Aerodynamic Flight-Test Results for the Adaptive Compliant Trailing Edge

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Outline

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Introduction

• Adaptive Compliant Trailing Edge (ACTE) effort was a joint project with NASA’s Environmentally Responsible Aviation (ERA) project and U.S. Air Force Research Laboratory (AFRL)
• The ACTE technology has the potential to reduce aircraft weight, improve aerodynamic efficiency, and reduce airframe noise
• NASA GIII airplane was modified, removing trailing edge flaps, along with flight and ground spoilers, and installing seamless compliant flaps
• Flaps were fixed at specific flap deflections, ranging from -2 degrees (trailing edge up) to 30 degrees (trailing edge down) and only adjustable on the ground
• A series of flights was flown to obtain aerodynamic and structural data for the modified GIII airplane with the ACTE flaps installed
GIII SubsoniC Research Aircraft Testbed
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- **GIII Airplane Information:**
  - Service Ceiling: 45,000 ft
  - Max Speed: 340 KCAS, Mach 0.85
  - Zero Fuel Weight: 38,000 lb, Max Takeoff Weight: 69,700 lb
  - 75 ft wingspan

- **Standard Research Instrumentation:**
  - Pitot-static and total temperature parameters
  - Flow angle vanes
  - Embedded GPS/INS (EGI) unit
  - Surface position measurements

- **ACTE Research Instrumentation:**
  - Structural sensors, including strain gages, fiber optics strain sensing, accelerometers
  - Aerodynamic sensors, including steady and unsteady pressures, a leading-edge stagnation sensing system, separation detection sensors, and tufts
ACTE Flaps

- Replaced conventional GIII Fowler flaps
- Span of 18 ft
- Roughly 20% chord
ACTE Aerodynamic Instrumentation
Flight Test Approach

• Prior to ACTE modifications, baseline flights, including some with the flight spoilers disabled, were completed and used to update existing aerodynamic models for the GIII airplane

• CFD analyses were performed with Star-CCM+ code over the planned flight range of flap deflections and flight conditions

• CFD results were used to create an aerodynamic model, investigate effects of the flaps on stall speed and evaluate potential loss of aileron effectiveness

• An aerodynamic model of the force and moment effects of the ACTE flaps was created from predictive tools and incorporated into a 6-DOF flight simulation

• Flights were performed with the ACTE flaps installed, starting with 0 degree flap deflection

• The flight envelope for each flap deflection was cleared, then incrementally increased for the next set of flights
Star-CCM+ Vehicle Aerodynamics

- Unstructured Navier-Stokes solver
- Full airplane was modeled
- Operating engines were modeled using flow conditions from 1-D engine model
- 35 million finite volume cells
- SST K-Omega turbulence model used with an all y+ wall treatment
- 19 prism layers were used within a normal distance of approximately 1.8 inches from the wall
ACTE Flight Envelope

![Graph showing ACTE flap deflection](image)

**ACTE flap deflection**
- 0 to 2 deg
- −2 to 5 deg
- −2 to 15 deg
- −2 to 30 deg

**ACTE test points**

**Axes:**
- Altitude, ft
- Mach number

**Lines and Markings:**
- 150 KCAS
- 170 KCAS
- 200 KCAS
- 220 KCAS
- 250 KCAS
- 300 KCAS
- 340 KCAS
- 350 KCAS
Investigation Methods

• Vehicle Aerodynamics
  – 2-1-1 maneuvers performed in-flight
  – Parameter estimation using equation error and output error techniques

• Sectional Pressures
  – Constant airspeed and altitude “steady-state” maneuvers were flown
  – Pressures were averaged over 5-second time spans with minimal change in Mach, altitude, and angle of attack
  – Pressure coefficients and sectional lift coefficients were calculated

• Pitot-Static System
  – Level acceleration and deceleration maneuvers were performed at various altitudes
  – Meteorological data was combined with differential GPS to produce correction curves
Flight Test Results

