, ….
- Warping in aircraft is not new !
  - Wright Flyer
    - Wing warping for seamless flight control





Morphing in Birds

- From Takeoff to Cruise mode
- From Cruise to Dive mode
  - By changing wing profile



Morphing of wings in Eagles

Need for morphing

- Quest for improvements
  - Multi-role aircraft that are optimum in all roles
  - Improved efficiency in all flight conditions

Benefits of Morphing

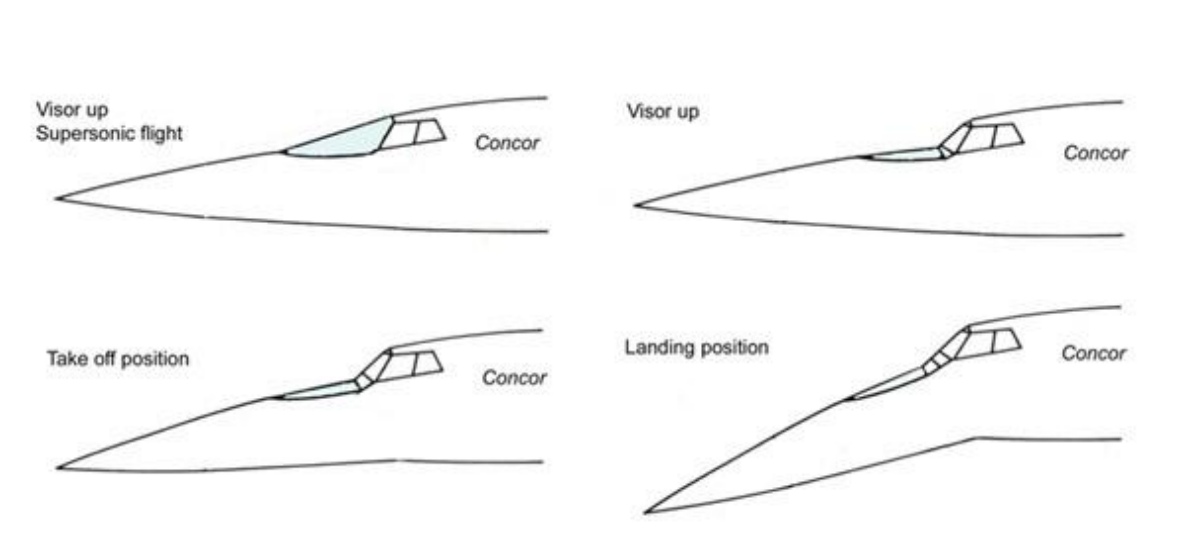
- Improve aircraft performance
  - to expand its flight envelope
    - High amplitude but low frequency
- Replace conventional control surfaces
  - improved performance and stealth
- Reduce drag
  - improve Range
- Reduce vibration or control flutter
    - High frequency but low amplitude
- **At the cost of increased cost, weight, complexity**

Challenges to bring about Morphing

- What to Morph ?
  - Wing, Tail, Engine, Fuselage, ……
- How to Morph ?
  - Mechanism
  - Loaded Structure
  - Conflicting need for Rigidity and Flexibility
- How much to Morph ?
  - Amount of area, wing span, sweep, camber change
- Controllability issues
  - Change in Aerodynamic Center

Morphing in current aircraft

- Flaps and Ailerons
  - Limited maneuverability and efficiency
- Variable Nose
  - Concorde
- Variable Sweep
- Variable Camber

