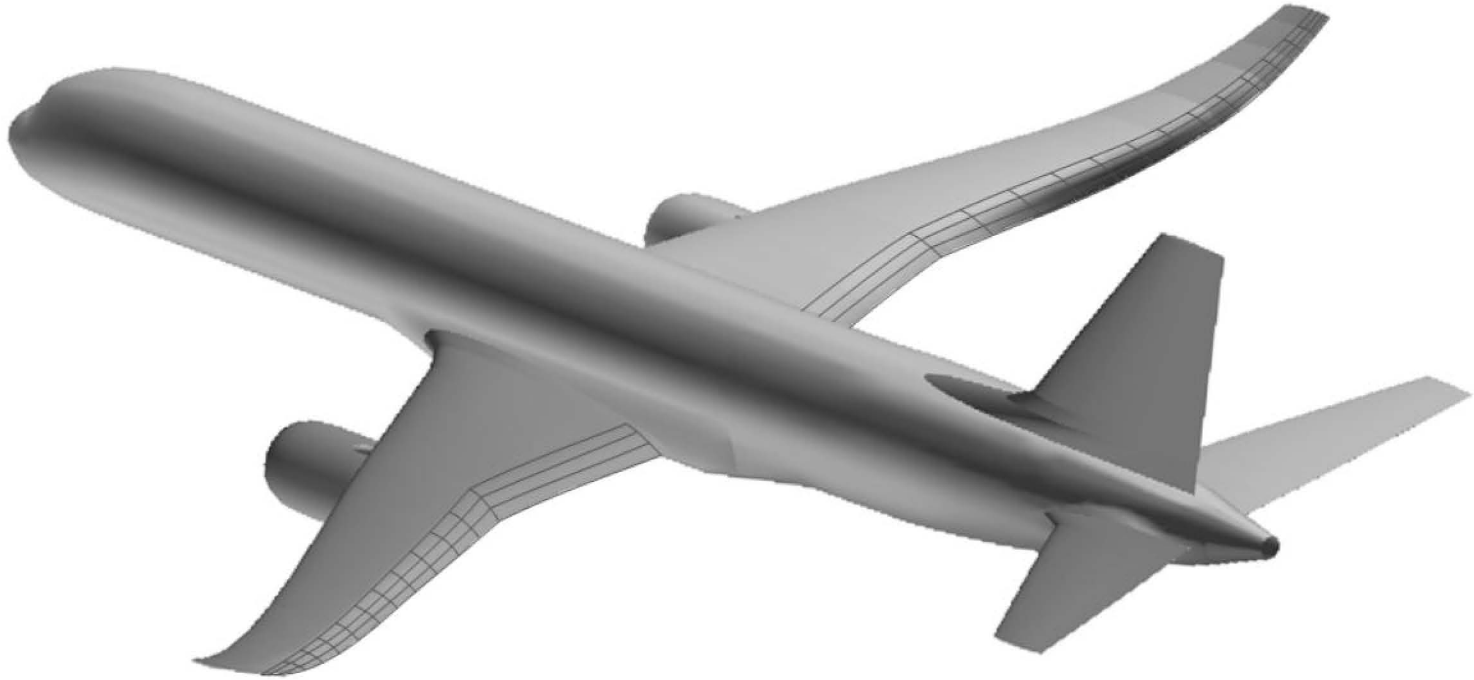
Development of Variable Camber Continuous Trailing Edge Flap System



Fundamental Aeronautics Technical Conference
13 March 2012

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John Dykman – The Boeing Company

Program Objectives

1. Develop a design concept of a Variable Camber Continuous Trailing Edge Flap (VCCTEF) system.
2. Define the flight control system requirements to continually shape the wing to achieve optimum performance for minimum drag. Provide faster flap response that will achieve level 1 handling qualities.
3. Investigate use of Shape Memory Alloys and other actuation designs that will be the control effectors for achieving the wing shape needed to maintain optimum lift to drag ratios.
4. Assess flight control modes to achieve satisfactory airframe aeroelastic stability margins and gust load allevation.

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Program Plan

1. Update the Generic Transport Model (GTM)
   - Aeroelastic data
   - Trailing Edge Flap definition
2. Using the updated GTM, conduct analysis of various VCCTEF deflections
   - Assess L/D performance
   - Assess aeroelastic stability margins
3. Reduce the wing stiffness
   - Determine change in L/D performance
   - Determine need for ASE compensation
4. Provide requirements for VCCTE
   - Deflections needed
   - Hinge moment requirements
5. Select and size VCCTE Flap actuation components
   - Hinge line actuation on each flap section
   - Provide weight, power requirements
6. Revise VCCTEF requirements for different flight condition, mass properties, wing stiffness
   - Make design changes
   - Identify trade-offs needed

