Adaptive Compliant Trailing Edge (ACTE) Flight Testing

EAA Airventure Osk Kosh
July 27, 2018

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Agenda

Topic
Introduction & Project Overview
Flight Test Overview Pilot Comments
Flight Instrumentation
Flight Operations
Technical Outcomes
Wrap-Up

ACTE I + II

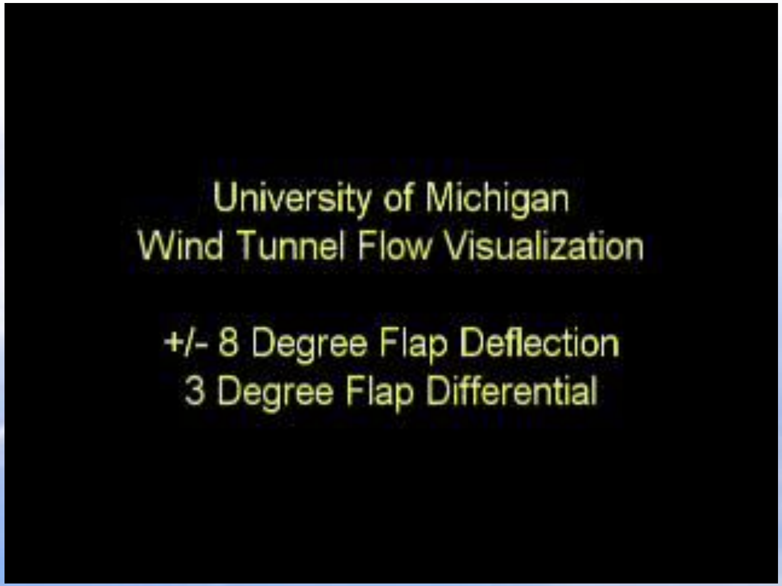
- **Air Force Research Labs (AFRL) funded initial ACTE experiment**
- **FlexSys contracted to develop and fabricate ACTE technology**
- **NASA engaged to execute structural demonstration of ACTE in flight**
- **During ACTE I flight testing, additional funding became available for ACTE II**

Historical Timeline

- Nov 2014 thru May 2015 - ACTE I flights
- Feb 2015 - Proposal for ACTE II
- Aug thru Oct 2016 - ARM (Acoustic Research Measurements) Phase I noise testing with baseline landing gear and ACTE flaps
- Mar thru Apr 2017 - ACTE Mach Extension & Performance tests ACTE Performance and first Twisted Flap flights
- Aug thru Oct 2017 - ARM II noise testing with Landing Gear Noise Reduction hardware and ACTE flaps
- Nov 2017- ACTE II final flight for Twisted Flaps
- Nov 2017 thru Feb 2018 – aircraft restoration to fowler flaps
- Mar thru May 2018 - ARM III noise testing

ACTE Project Overview

- **AFRL funded initial development of Adaptive Compliant Trailing Edge (ACTE) technology**
  - Cruise drag reduction, load alleviation, structural demonstration, community noise reduction
  - FlexSys engaged for the development and fabrication of the compliant flaps
  - Flap geometry is approximately 19ft in span for each surface



ACTE Project Overview

- **Compliant flap replaced both aircraft fowler flaps**
- **Compliant technologies pursued for next gen aircraft design**

SubsoniC Research Aircraft Testbed (SCRAT)

- GIII acquired and developed into a SubsoniC Research Aircraft Testbed
- Flight Research quality Instrumentation System developed and installed.
- Telemetry System installed.
- Power System modified.
- Aircraft cabin modified to be reconfigurable and allows for researchers to fly along with their experiments
- Extensive data collected to characterize aircraft.

Benefits:
- ✓ Supports a wide range of aeronautics related research.

Benefits:
- ✓ Provides high quality flight data suitable for conducting flight research

Benefits:
- ✓ Allows for control room monitoring during envelope expansion & for additional researchers

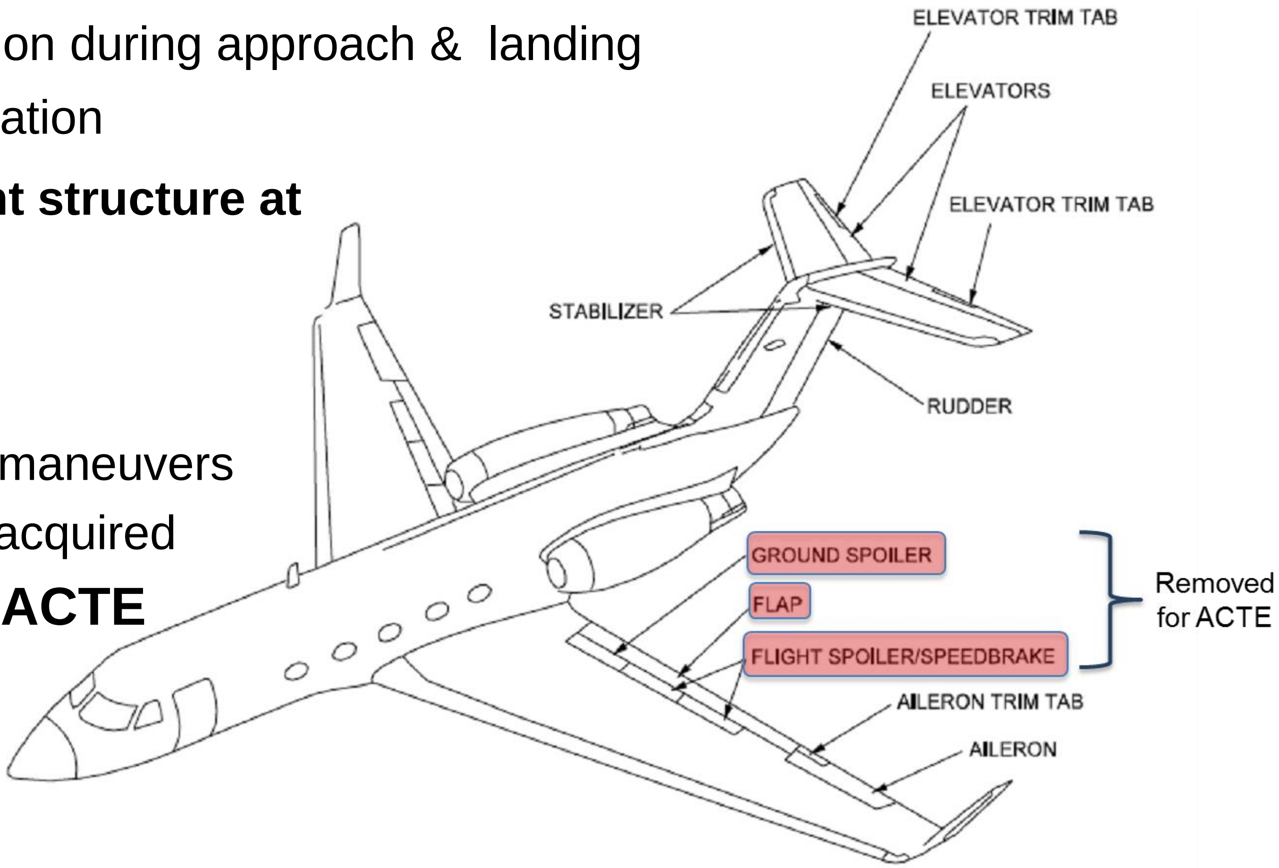
Benefits:
- ✓ Power budget for future experiments

Benefits:
- ✓ Configurable cabin
- ✓ Researchers can fly and monitor progress real-time

Benefits:
- ✓ Verifies & Validates usefulness as a testbed for aeronautics experiments.
- ✓ Gathers flight data that will be used by follow-on flight research experiments.
- ✓ NASA has a transport class testbed aircraft for developing aeronautics technologies.

