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# Evaluation of Load Analysis Methods for NASA's GIII Adaptive Compliant Trailing Edge Project

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# Outline

- Introduction
- Aircraft Configuration
- Instrumentation
- Flight-Test Envelope
- Modeling and Simulation Procedure
- Results
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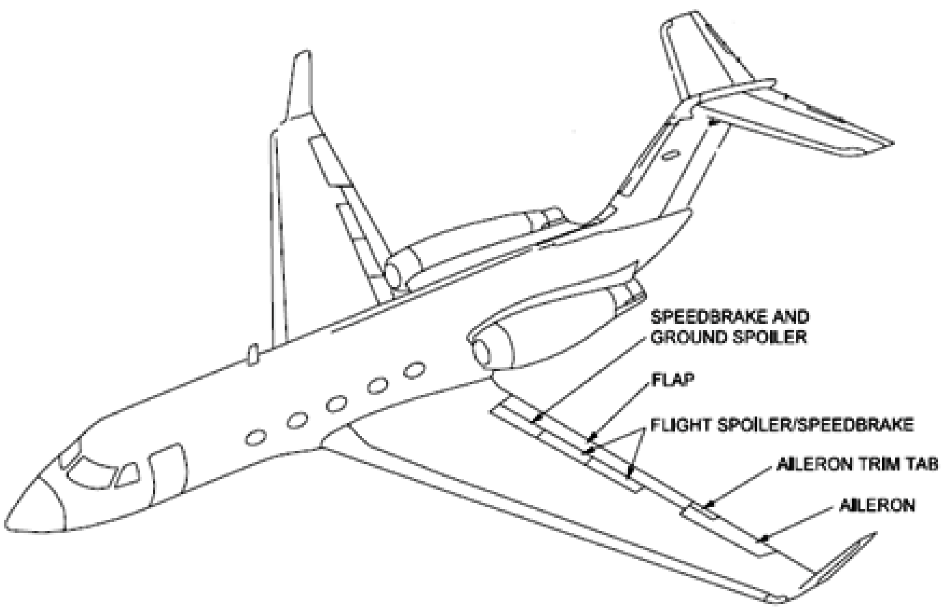
- Acknowledgements

# ACTE Project Overview

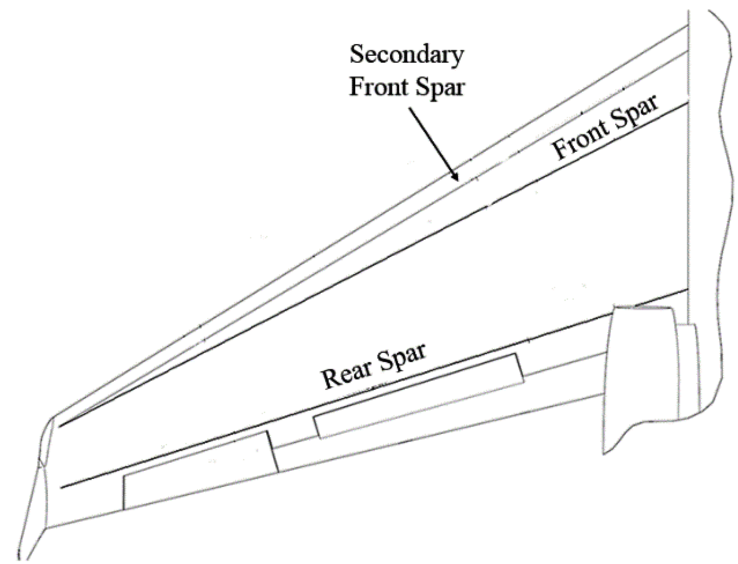
- Project objective: Flight demonstrate a compliant structure that replaces a large control surface
- Partnership between: NASA, AFRL, and FlexSys Inc.
- Adaptive compliant trailing edge (ACTE) potential performance benefits:
  - Cruise drag reduction, wing weight reduction through structural load alleviation, and noise reduction during approach & landing
- Status:
  - Phase 1 complete: -2 to 30 deg deflection; flight envelope to 0.75, 40kft, 340 KCAS, 2g load factor
  - Phase 2 test planning: Mach expansion to 0.85; Flap twist for load/cruise performance tailoring; Drag characterization; Noise characterization
- The objective for this paper is to present the analysis tools used for predicting wing loads


# Aircraft Configuration

- 19-passenger aircraft
- MTOGW 69,700 lbs.
- Swept wing with a wingspan of 77.8 ft.
- Swept wing reference frame origin located on the wing root at 40-percent chord
- Wing Area of 934.6 sq ft