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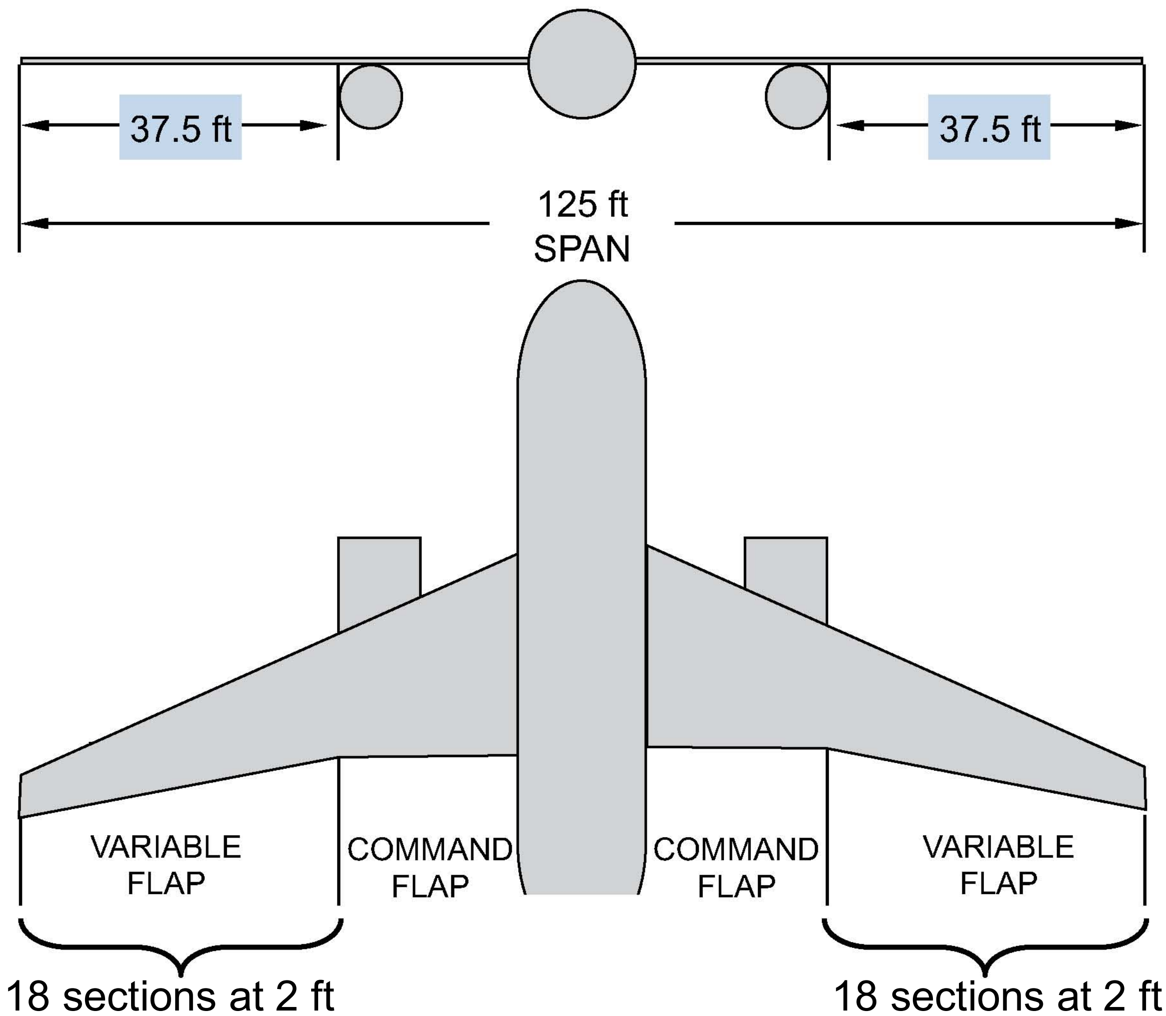
Wing Geometry and Flap Control Sections



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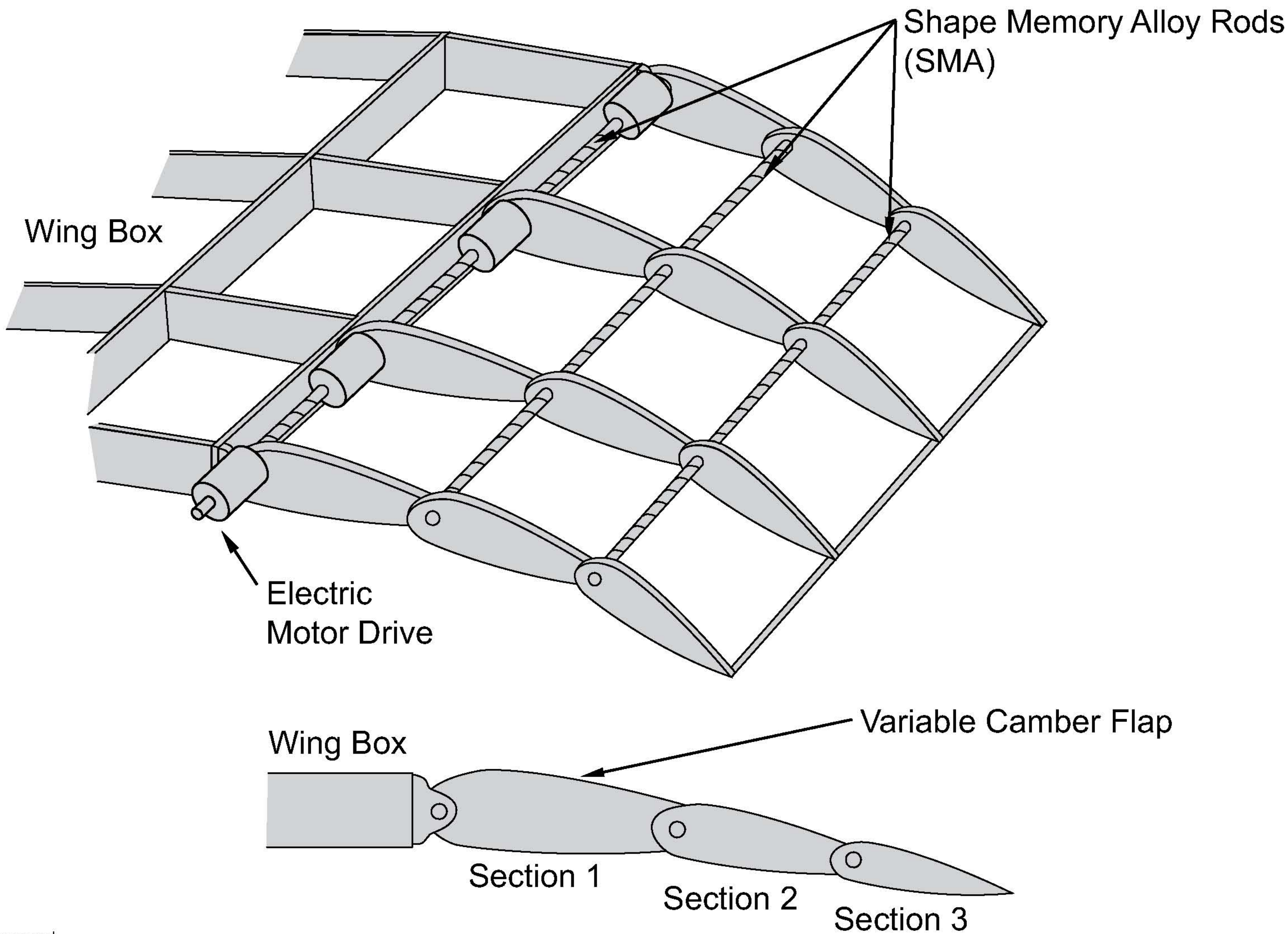
Variable Camber Flap with Electric Motor Drive