ACTE I

- **Advance the integration of compliant technologies**
  - 3-10% Cruise drag reduction and resulting fuel burn savings
  - 20% Wing weight reduction through a 20-30% reduction in wing root bending moment
  - 4-6 dB Noise reduction during approach & landing
  - Structural load alleviation
- **Flight test of compliant structure at various deflections**
  - Fixed structure
  - Flight to M0.75
  - Variety of flight test maneuvers
  - Multiple data types acquired
- **Learned a lot about ACTE structure**



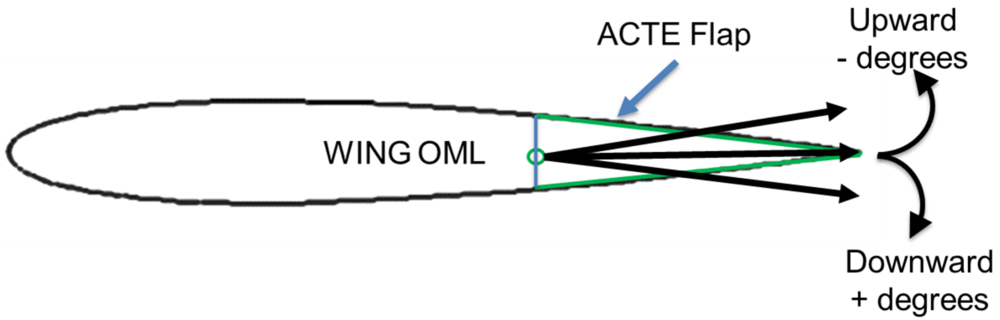
ACTE II

- **Flight Demonstrations & Capabilities (FDC) funding following on flights with the ACTE flaps with the following goals:**
  - Demonstrate ACTE technology in-flight out to Mach 0.85
  - Demonstrate twisted deflections of the ACTE technology in-flight
  - Acquire data to characterize the integrated SCRAT/ACTE drag.

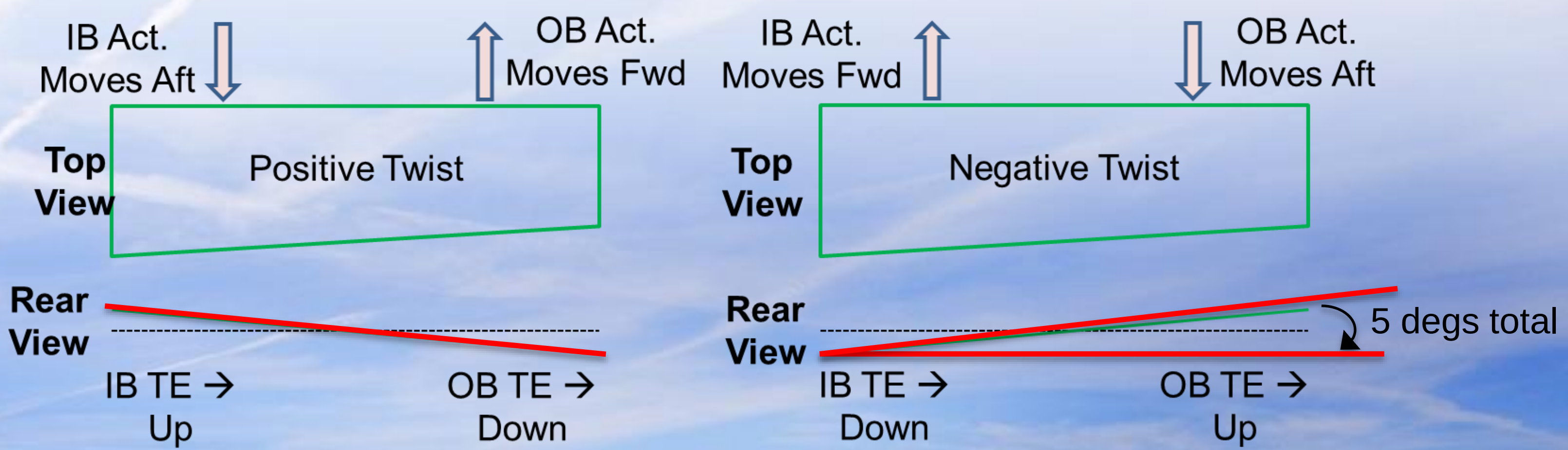
- **ACTE II flights began in the Fall of 2016**

ACTE Deflection Definitions

- **ACTE downward deflections are denoted as positive; upward deflections are marked as negative**



- **"Twist" is defined as the difference in ACTE flap deflection measured at the inboard and outboard edges of the ACTE main flap for each side of the aircraft.**
  - Positive Twist = Outboard edge deflected down, inboard edge deflected up
  - Negative Twist = Outboard edge deflected up, inboard edge deflected down



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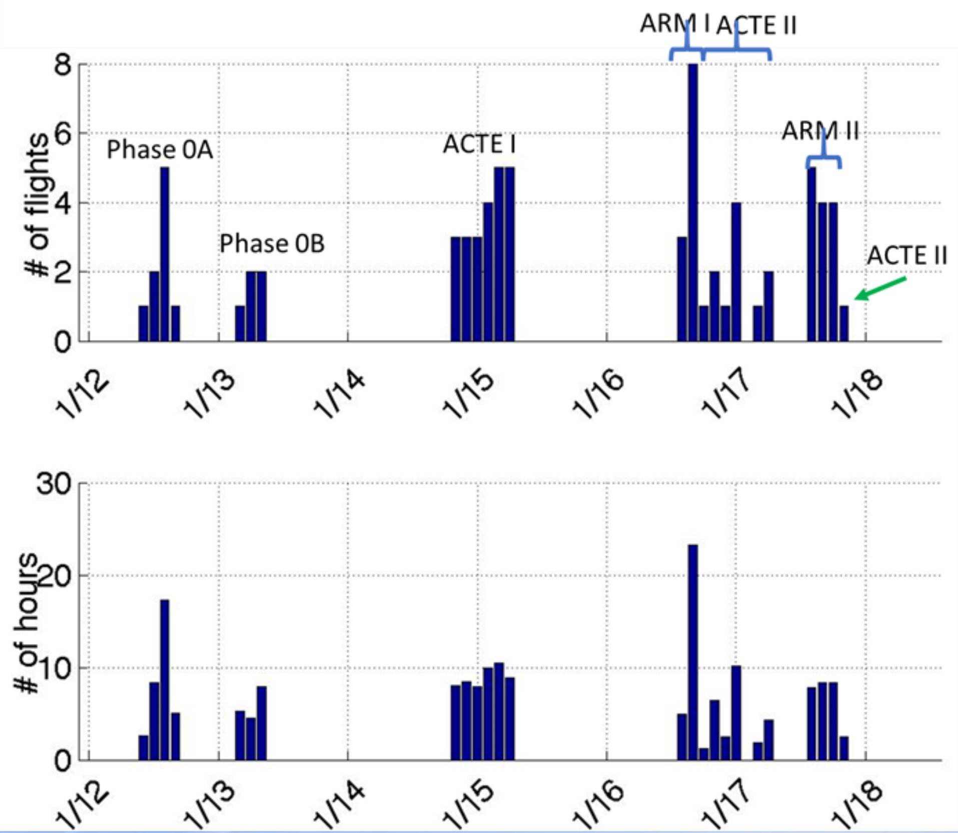
ACTE II