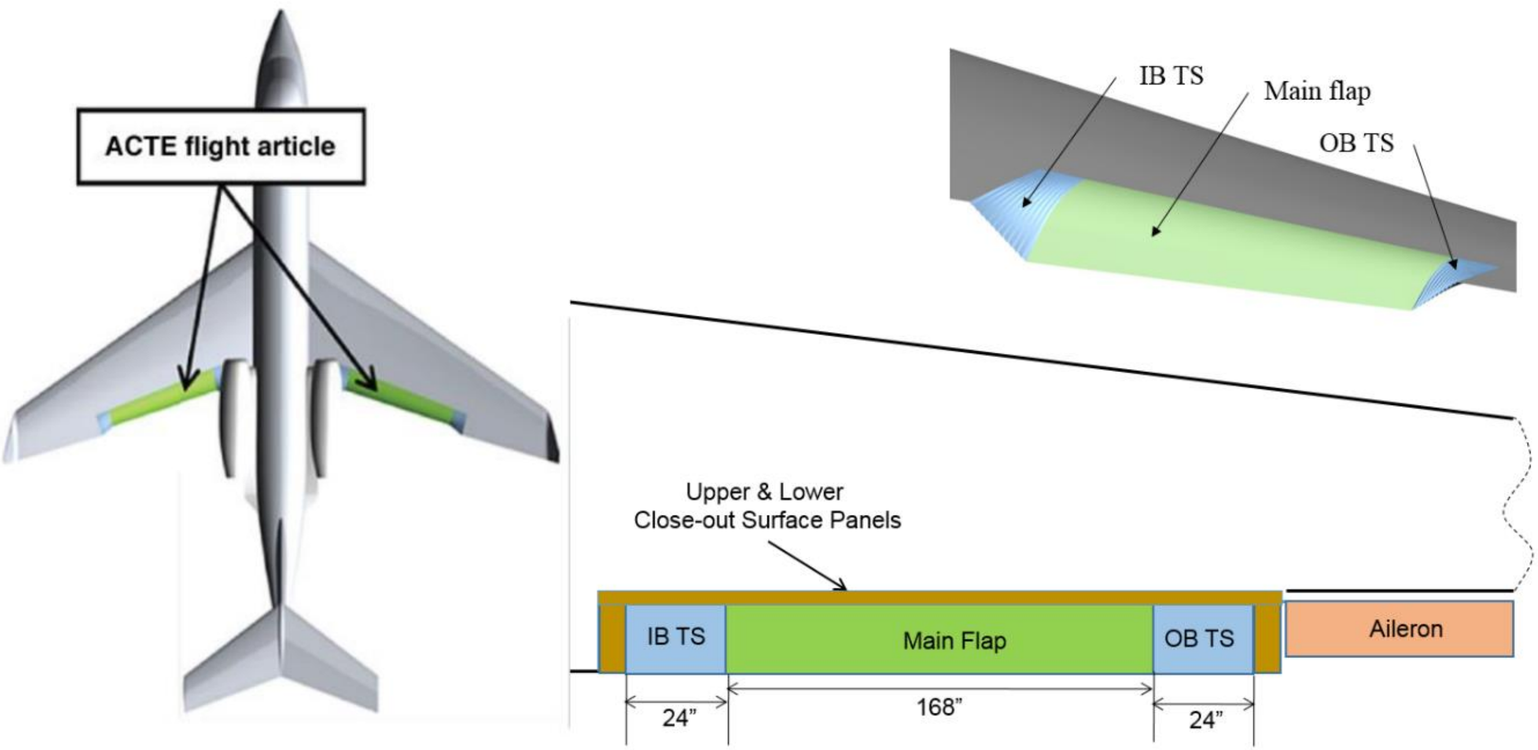

GIII wing control surfaces configuration without ACTE installed




Left wing schematic with ACTE not installed

# Aircraft Configuration

- ACTE structure composed of four primary components
- Main flap spans 168 in and is the main lifting surface
- Inboard transition surface (IB TS) and outboard transition surface (OB TS) each span 24 in and blend the main flap structure into the inboard and outboard wing structure
- Closeout panels were added around the ACTE boundary to create the seamless structure.