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VCCTEF Actuator Types:

PROS:
- WEIGHT VS. POWER LVL
- ADAPTABLE CONTROL
-

CONS:
- SPEED OF OPERATION
- TRL LEVEL LOW
- POWER LEVEL DEMONSTRATED LOW
- ROD DIAMETER VS TORQUE CAPACITY

SHAPE MEMORY ALLOY - (SMA)

PROS:
- SPEED OF OPERATION
- SIZE/ POWER VS ELECTRIC

CONS:
- REQUIRES FLUID LINES
- REQURIES CENTRAL HYD SYS.
- CONTROL REQUIRES VALVES

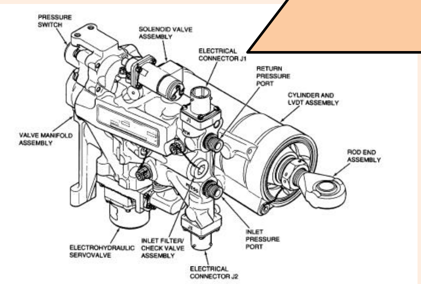
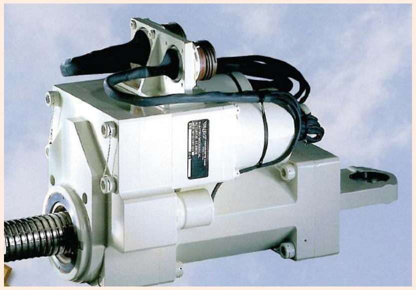


Figure 1. Aileron Hydraulic Servocylinder

HYDRAULIC ACTUATOR W/ SERVOCYLINDER CONTROL

PROS:
- POWER EASY TO ROUTE
- ADAPTABLE CONTROL
- SPEED OF OPERATION

CONS:
- SIZE/ POWER VS HYDRAULIC



ELECTRO-MECHANICAL - (EMA) W/ LINEAR DRIVE BALL-SCREW

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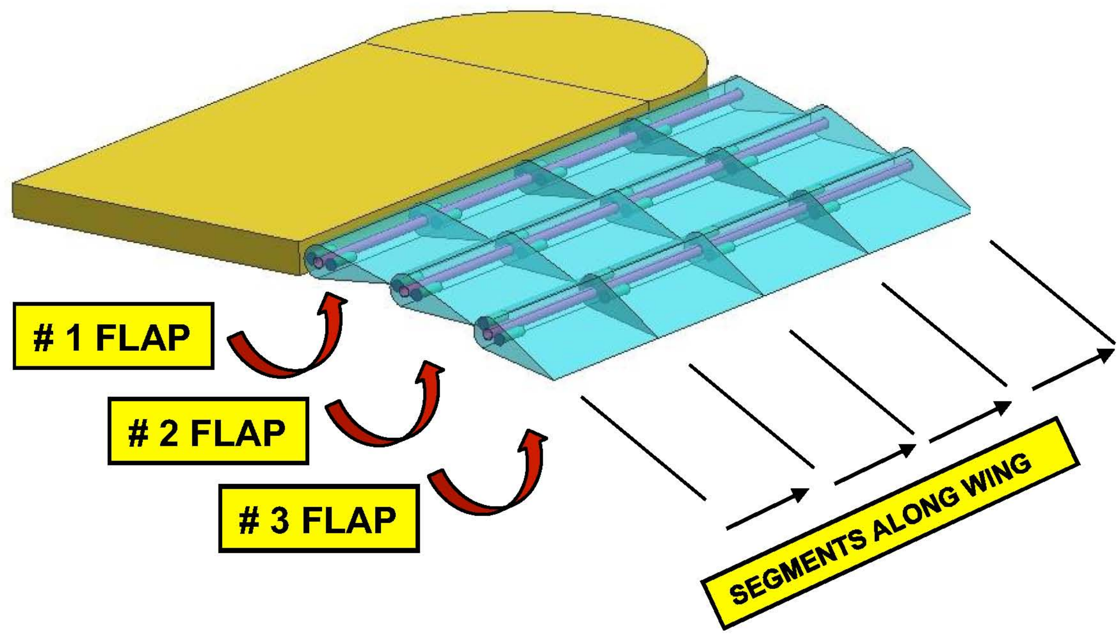
Each Type for Actuation May Have a Role