- **Demonstrate ACTE technology in-flight out to Mach 0.85**
  - Initially planned to achieve with ACTE deflected from 2 degs upwards to 5 degs downward
  - Actually only achieved flight to M0.85 with 0 degs deflection
- **Demonstrate twisted deflections of the ACTE technology in-flight**
  - Initially planned:
    - 0 degs +/- 5 degs peak to peak
    - 5 degs +/-5 degs peak to peak
  - Unable to fly twist about 5 degs due to high structural loads caused by configuration
- **Acquire data to characterize the integrated SCRAT/ACTE drag.**
  - Flew test points to M0.75

ACTE Structural Life

- **ACTE Flew substantially more flights than originally intended.**
- **ACTE flaps flown for total of 135.5 hours, 59 flights**
  - ACTE I required 53.7 hours, 23 flights
  - ACTE II required 27.8 hours, 11 flights
  - ARM required 54 hours, 25 flights

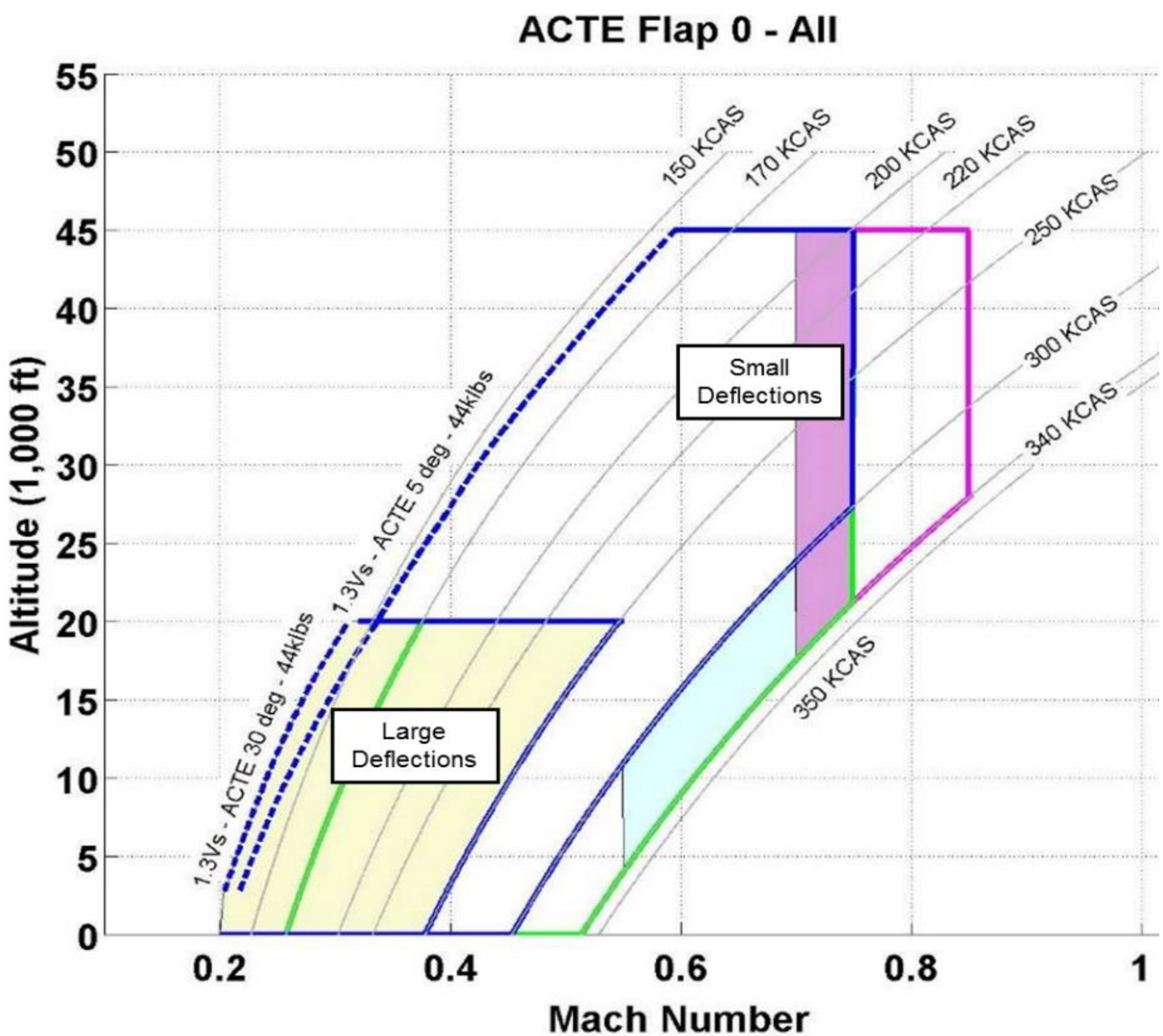
ACTE Flight Campaigns	Flight Hours	# of Flights
All Flights	135.5	59
ACTE I	53.7	23
ACTE II	27.8	11
ARM I	29.4	12
ARM II	24.6	13
	135.5	59



Flap Deflection	Flight Hours	# of Flights
-2	10.8	5
0	33.8	14
2	13.0	4
5	11.3	5
10	9.0	3
12.5	2.7	1
15	6.5	3
17.5	1.7	1
20	3.5	2
25	31.0	15
30	7.4	4
0 -twist	2.5	1
0 +twist	2.5	1
	135.5	59

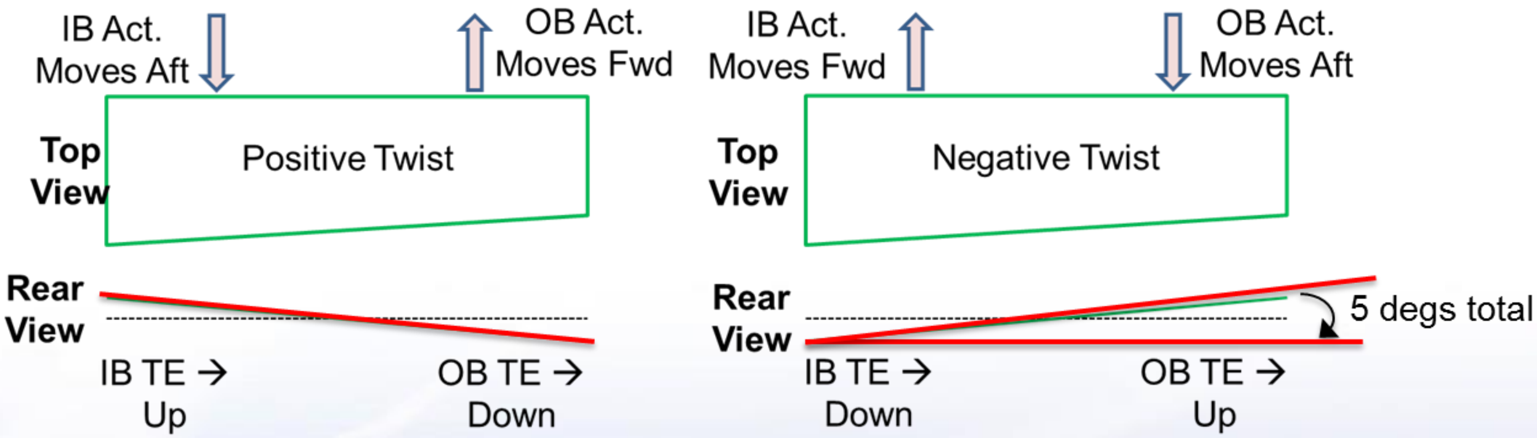
All Planned Flight Test Points

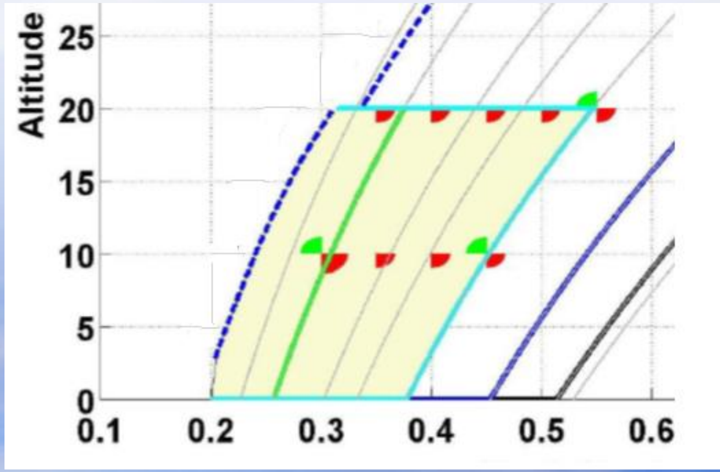
- Full envelope expansion to M0.85
- Loads, Flutter, Controls and Aerodynamics were defined for all flight objectives
- Performance test points limited to M0.75
- Typical buildup approach