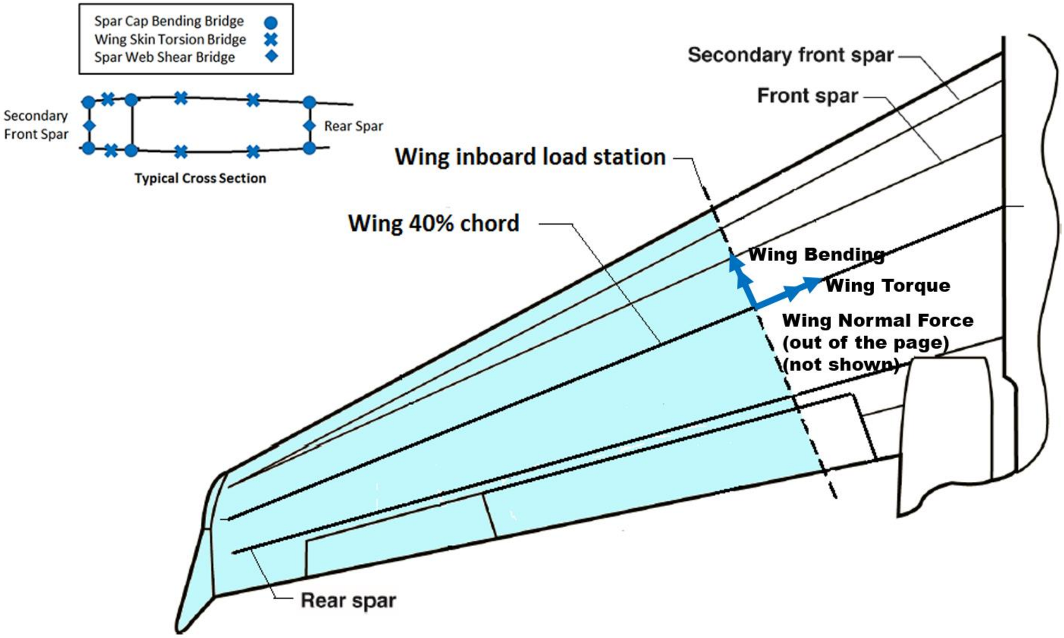



ACTE flap components as installed for flight-testing

# Instrumentation

- GIII wing instrumented with 141 surface pressure ports, 47 ports on each buttline (BL) ~136 in, ~201 in, and ~269 in
- Load calibrated strain gages installed on the left wing for measuring normal force, bending moment, and torque loads
- Load calibration methodology replicates the techniques used on past load calibration projects
- Wing box structure instrumented at two wing span stations located at Rear Beam Station (RBS) 152 and RBS 343


NASA's GIII inside the hangar




Loads definition on the ACTE wing

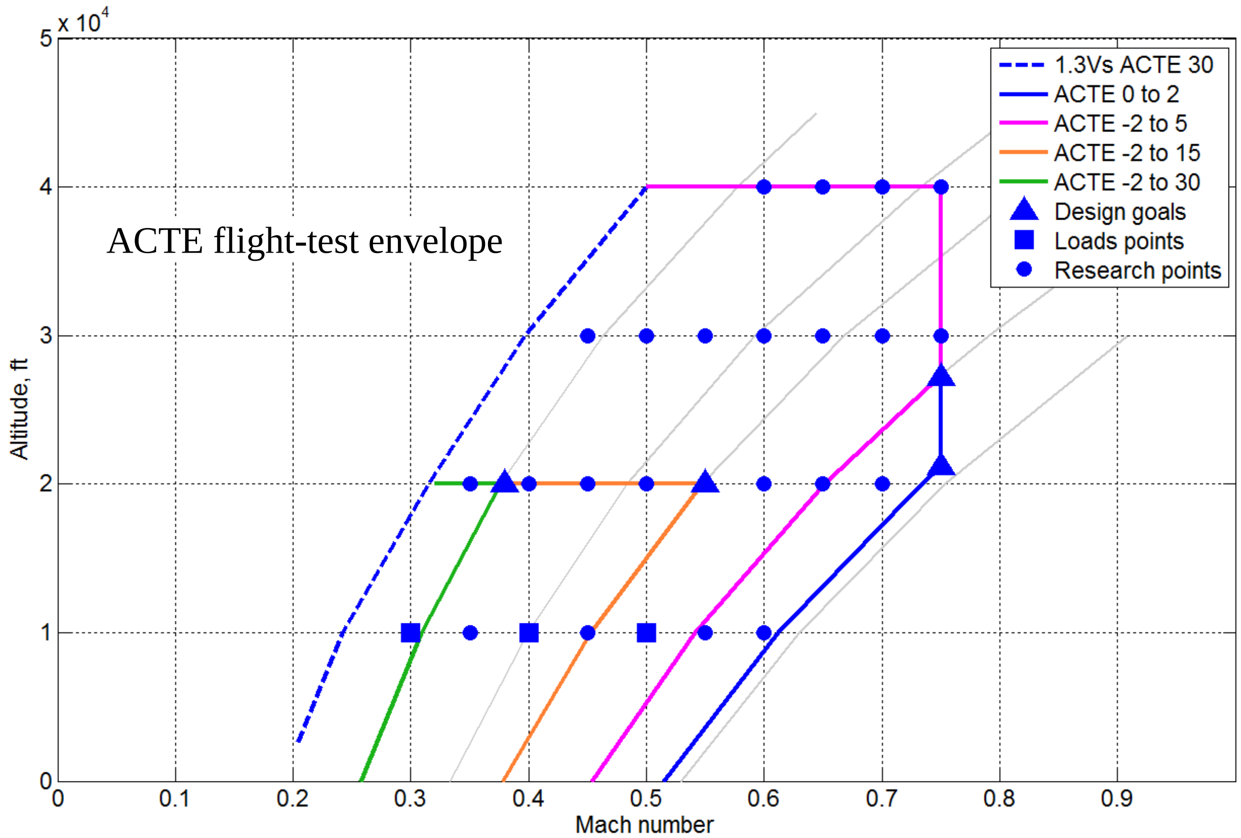
# Instrumentation

- Load equations derived using linear regression methods
- Aircraft supported by airbags for the strain gage loads calibration testing to minimize the influence of the main gear reaction loads into the derivation of the load equations
- Wing interface ACTE fittings calibrated for monitoring loads into the wing (Ref. "Strain Gage Load Calibration of the Wing Interface Fittings for the Adaptive Compliant Trailing Edge Flap Flight Test," AIAA 2014-0277)
- Normal force, bending moment, and torque loads were monitored during ACTE flight-test