EXAMPLE: 3 - SECTION FLAP:
(*sections not to scale*)



 # 1 – Inner Flap – SMA/Hydraulic/EMA Hybrid Most Likely
 # 2 – Centermost Flap – SMA/EMA/Hydraulic Trade Offs
 # 3 – Outermost Flap – EMA Best Candidate
- **Highest Operating Speed Required During Motion**

BOEING PROCEEDING TO MODEL SYSTEM GEOMETRY FOR SECTIONS TO FIT 757 VCCTE NEW GEOMETRY

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Benefits of SMA Based Design

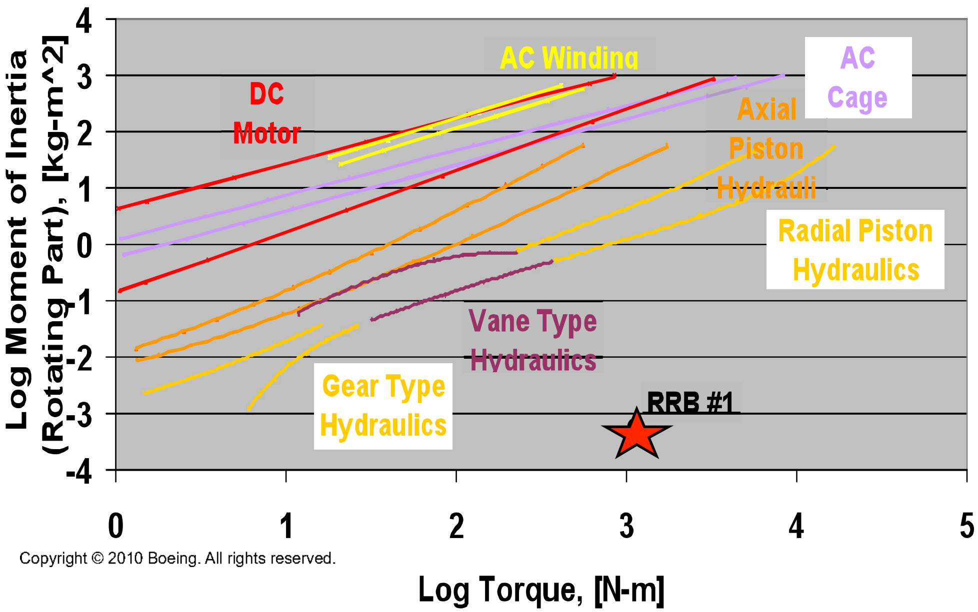
- SMA Actuator Technology benefits
  - Robust Technology
  - Lightweight
  - Integrates well
  - Simple system design
  - Efficient thermal energy harvesting
- Boeing is world leaders in this technology

Motor:
Torque 66 in-lbs
25 lbs

Gear box :
190 in-lbs
16 lbs

SMA Rotary Actuator :
150 in-lbs
1 lbs

Rotary Actuator Characteristics



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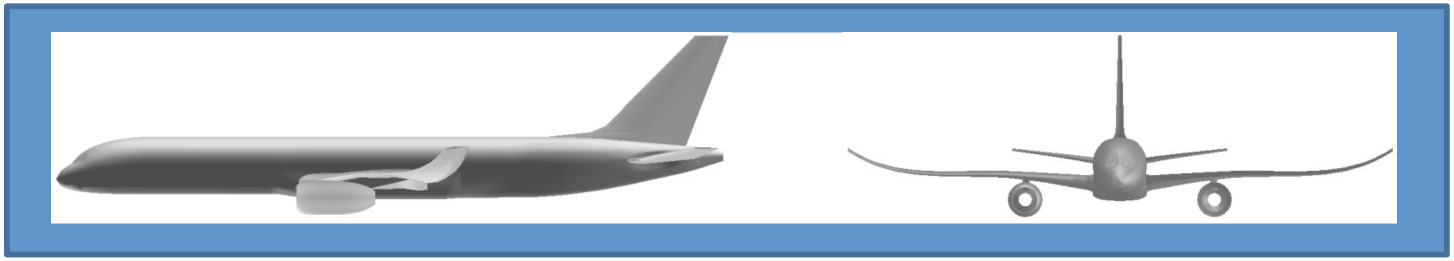
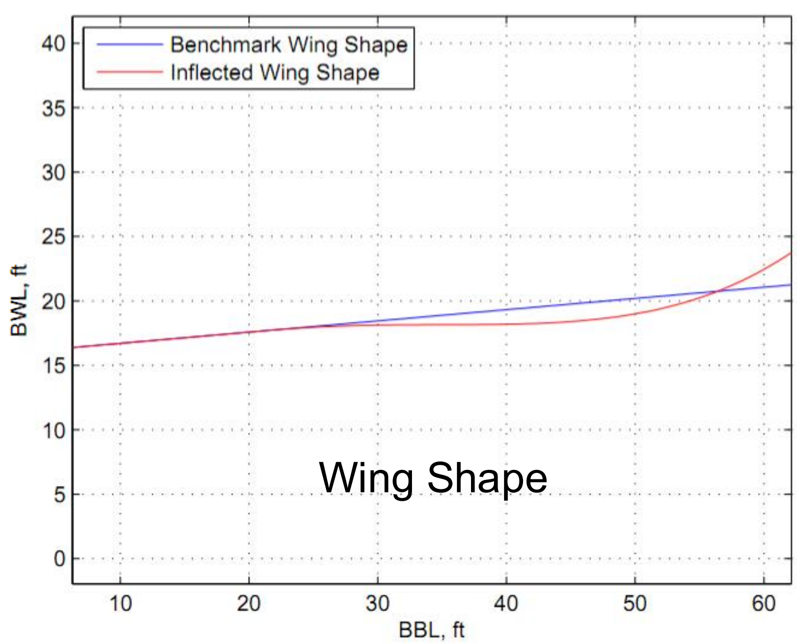
Conclusion:

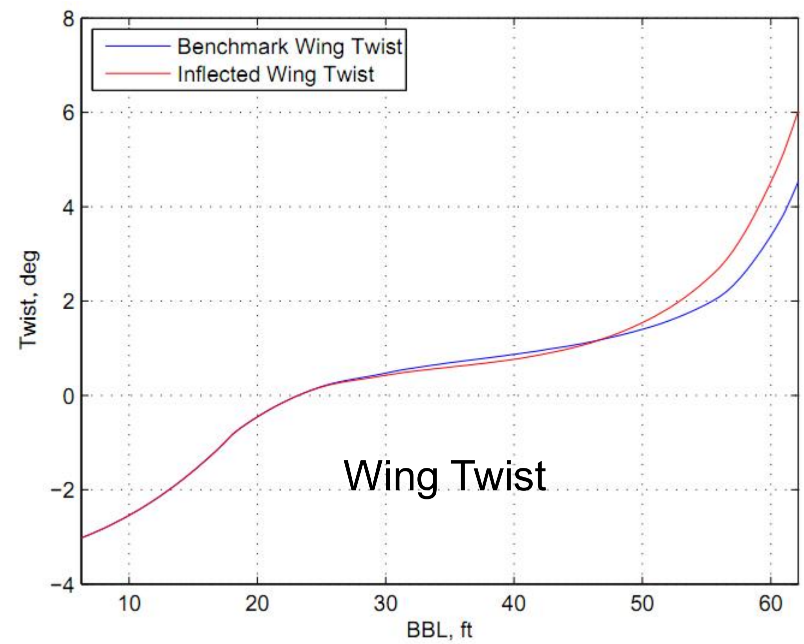
- **NiTinol is ideal for torque high stroke, low duty cycle applications where weight is a premium**
- **Technology can provide major benefits for countless applications**