Twist Flight Test Points

- Twist flights done in reduced flight envelope
- Each deflection completed in one flight





Flight Test Challenges

- **Aging Aircraft & Instrumentation System**
- **Aging Flaps**
  - Extended usage past originally intended life
- **Working ACTE and acoustic measurements simultaneously was tough**
- **Control Room Ops were challenging**
- **"Off-the-shelf" or "Mature" boxes / systems / solutions still require a lot of work to integrate properly**
- **Maintained good working relationship with prime contractor**
- **Documentation was important with the new team members**

Pilot Comments - Perspective

- **Cross-wind limitations appear to be appropriate based on the degradation handling qualities**
- **Pitch and yaw control were satisfactory at all airspeeds**
- **Without exploratory “No-spoiler flights”, we would not have definitive data to confirm the degraded handling qualities were not due to the ACTE flaps**
- **Approach speeds were safe but appeared high – long touchdowns were normal**
- **No stall or Mach buffet issues – *as expected***
  - Control room did notice buffet once during ACTE I, but it was not noticeable in the cockpit

Pilot Comments - Perspective

- **Experience conducting certain maneuvers (2-1-1s) on previous projects, was invaluable.**
- **Lateral inputs less conservative for ACTE II**
  - Tail loads were a concern for ACTE I

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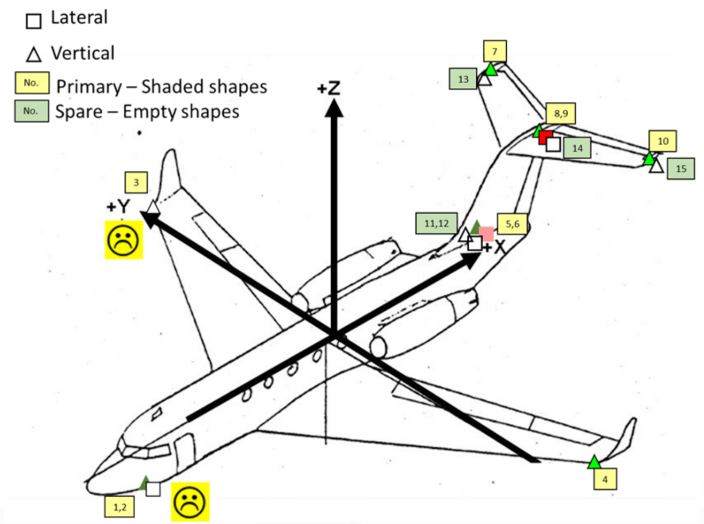
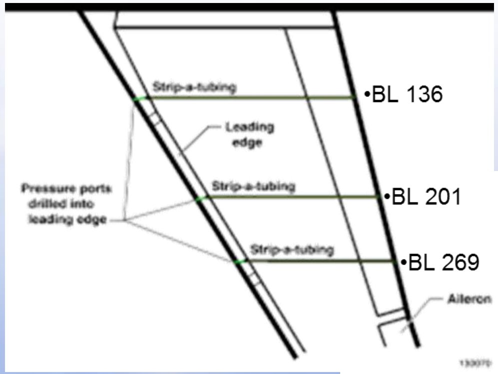
Data Acquired

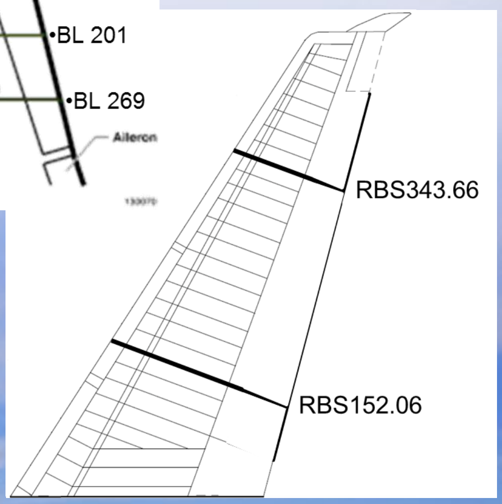
- **The instrumentation system for ACTE II telemetered 4293 measurands**

Measurand Type	Twist	Mach Ext	Perf
Safety of Flight	95	95	2
Safety of Test	109	115	16
Mission Critical	323	338	146
Technically Desired	913	892	1276



- **There were a number of systems archiving data on board for post processing.**
  - GPS
  - Fiber optic strain sensing
  - High Definition Video
  - Standard def video recorded on DVR
  - Flight Test Engineer and Instrumentation Operator screen shots





Developing Subsystems

- **Developing subsystems as part of ACTE**
  - Fiber Optic Strain Sensor
  - Hot Films Sensor
  - Electronic Tufts
- **New systems installed for ACTE II**
  - Fuel Flow Integration
  - Updated GPS Installation
  - High Definition Cameras

- **Performance flights were flown without a control room**
- **Control room operations**
  - All disciplines had dedicated displays and minimum required personnel in control room
  - Performed training as a team and as discipline groups

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Flight Timeline

- **T-1**
  - 0800 Instrumentation Preflight – 6 hours
  - 1300 Aircraft Preflight – 2 hours (fueled day prior)
  - 1300 T-1 Brief
- **T0**
  - 0700 Flight Crew Brief / Aircraft Power On / DOF Start
  - 0800 Control Room Staffing
  - 0930 Takeoff
  - 1230 Landing
  - 1330 Fuel for next flight / Start Aircraft Post Flight
- **T+1**
  - 0630 Aircraft Post Flight / ACTE Post Flight – 5 hours
  - 0800 Instrumentation Post Flight – 4 hours
  - 1200 Change Flap Setting – 2+ hours

Sun	Mon	Tues	Wed	Thur	Fri	Sat
	T-1	Flight	T+1	T-1	Flight	

Instrumentation Checks

- **Go/No-Go – 65 Parameter Types**
  - Safety of Flight/Safety of Test – Verified during pre-flight and Day of Flight (DOF), qty.13
  - Mission Critical – Verified during pre-flight and Day of Flight (DOF), qty. 33
  - Technically Desired – Verified during pre-flight and Day of Flight (DOF), qty. 20
- **Large number of parameters**
  - Long Pre/Postflight and DOF checks
  - More that can break
- **Some sensors hard to repair/replace**
  - Long lead items
- **High Definition video long download time**