Photograph of hydraulic up load case with aircraft supported on airbag

# Flight-Test Envelope

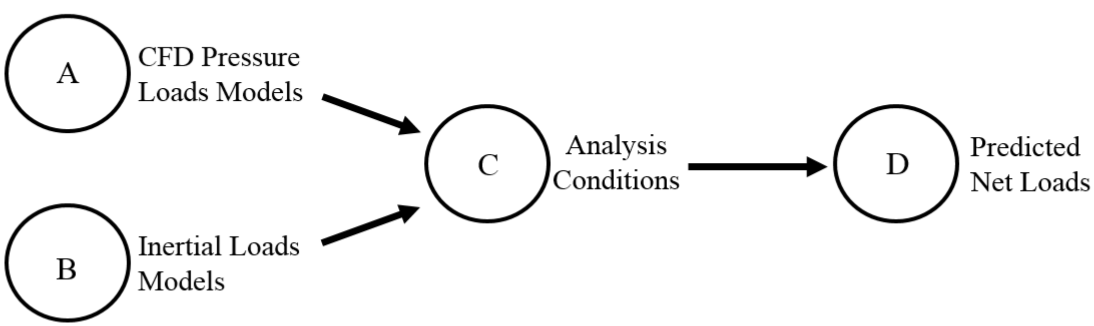
- ACTE flaps flight-tested to a max airspeed of 340 KCAS and Mach 0.75
- Altitude limited to 40,000 ft to minimize testing requirements
- Range of maneuvers flown at each test point which included steady state trim points, doublets and raps in all three axes, pushover-pullups, and wind-up turns
- Aircraft limited to a normal acceleration of 0 g to 2.0 g for all test conditions.
- Analysis presents data for steady-state maneuvers at 1.0 g, and 0.0 to 2.0 g pushover-pullup data



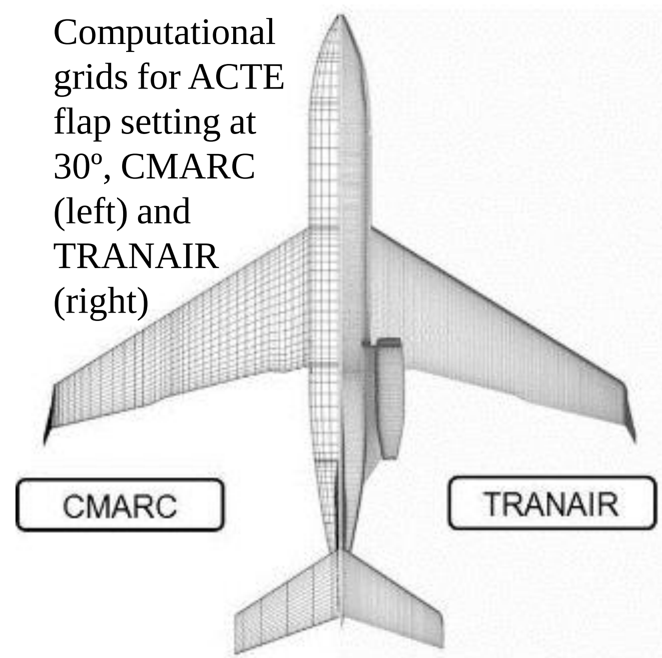
# Modeling and Simulation Procedure

## A. Computational Fluid Dynamics Models

- Pressure load models generated using two computational codes, CMARC and TRANAIR
- CMARC is a panel code
  - Grid modeled as a half configuration with a symmetry plane
    - 2463 surface panels, 1174 correspond to wing and winglet
- TRANAIR is a non-linear full potential solver directly coupled with an integral boundary layer solver
  - Grid modeled as a half configuration with a symmetry plane
    - TRANAIR was approximately 0.9 million cells in the entire domain
    - Approximately 72,500 surface panels, 32,000 correspond to the wing and winglet



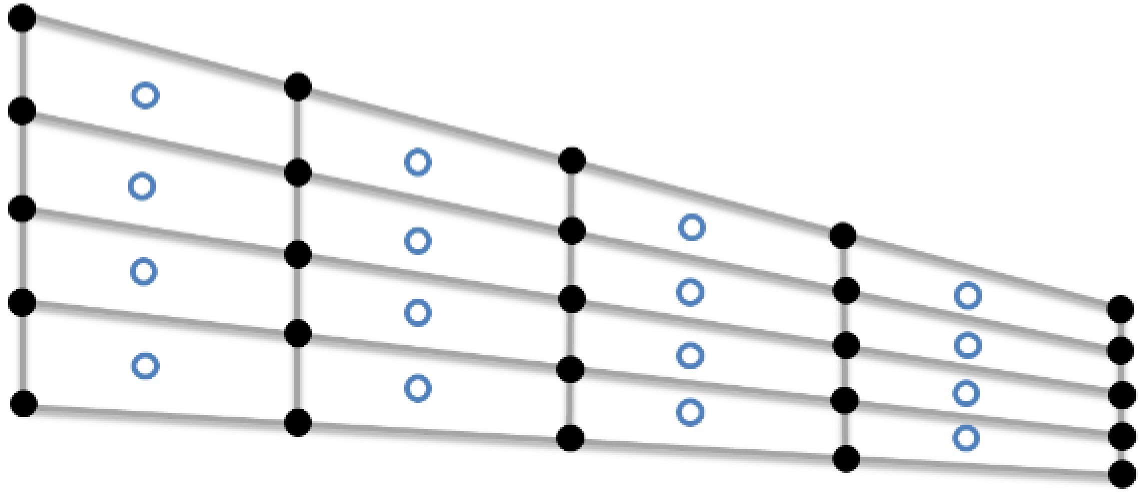

Loads prediction analysis flow chart




Computational grids for ACTE flap setting at 30º, CMARC (left) and TRANAIR (right)