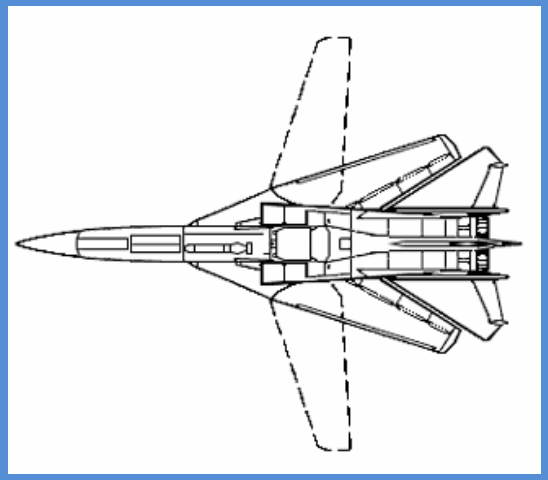


Leading Edge & Trailing Edge Flaps

Morphing by Variable Sweep

B-1B *Lancer*

MiG-23 & 27M



Morphing by Variable Camber

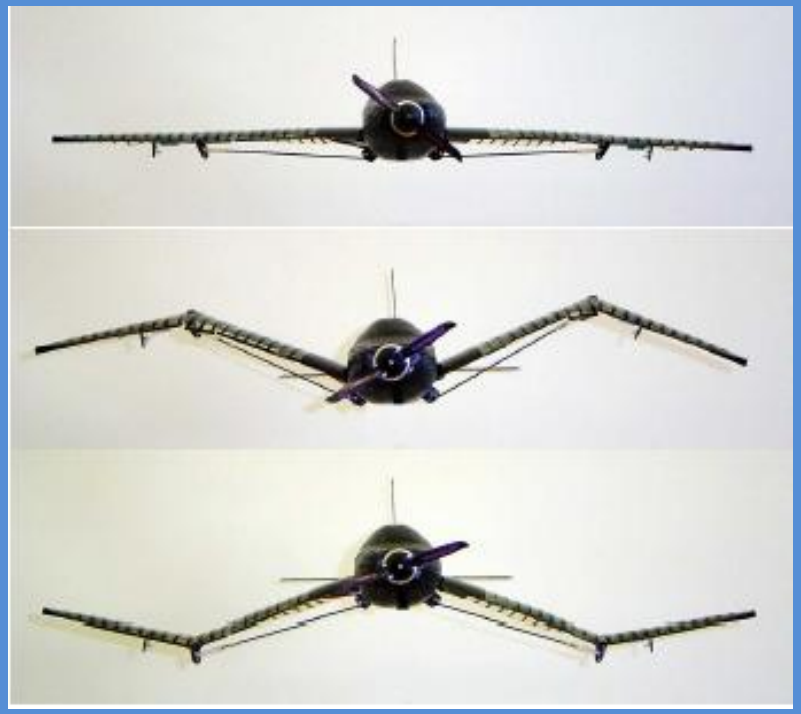
F-111 MAW

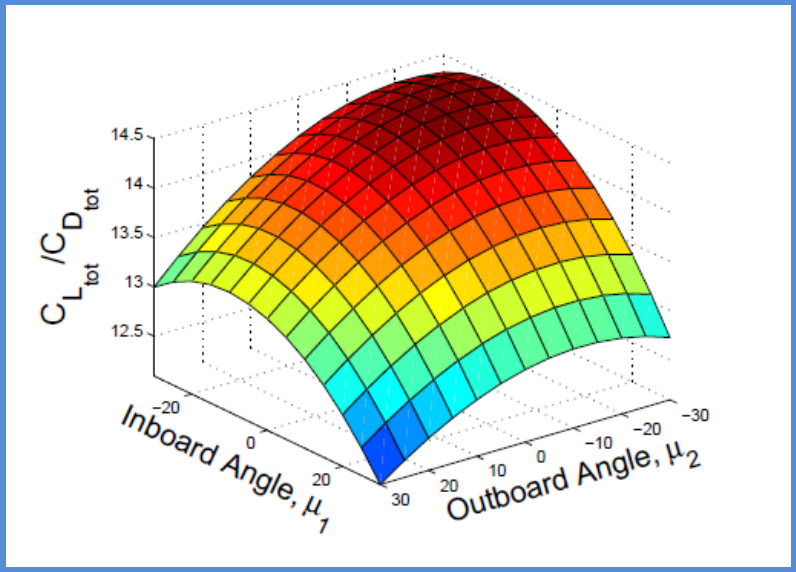
F-18 Super Hornet

Structural Technologies for Morphing

- Planform changes using rigid mechanisms
  - Wing extension, folding or sweep
- Compliant mechanisms
  - Wing camber, twist
- Vibration control systems
  - usually based on directly applying force
- Shape control systems
  - actuators to effect the shape change
  - sensors to measure the actual deflections