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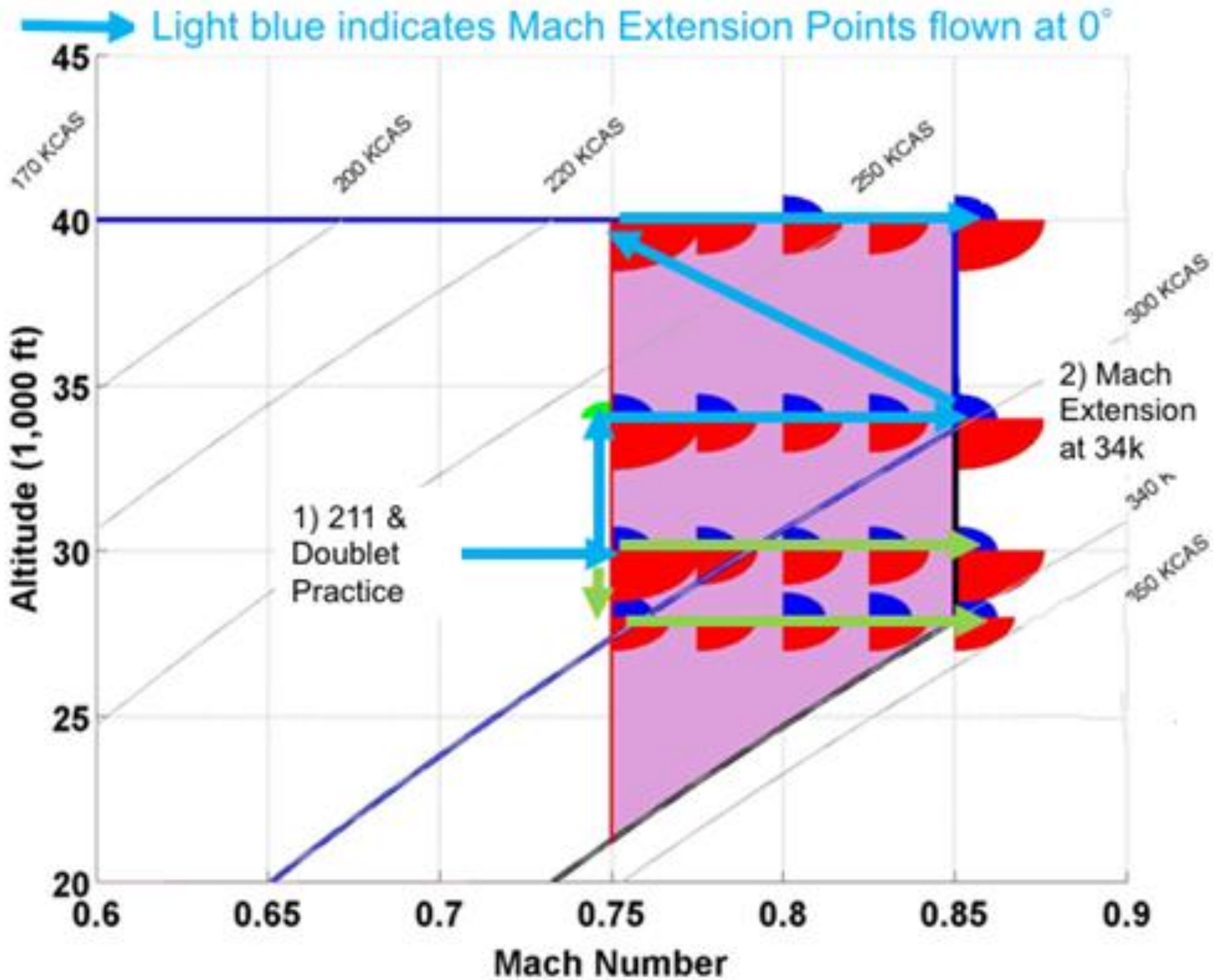
Mach Extension Flight Test Point Order
ACTE Flap Deflection = 0° & -2 °

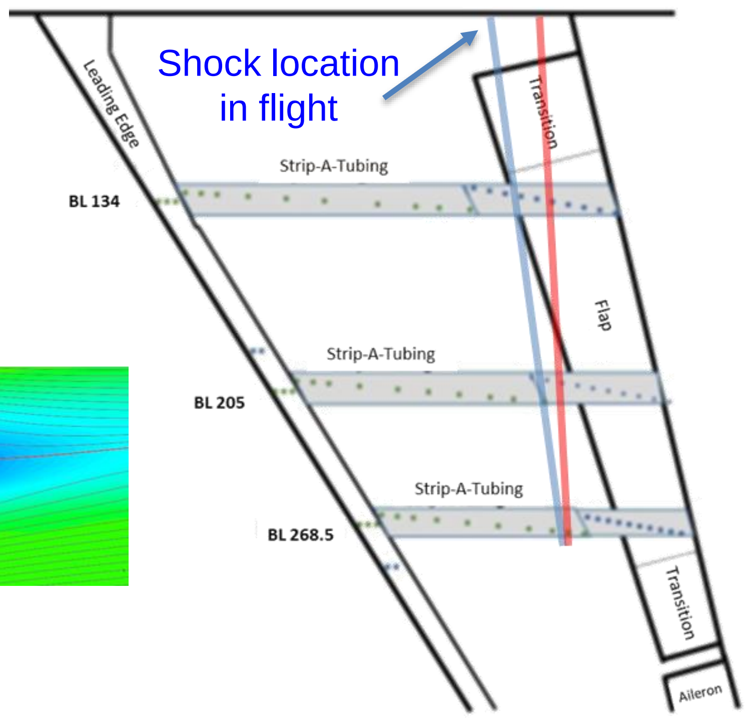
- Mach Extension a compromise between flutter, loads and buffet concerns
- Flutter and aero maneuvers were executed