## B. Inertia Loads Models

- Mass properties of the ACTE flap and wing obtained from two separate sources
- ACTE flap mass distribution from NASA's analysis
- Wing mass distribution modeling completed from information outlined in the Gulfstream Aerospace Corporation loads report
- Wing and winglet discretized into multiple panels; weight assigned to each panel for multiple fuel configurations



Example of wing grid with panel edges and centroid locations

# Modeling and Simulation Procedure

## C. Analysis Conditions

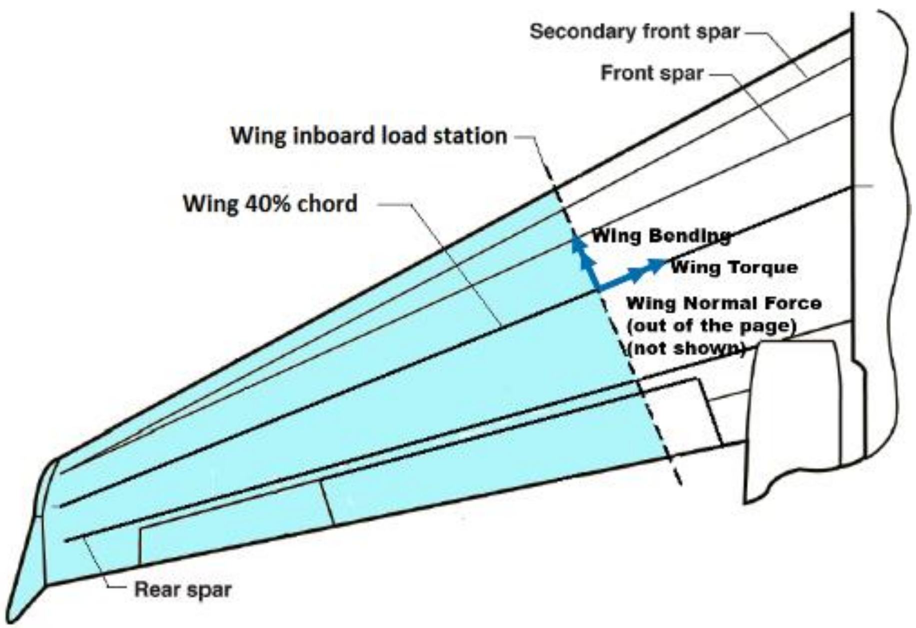
- CFD lift coefficient and the center of gravity (CG) calculated from flight test data
- Rigid-body approach primarily used, which provides a conservative estimate of the aircraft loads
- While incorporating elastic-body effects could result in more accurate load predictions, it was determined that the rigid-body analysis was sufficient to meet project requirements