Twist Distribution for an Inflected Wing Shape



Wing Shape Optimization to Minimize Cruise Induced Drag





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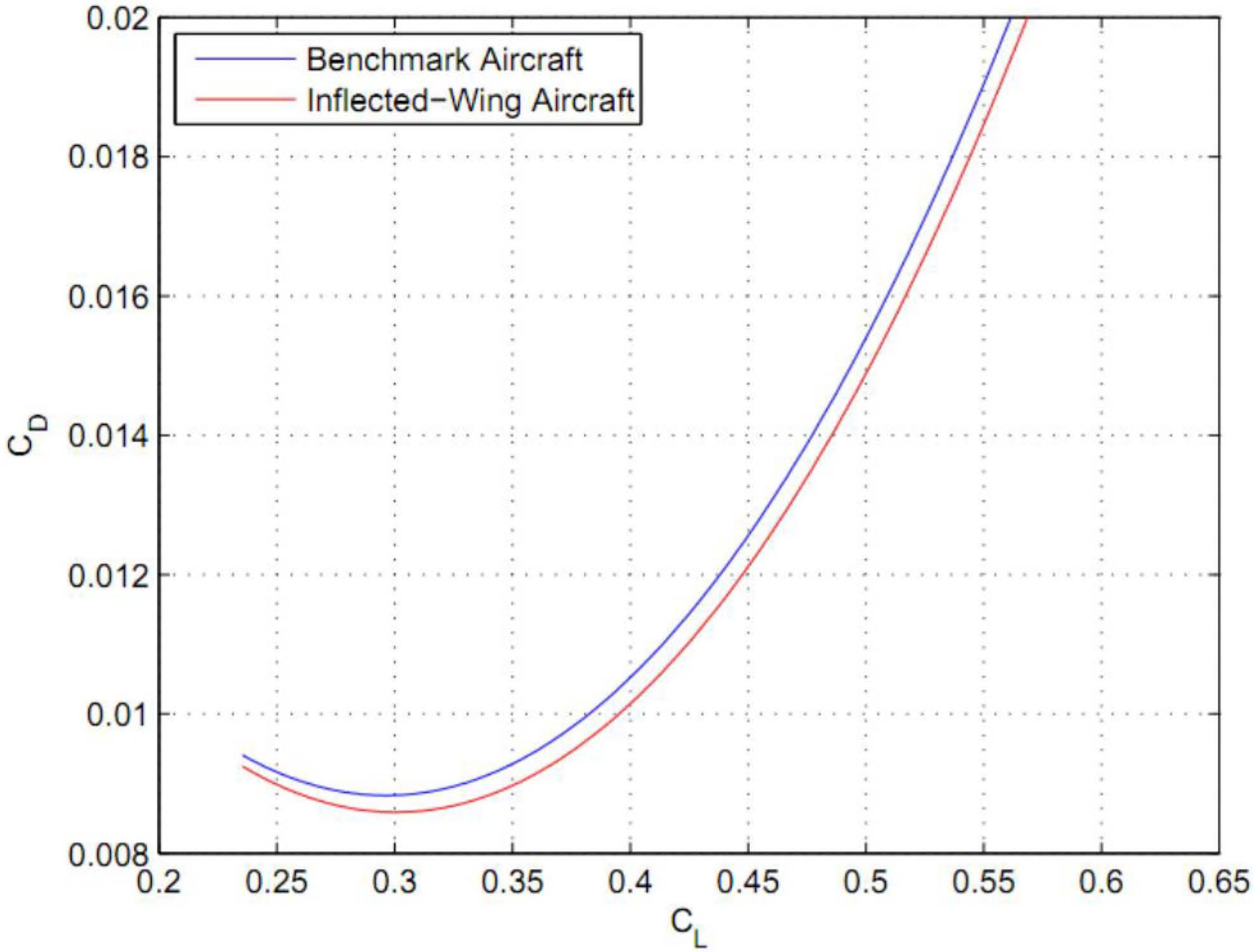
Nguyen, N., “Elastically Shaped Future Air Vehicle Concept,” NASA Innovation Fund Award 2010 Report, October 2010, Submitted to NASA Innovative Partnerships Program

Drag Comparison



3.5% Induced Drag Reduction over Baseline Wing Configuration

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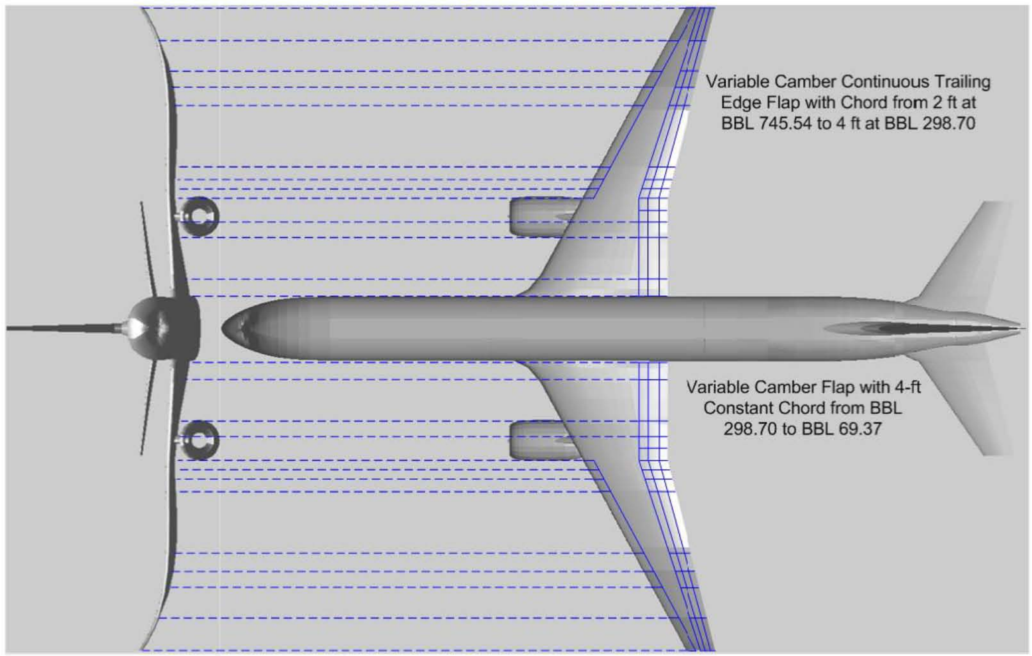
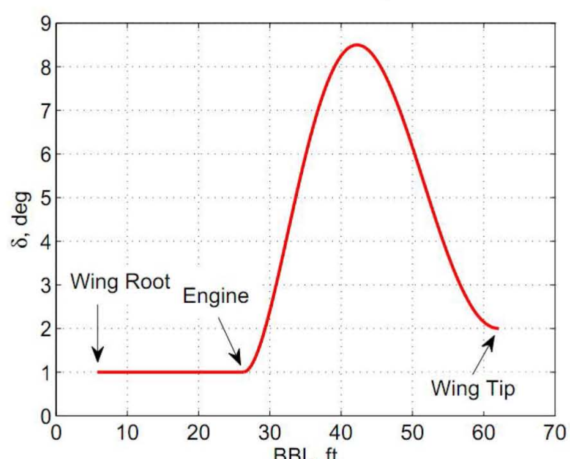
Variable Camber Continuous Trailing Edge Flap