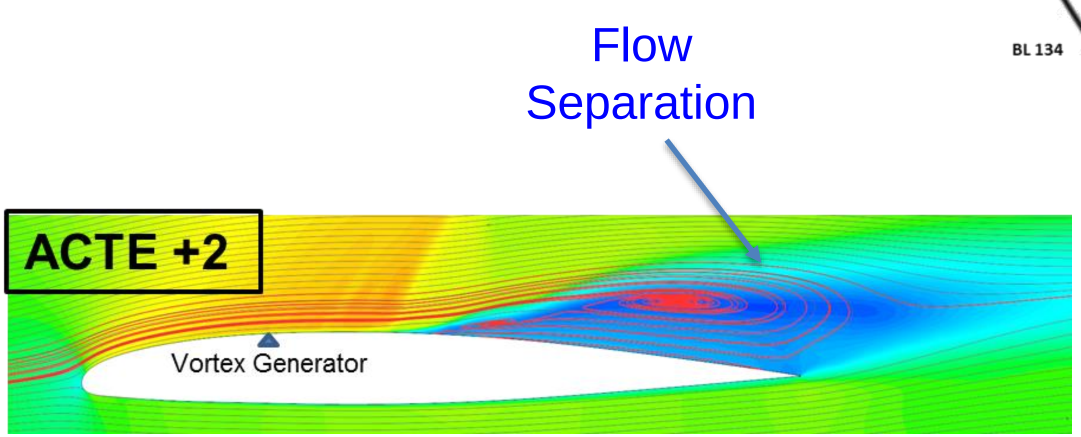


Mach 0.85 Aerodynamics

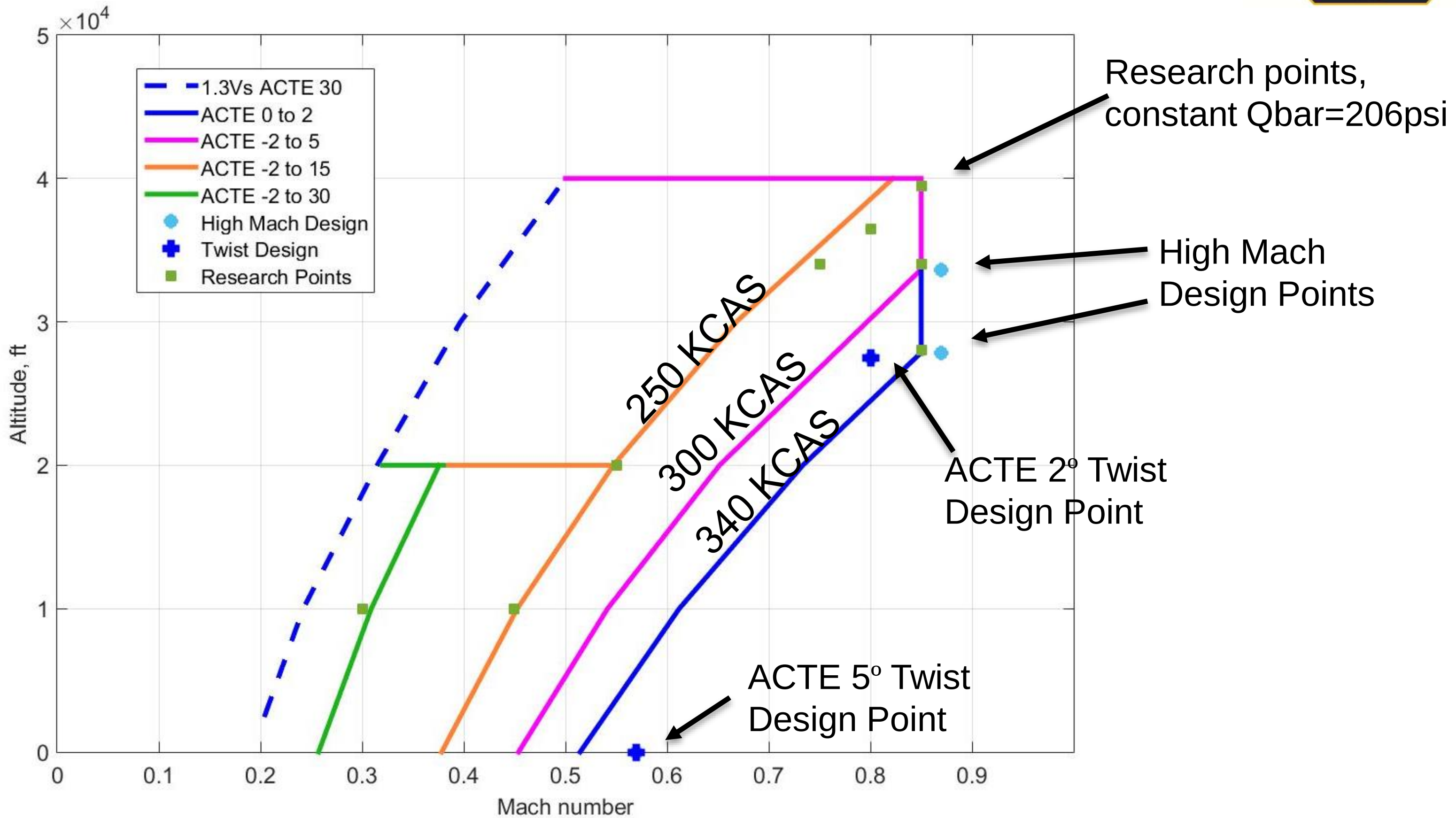
- CFD Predictions influenced flight test approach
  - Actual shock was less severe than predicted
  - Aileron effectiveness remained consistent, in keeping with predictions
- Positive ACTE deflections created large separation
  - Unsafe to fly positive deflections
  - Test objective de-scoped

Left Wing and Flap ESP Port Locations & Parameters





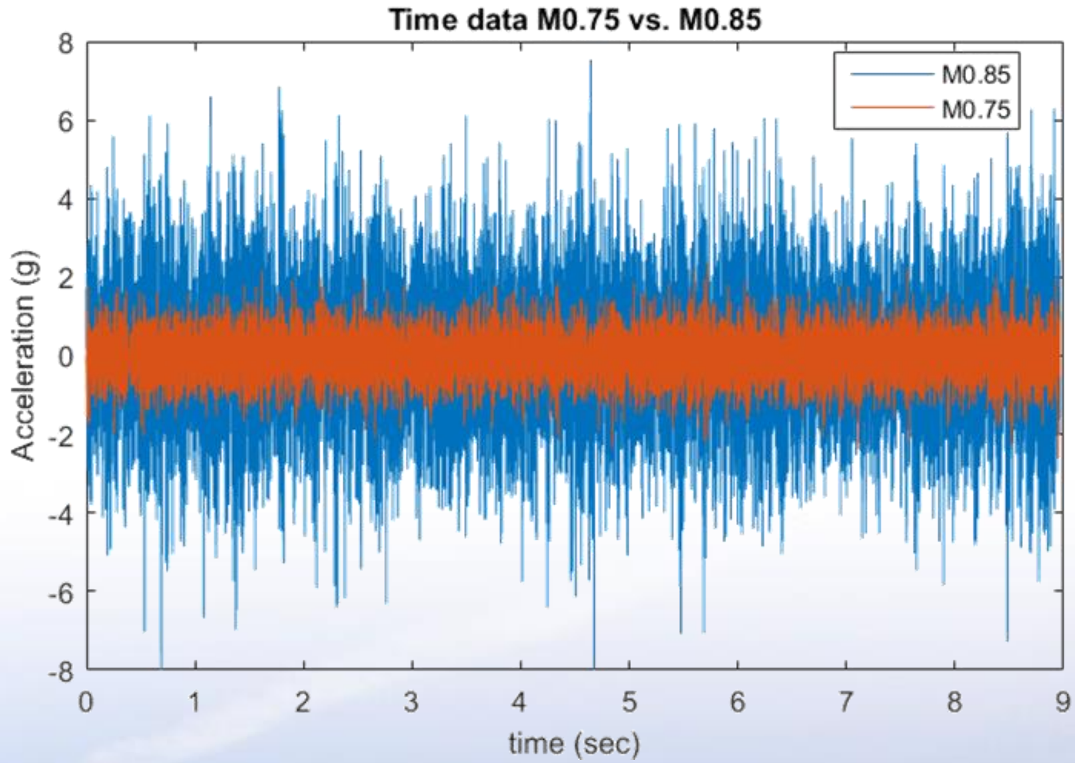
M 0.85 Loads Analysis

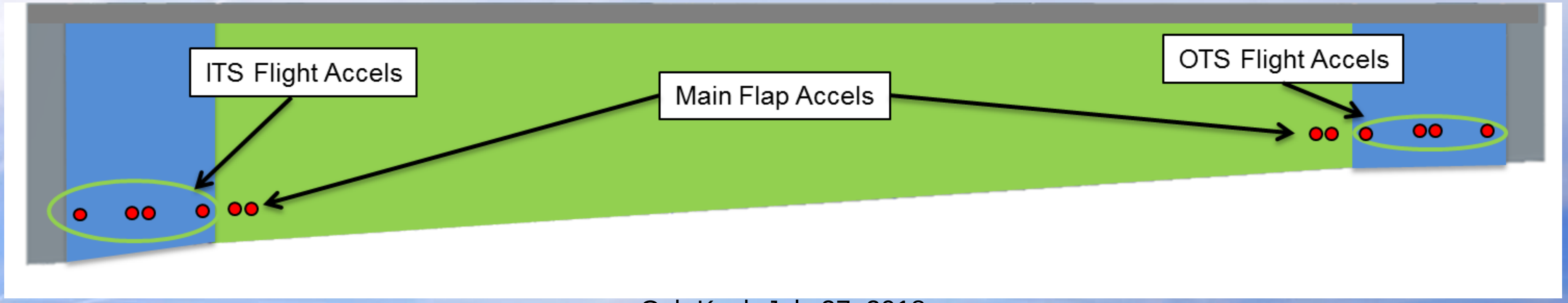


- **Analysis**
  - Calculated conservative load cases for high Mach and twist flight conditions
- **Testing**
  - Applied twist configuration on the ground
- **Instrumentation**
  - Monitored loads and strains on the ground and in-flight
- **Inspections**
  - C-Scan and visual inspections post flight phase

