Development of Variable Camber Continuous Trailing Edge Flap System

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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 alleviation.
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
Wing Geometry and Flap Control Sections

125 ft SPAN

37.5 ft

VARIABLE FLAP

COMMAND FLAP

COMMAND FLAP

VARIABLE FLAP

18 sections at 2 ft

18 sections at 2 ft
Variable Camber Flap with Electric Motor Drive

Wing Box

Electric Motor Drive

Shape Memory Alloy Rods (SMA)

Wing Box

Variable Camber Flap

Section 1

Section 2

Section 3
VCCTEF Actuator Types:

**SHAPE MEMORY ALLOY - (SMA)**

**Pros:**
- Weight vs. Power Lvl
- Adaptable Control

**Cons:**
- Speed of Operation
- TRL Level Low
- Power Level Demonstrated Low
- Rod Diameter vs Torque Capacity

**Hydraulic Actuator w/ Servocylinder Control**

**Pros:**
- Speed of Operation
- Size/Power vs Electric

**Cons:**
- Requires Fluid Lines
- Requires Central Hyd Sys.
- Control Requires Valves

**Electro-Mechanical - (EMA)**

**Pros:**
- Power Easy to Route
- Adaptable Control
- Speed of Operation

**Cons:**
- Size/Power vs Hydraulic

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Each Type for Actuation May Have a Role

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

# 1 FLAP
# 2 FLAP
# 3 FLAP

# 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

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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

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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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Drag Comparison

3.5% Induced Drag Reduction over Baseline Wing Configuration
Variable Camber Continuous Trailing Edge Flap

Flap Layout

Continuous Trailing Edge

Variable Camber Flap

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Example Drag Polars: Variable Camber Continuous Trailing Edge Flap

- 80% Fuel w/ Aeroelastic Deflection
- 50% Fuel @ Design Condition
- 20% Fuel w/ Aeroelastic Deflection
- VCCTE Flap Down 3.9 deg
- VCCTE Flap Up -3.3 deg

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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.
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
Aeroelastic Flutter Analysis

Representative Wing Stiffness

Representative Flutter Boundary
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.