**Steady State Flight Conditions**

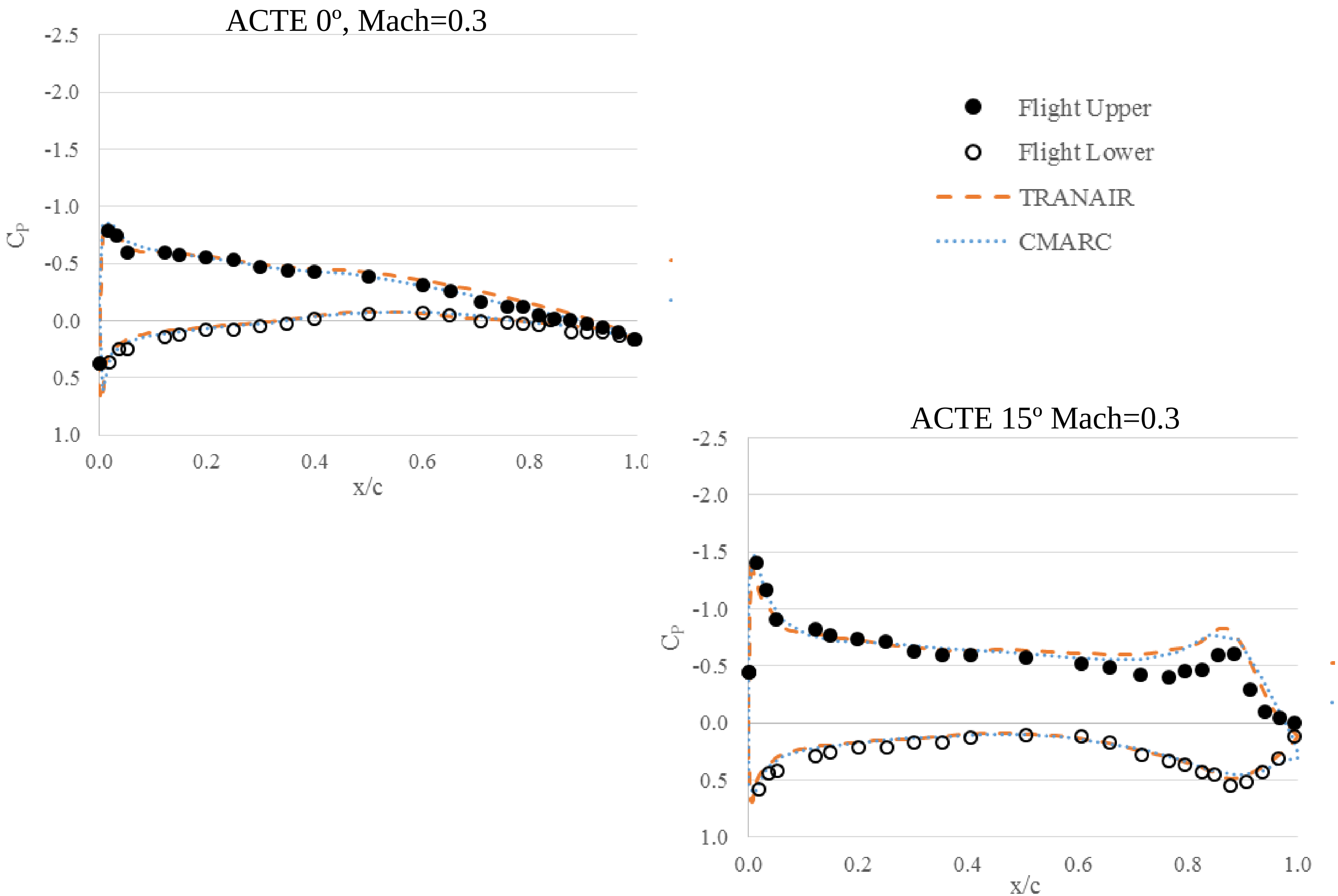
| | Mach | Altitude, ft. | ACTE deflection, deg |
|---|---|---|---|
| 1 | 0.30 | 10,000 | 0 |
| 2 | 0.40 | 10,000 | 0 |
| 3 | 0.50 | 10,000 | 0 |
| 4 | 0.30 | 10,000 | 5 |
| 5 | 0.40 | 10,000 | 5 |
| 6 | 0.50 | 10,000 | 5 |
| 7 | 0.30 | 10,000 | 15 |
| 8 | 0.40 | 10,000 | 15 |
| 9 | 0.55 | 20,000 | 15 |
| 10 | 0.30 | 10,000 | 30 |

**D. Calculation of Wing Loads**

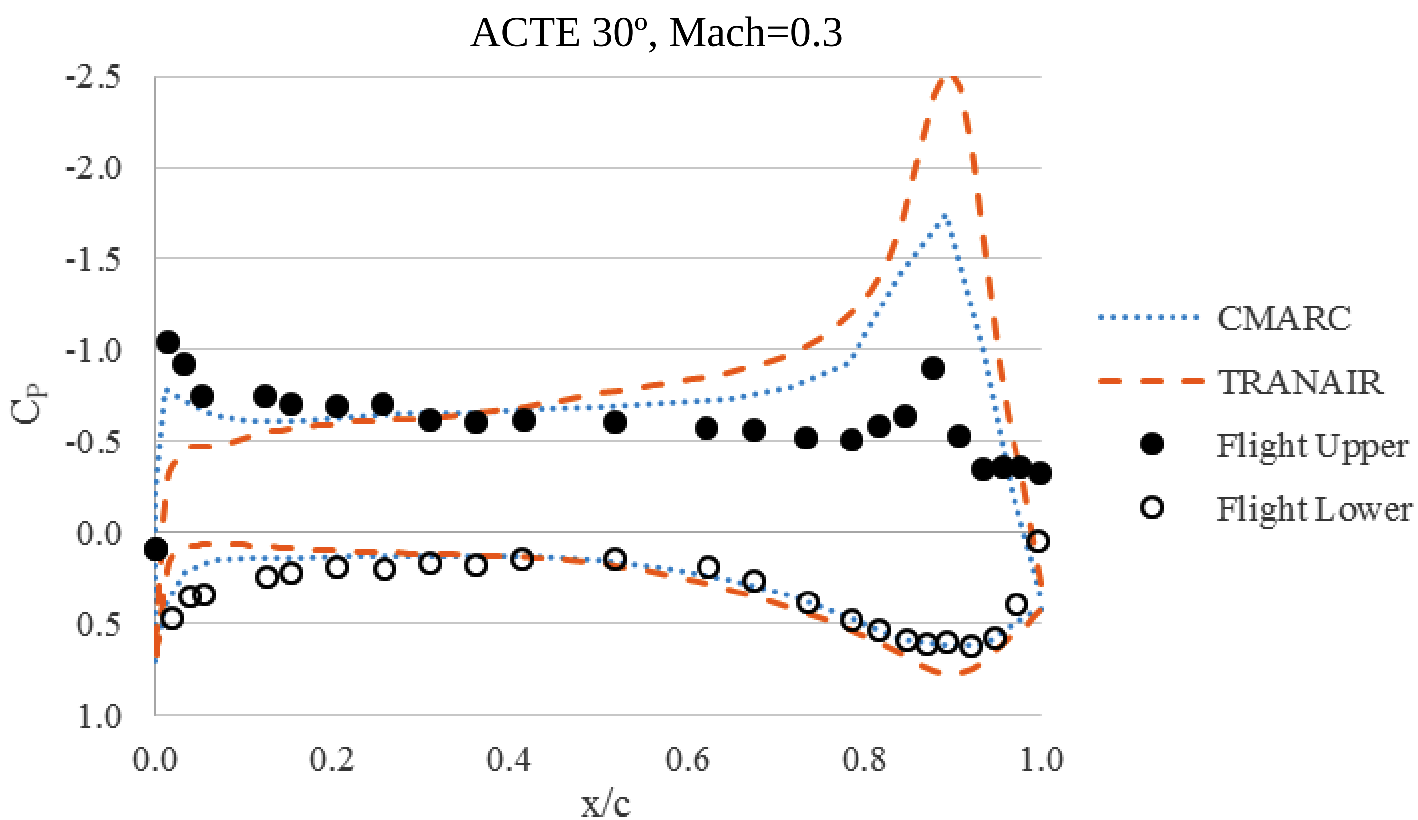
- Integrated loads consisting of the normal force, bending moment, and torque obtained from a load distribution on the wing (aero and inertial)
- Pressure discretized into panels. Each panel has an associated pressure coefficient value ($C_P$), and X, Y, Z coordinates of the corner nodes.
- Pressure and inertial loads distributed along the wing
  - Segmented into three parts: wing normal force ($N_W$), bending moment ($B_W$), and torque ($T_W$)
  - Origin of the swept wing reference frame is located on the wing root at 40% chord
  - Y-axis is rotated such that the axis runs parallel to the 40% wing chord line