M0.85 Structural Dynamics

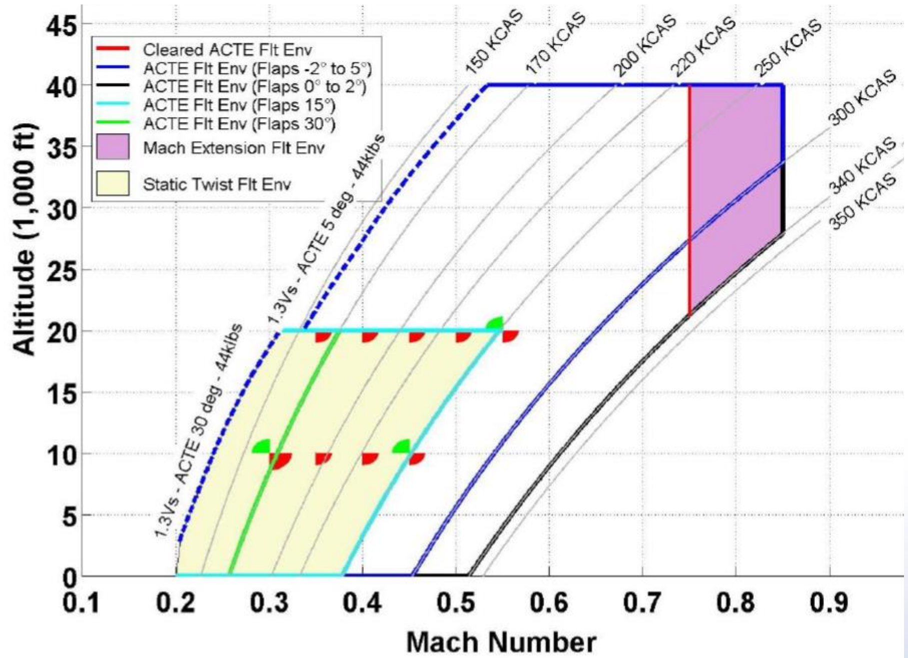
- **Monitoring strategy updated from ACTE I**
- **Same instrumentation**
- **Monitoring scheme updated for expansion to M0.85**
- **Excitation observed at M0.85 to indicate shock induced separation, but aeroelastically stable**





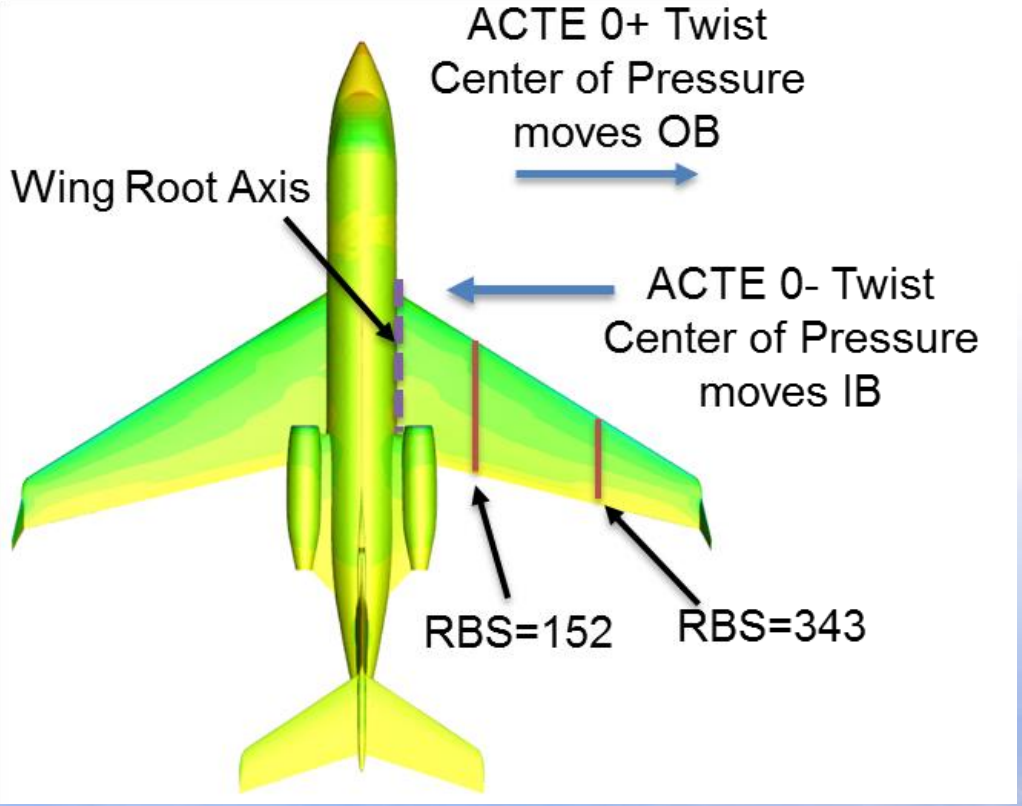
Flight Test Points
Twist Objective

- Twist about 5 degs not achievable due to high structural loads
- Twist loads were highest loads observed
- Antelope Valley Winds presented a challenge to completing flights



Twisted Deflections

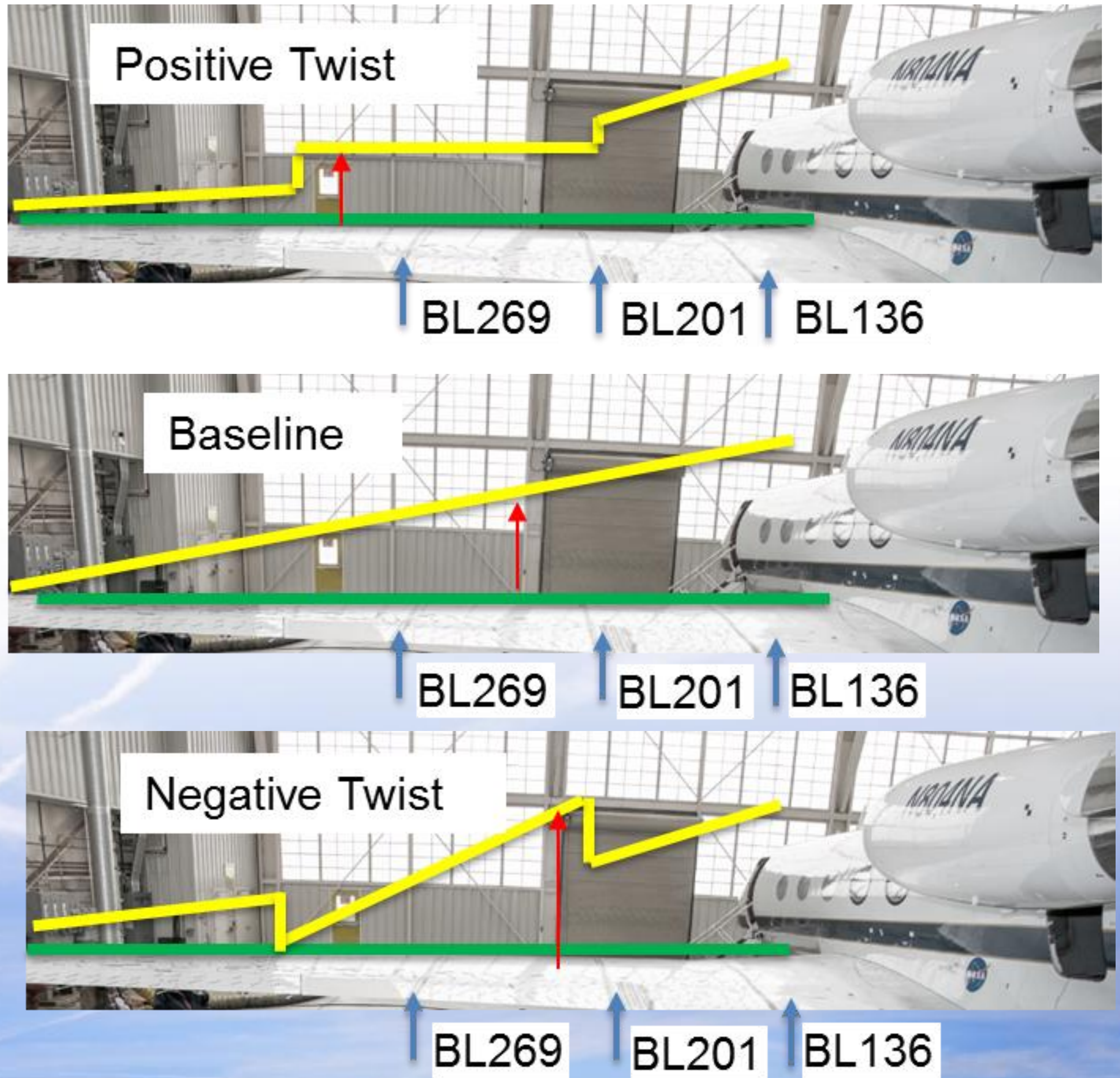
Mach=0.55, Alt= 20,000 ft., AoA=4.0 deg.