Morphing using rigid mechanisms





Morphing using compliant mechanisms

- Usually small amount of structural change
  - Twist, Camber change, asymmetric wing changes

F-111 MAW

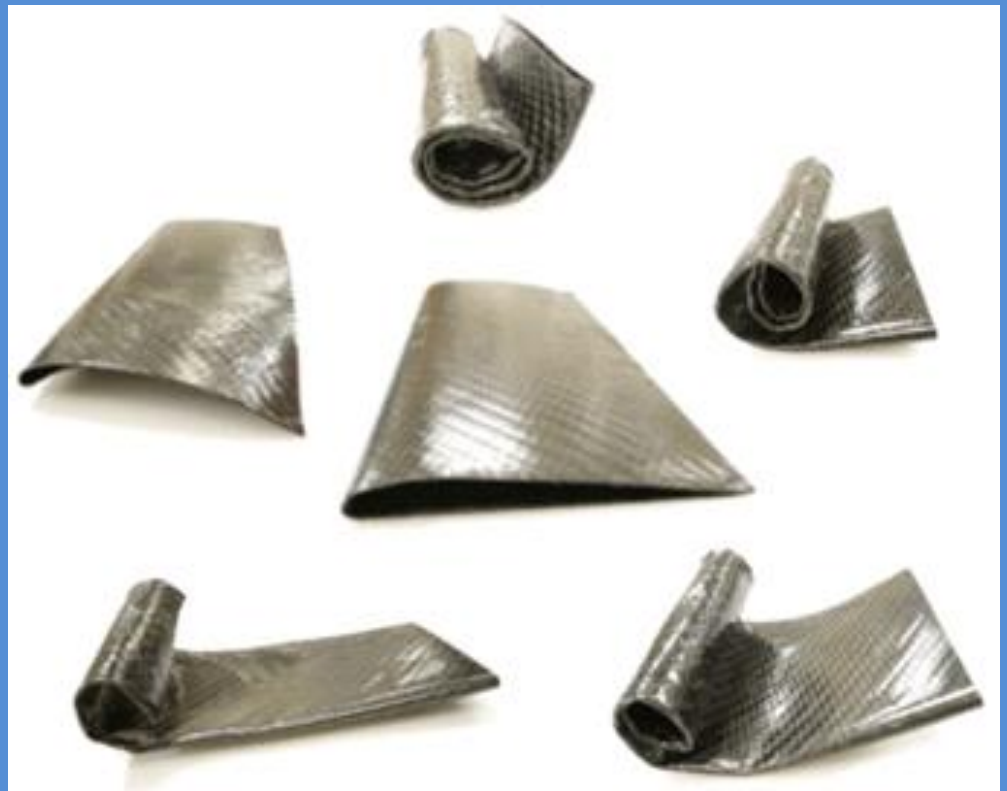
Current research On Morphing

- Smart materials
- Adaptive Aeroacoustics
- Smart Controls
- Telescopic Wing

NASA Morphing Aircraft

Shape Memory Alloys

- Shape Memory Alloys
- Piezoelectric devices
- Shape morphing truss structure



NextGen Aeronautics

- MFX-1 UAV (2006)
  - Changing Area, Sweep, Chord, Aspect Ratio
- MFX-2 UAV (2007)
  - Flexible skin wing
    - 40% ΔS_w
    - 73% Δb_w
    - 177% ΔAR_w

NextGen MFX-1

NextGen MFX-2

Challenges in Morphing

- Ensure structural integrity
- Realizable actuation forces
- Aerodynamically smooth load-bearing surfaces
- Efficient engines for low & high speed operation
- Highly coupled control effectors in control systems
- Design to encompass multiple flight regimes