Flap Layout



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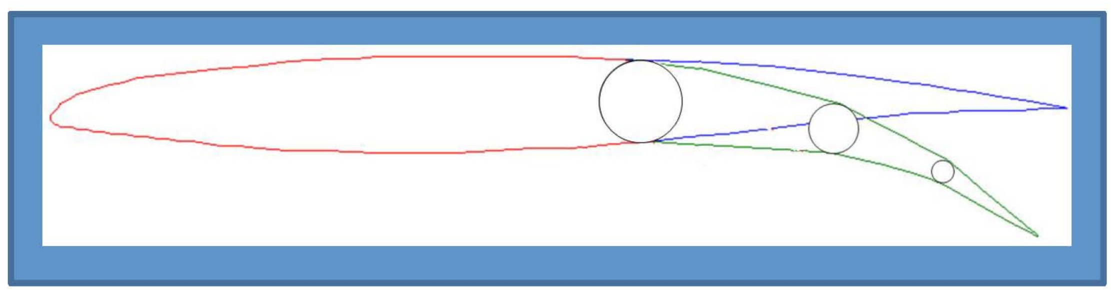
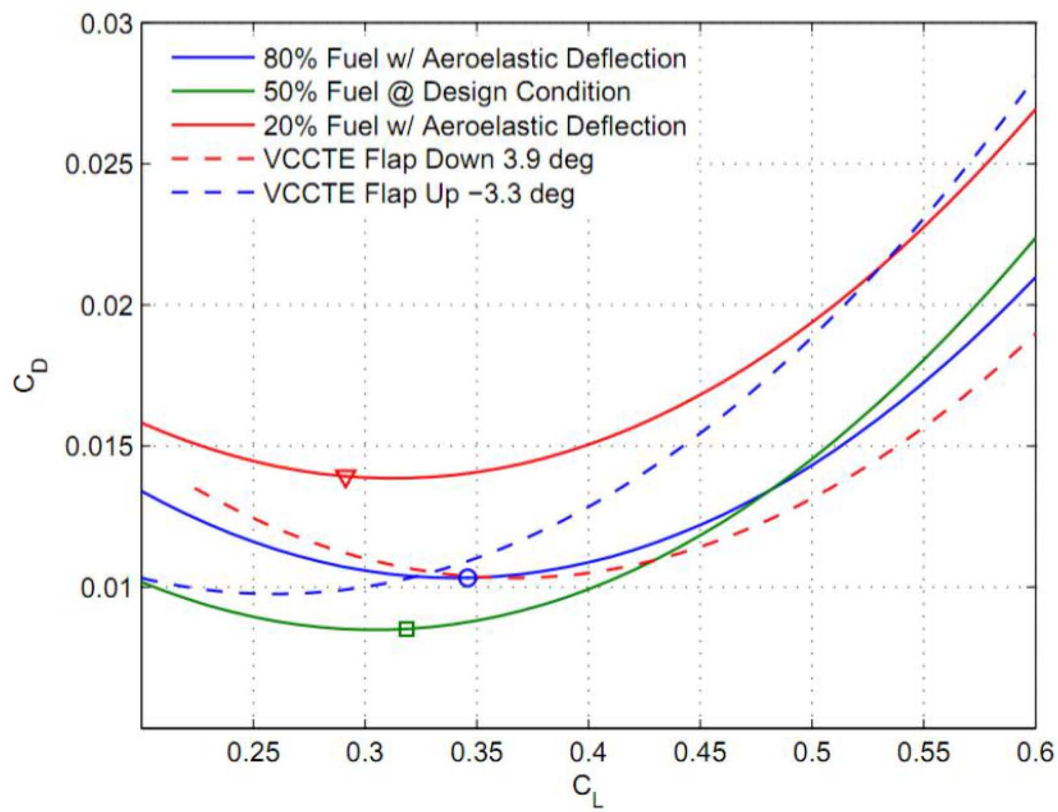
Continuous Trailing Edge



Variable Camber Flap

Example Drag Polars: Variable Camber Continuous Trailing Edge Flap



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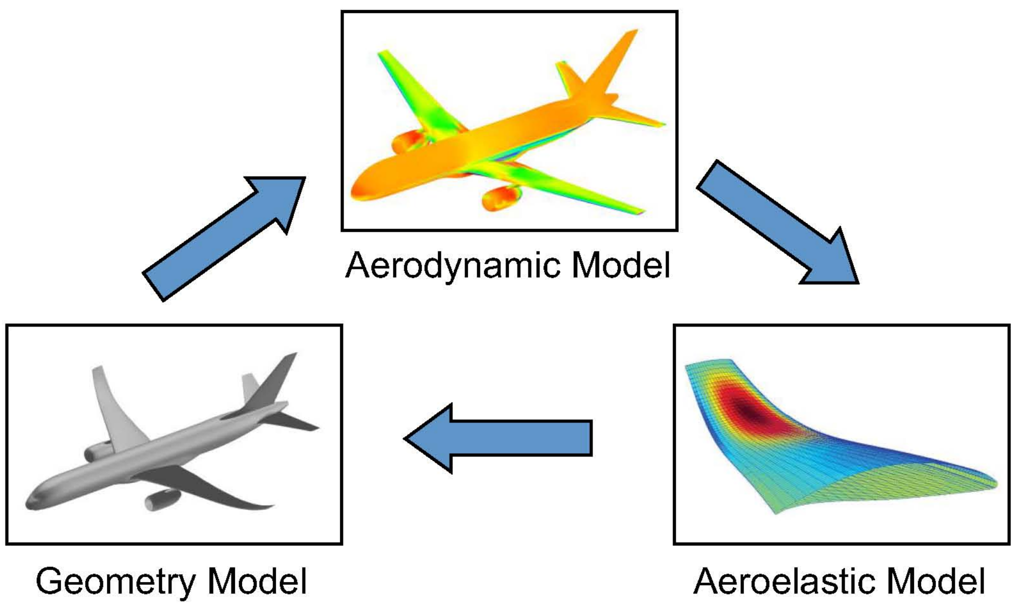
Wing Shaping:
Optimized Aeroelastic Flap Design