Normalized to ACTE No Twist Lift

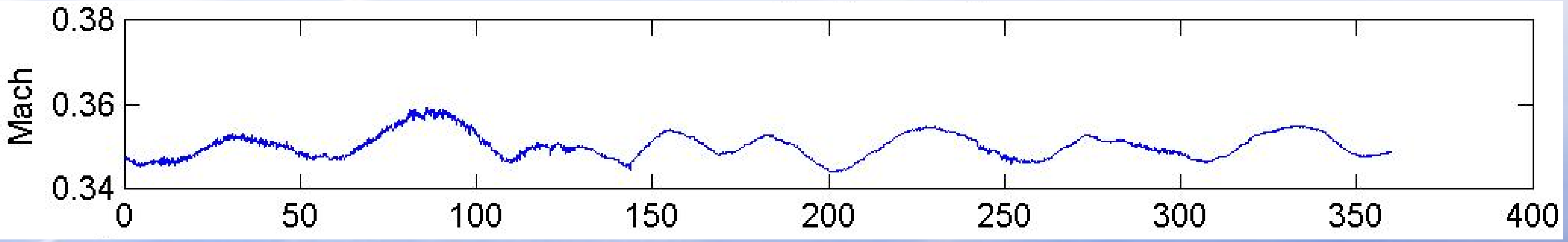
Configuration	Lift	Pressure Center Δ
Degrees	lbs.	in
No twist	40,081	0.0
Positive Twist	40,081	2.9
Negative Twist	40,081	-4.1

Twisted Flaps Pressure Data



Performance Assessment

- The GIII hydromechanical engine controllers exhibited difficulty stabilizing at lower speeds.
- Engine model required to determine in-flight drag and lift
- Starting point for creating the engine model was to match the known physical characteristics of the engine
- Attempted to tune performance based on using takeoff roll data as ‘truth case’



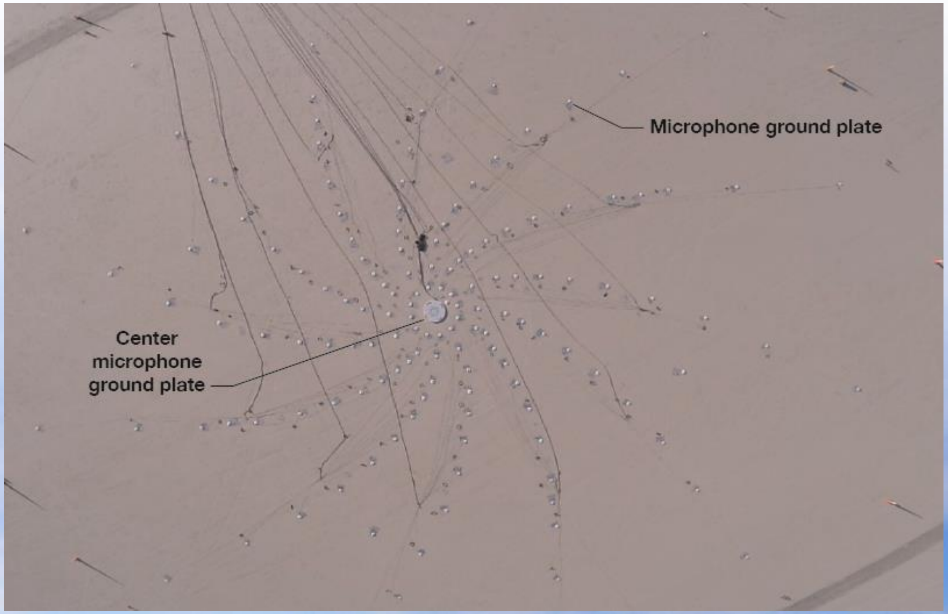
Drag Estimates

- **No fowler flap data at high speeds, only characterized drag trends as a function of ACTE deflection**
- **Equivalent data with the fowler flaps at lower speeds was not acquired**
- **The flaps 2 degs upwards deflection case offered the best drag reduction with the highest reduction occurring at Mach 0.6, equivalent to a decrease in drag of about 4.5%.**
- **The flaps 5 position resulted in higher drag across all flight conditions**

Mach	Flap Setting	% Improvement from 0 degs
0.6	-2	4.5
0.6	2	1.4
0.7	-2	5.5
0.7	2	0.3
0.75	-2	3.6
0.75	2	0.06

Community Noise Reduction

- **The goal of ARM was to examine the acoustic benefits of landing gear noise reduction and ACTE technologies**
- **LaRC microphone array placed on the Lakebed and North Base Runway**
- **Preliminary analysis data collected showed the ACTE technology has the potential to reduce airframe noise by 10dB.**



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Conclusions

- **Structural Demonstration**
  - The ACTE flaps were exposed to significantly more flight hours than originally anticipated. Structure showed no major issues across the original flight test campaign and the three additional ACTE II campaign.

- **Mach Extension**
  - Due to the anticipated shock wave in the transonic regime, sensors were monitored for any shock-induced separation.
  - Observed oscillations indicated standing shock.
  - Structural vibrations measured were stable.

- **Twist**
  - Verified that flaps were structurally capable of twist
  - Demonstrated that twist can be used to manipulate the center of pressure, which enables the redistribution of loads.
  - Twist loads were the highest structural loads, but showed no issues

Conclusions

- **Drag**
  - Fowler flap data wasn't acquired for direct comparison to ACTE flap deflection
  - The ACTE flap was evaluated as a function of deflection
  - The ACTE at 2 degs upwards showed the greatest drag reduction

- **Acoustics Measurements**
  - ACTE flaps enabled a 10dB reduction in airframe noise

- **Integration of compliant flaps will produce next gen aircraft that are more efficient and quieter.**

Final Thoughts

- **SCRAT/ACTE II Continued to Serve as a great opportunity to train a number of people.**

- **SCRAT / ACTE / ACTE II were successful because of all of the great people we've had on the team over the years.**

Osh Kosh July 27, 2018