• All flight test objectives were met
• A total of 23 ACTE flights were completed
• The flight tests successfully cleared the planned envelope and captured aerodynamic and structural data
• Results in the areas of vehicle aerodynamics, sectional pressures, and effects on the pitot-static system will be discussed
Vehicle Aerodynamics Results

- The ACTE flaps affected airplane lift and pitching moment
- No significant effects to other stability and control derivatives
- The preflight ACTE aerodynamic model over-predicted lift due to the ACTE flap for flap deflections above 10 degrees
- Pitching moment due to ACTE flap was better predicted, but still over-predicted for flap deflections above 20 degrees
- $\Delta C_L$ and $\Delta C_m$ trends with Mach number were captured reasonably well by the preflight model
$\Delta C_L$ vs. ACTE Flap Deflection

![Graph showing $\Delta C_L$ vs. ACTE flap deflection, with data points and shaded confidence region.](image)
$\Delta C_m$ vs. ACTE Flap Deflection

![Graph showing $\Delta C_m$ vs. ACTE flap deflection, with data points and model confidence region.](image-url)
$\Delta C_L$ vs. Mach Number

The diagram shows the change in lift coefficient ($\Delta C_L$) as a function of Mach number across different ACTE flap deflections. The Preflight aerodynamic model confidence region is indicated by the shaded area. Different symbols and colors represent various flap deflections: -2, 10, 25, 2, 15, 30, 5, and 20. The x-axis represents Mach number, ranging from 0.3 to 0.8, while the y-axis represents $\Delta C_L$, ranging from -0.1 to 0.6.
$\Delta C_m$ vs. Mach Number
Sectional Pressures Results

- CFD results consistently over-predicted suction over the entire airfoil section (at all three butt lines)
- At high flap deflections, flow separation over the flap was under-predicted by CFD results
- Predictions for flow separation point were most accurate for the inboard pressures and least accurate for the outboard pressures
- Results for sectional lift mirrored overall aerodynamic model trends for lift due to ACTE flap
Sectional Pressures

$0^\circ$ ACTE flap at Mach 0.30, 10,000 ft

$C_{l,\text{flight}} = 0.66$

$C_{l,\text{CFD}} = 0.71$

- Flight, upper
- Flight, lower
- CFD, upper
- CFD, lower
Sectional Pressures

20° ACTE flap at Mach 0.30, 10,000 ft

$C_{l,\text{flight}} = 0.81$

$C_{l,\text{CFD}} = 0.96$

Flight, upper
Flight, lower
CFD, upper
CFD, lower
Sectional Pressures

30° ACTE flap at Mach 0.30, 10,000 ft

BL 136

BL 201

BL 269

$C_p$ vs. $x/c$

- Flight, upper
- Flight, lower
- CFD, upper
- CFD, lower

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Sectional Lift

![Graph showing sectional lift coefficient vs. ACTE flap deflection](image)

- Flight data
- CFD data

Legend:
- Blue circles: Mach 0.3, hp=10000 ft
- Red crosses: Mach 0.55, hp=20000 ft
- Black squares: Mach 0.75, hp=40000 ft
Effects on Pitot-Static System

• Despite noticeable effects on the pitot-static system by the standard fowler flaps, airplane pitot-statics were not substantially affected by the ACTE flaps
• Any potential effects of the ACTE flaps fall within the calibration uncertainties of the pitot-static system
Pitot-Static Effects

![Graph showing Pitot-Static Effects](image)
Conclusions

• ACTE flight tests were completed successfully
• Aerodynamic models compared well with flight data at lower ACTE flap deflections, but over-predicted lift at higher flap deflections
• CFD solutions consistently over-predicted suction over the airfoil and under-predicted flow separation over the ACTE flap when compared with flight data
• Airplane pitot-static system was unaffected by ACTE flaps
Questions?
Backup Slides
ACTE Flap Deflection Definition

Undelected flap

Horizontal reference line

ACTE flap deflection
Sectional Pressures

0° ACTE flap at Mach 0.55, 20,000 ft

\[ C_{l,\text{flight}} = 0.32 \]

\[ C_{l,\text{CFD}} = 0.37 \]