1. Increased wing flexibility can cause increase in cruise drag as wings operate at off-design conditions due to wing deflections.
2. VCCTE flap will be designed by NASA to re-shape wings to restore optimal aerodynamics for reducing cruise drag.
3. Flap design optimization needs to include aeroelasticity to account for wing deflections at cruise as a function of fuel weight and trim conditions.



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Aeroelastic Flutter Analysis

1. Decrease in wing stiffness decreases flutter margin
2. Determine L/D payoff for decreased stiffness
3. Discount engine / wing interaction for this study
   - Wing stiffness unchanged inboard of engine nacelles
4. Outer wing bending – torsion occurs at higher airspeeds
5. Determine control activation of VCCTE Flap to compensate outer wing
   - Active suppression to allowable ASE levels
6. Determine wing stiffness boundary that requires active suppression

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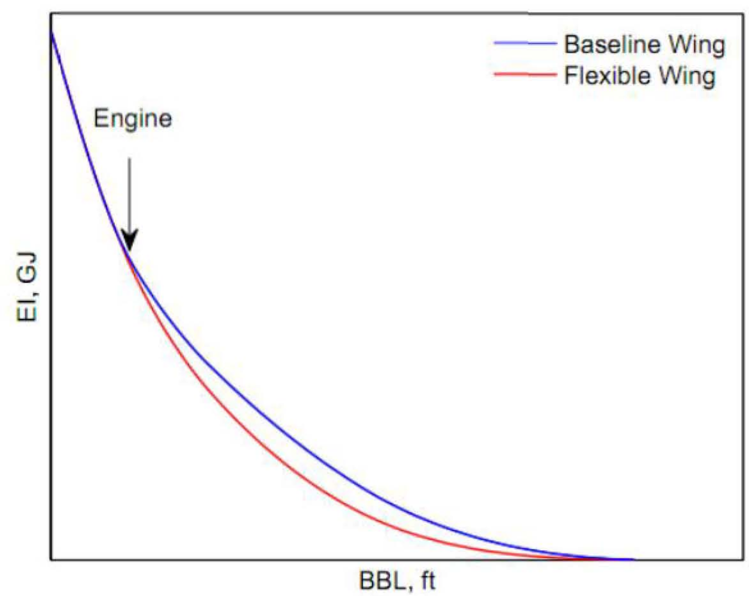
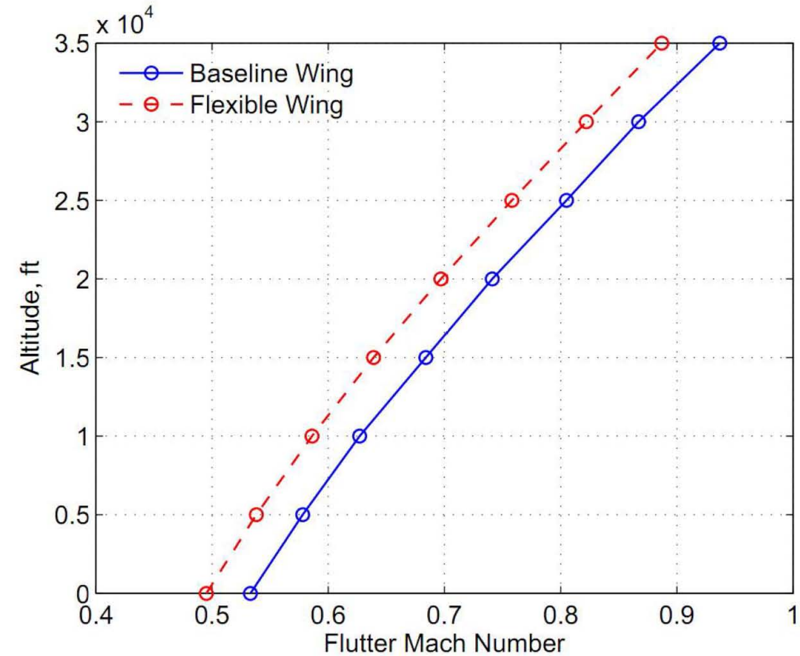
Aeroelastic Flutter Analysis



Representative Wing Stiffness



Representative Flutter Boundary

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Summary

1. VCCTE Flap project progressing, completed 1st Quarter of 1 year study
2. Flap geometry and hinge moment requirements for TE Flap determined
3. Shape Memory Alloy actuation has light weight advantage
4. Wing stiffness trade-off for increasing L/D using GTM wing as the example for the project
5. Determine wing flutter boundaries for decreasing wing stiffness, add active control for flutter suppression.
6. Apply method / lessons learned to a Truss-Braced Wing aircraft as the next step.

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