Some R&D programs in Morphing

- Virginia Tech Centre for Intelligent Material Systems and Structures.
- Morphing Project at Cornell University is about a biologically-inspired perching aircraft.
- Compliant Systems Design Laboratory, University of Michigan
- Compliant Mechanisms Design and Optimisation Laboratory, University of Washington
- FlexSys Inc., an engineering design company that specializes in innovative, mechanical systems that are simply engineered to flex.
- The DARPA Program for Morphing Aircraft Structures

R&D Projects related to morphing

- Virginia Tech, USA
- Purdue University, USA
- Delft University, NL
- Bristol University, UK

- IISc Bangalore
- Morphing Airship
- IIT Bombay

Flapping Flight

- Low Reynolds Number regime, unsteady flowfield
- Reduced Frequency (k):
  - Measure of flowfield unsteadiness

$$k = \frac{\omega c}{2U}$$

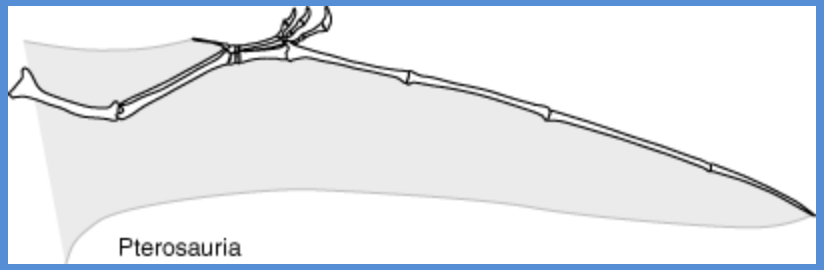
Aerodynamic modelling

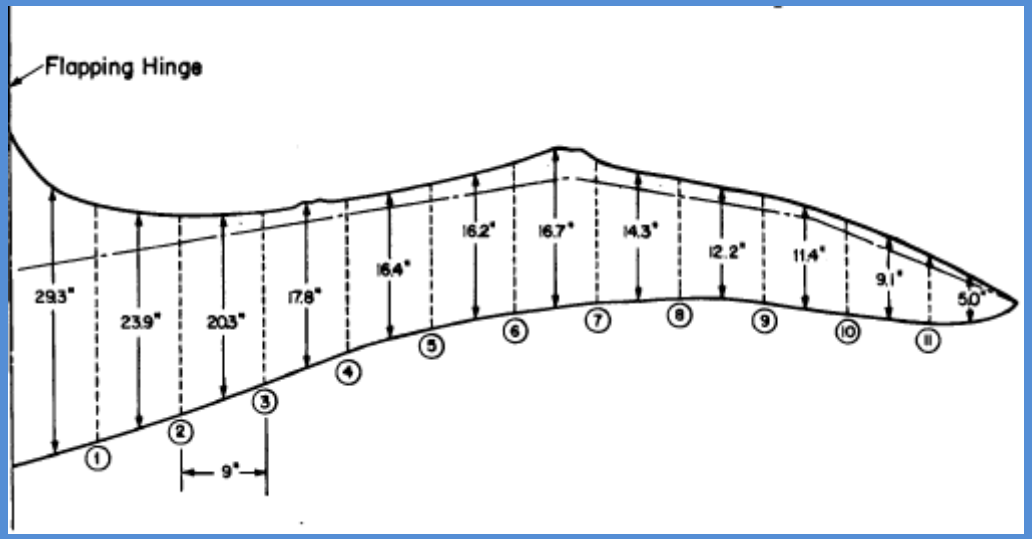
- This is not CFD!
- Watered down version of the problem
- Three major aspects
  - Leading Edge Vortices
  - Unsteady Wake
  - Circulatory force generation

Morphing Parameters

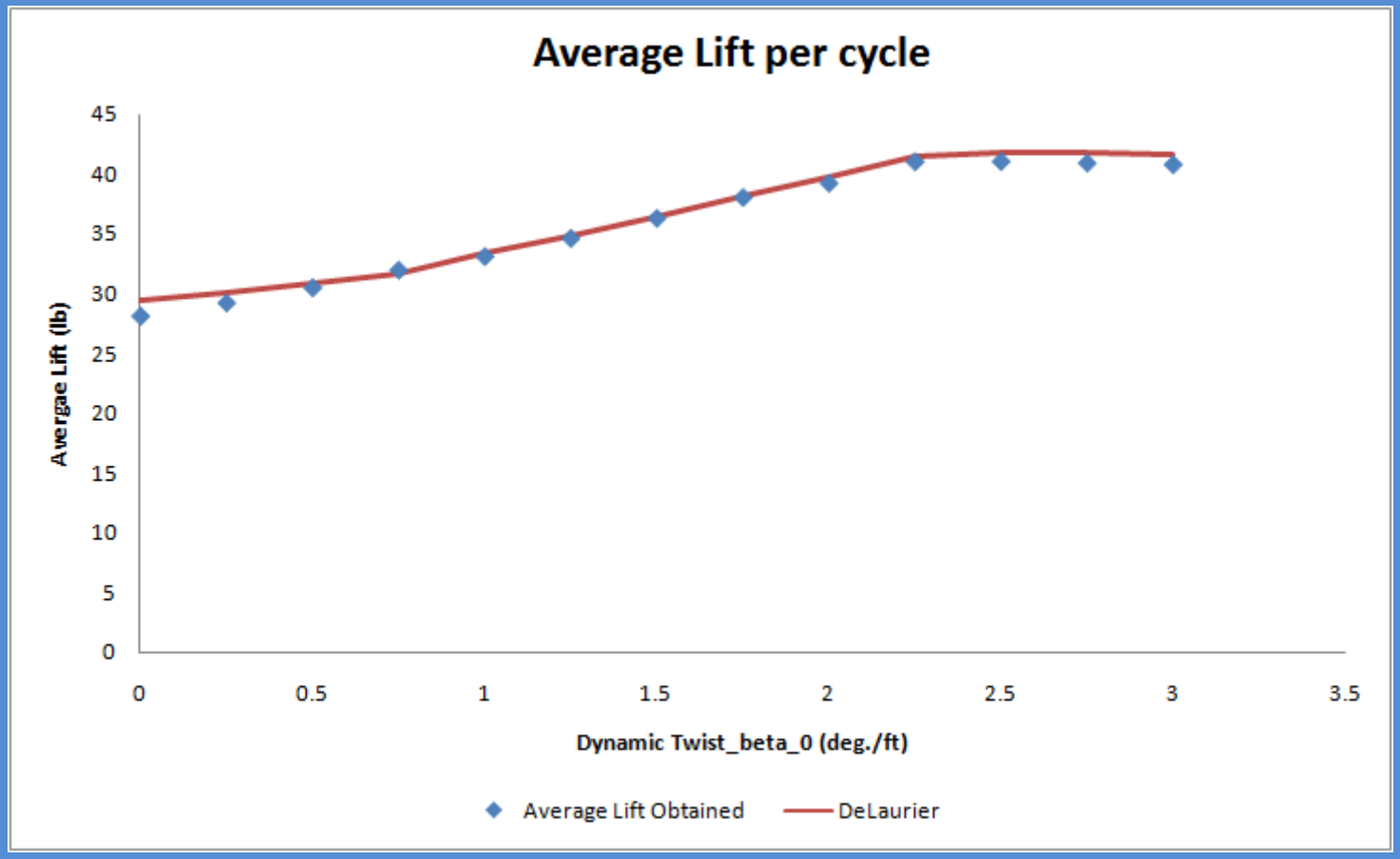
- Bending
- Twisting
- Cambering
- Flexing (Supination & Pronation)

Wing Shape Optimization





Results obtained



Observations

- One single Optimized morphing parameter can be sufficient
- Recovery from stall
- Dependence on the flapping frequency