# Cp Pressure Data @ BL 201, 10K ft.

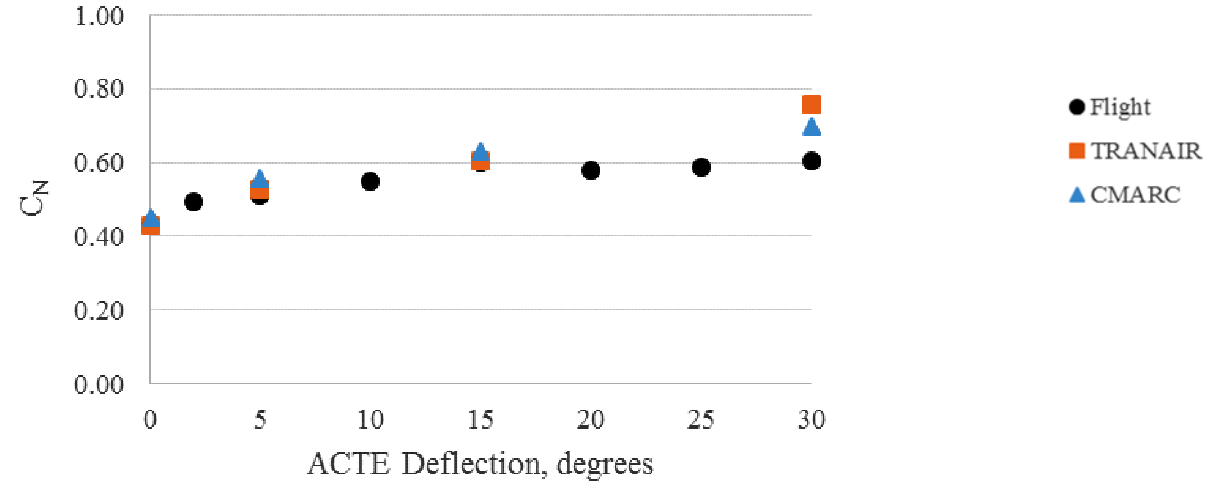


# Cp Pressure Data @ BL 201, 10K ft.

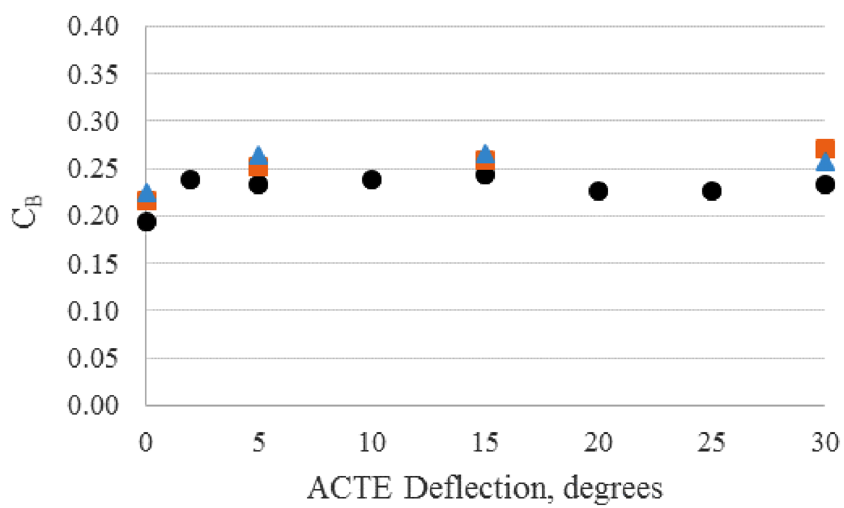


# Results, Mach=0.3 @ 10,000 ft.

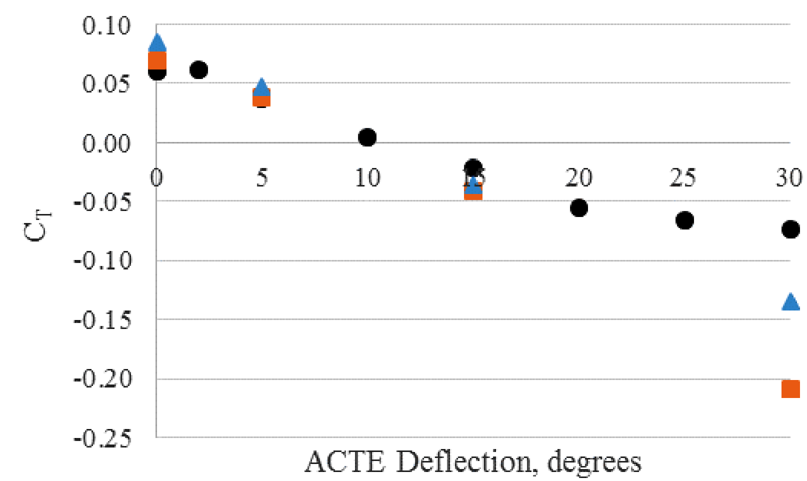
## Normal Force Coefficient




## Bending Moment Coefficient




## Torque Coefficient

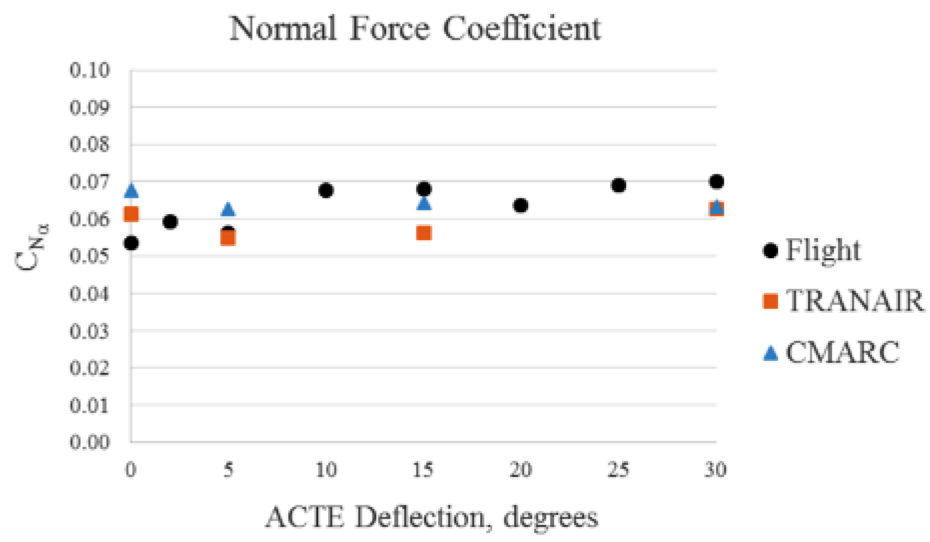


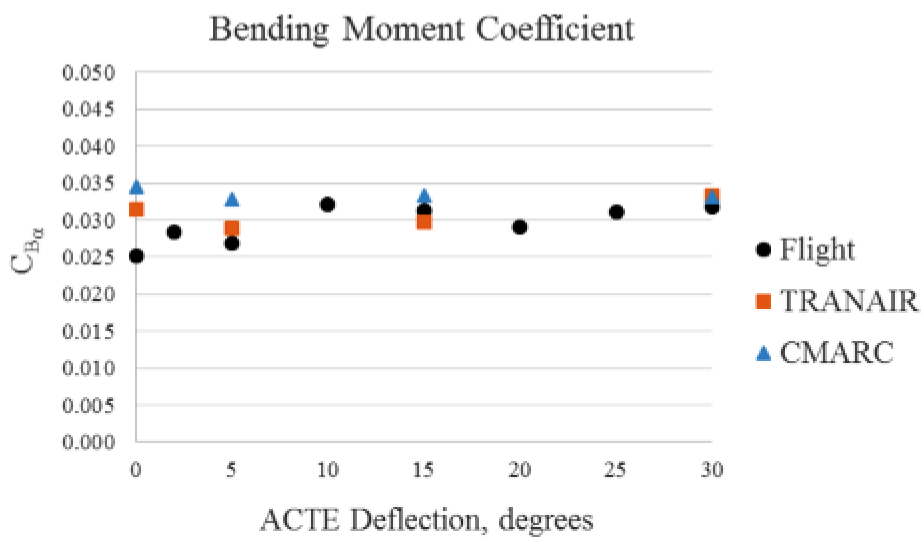
# Conclusions

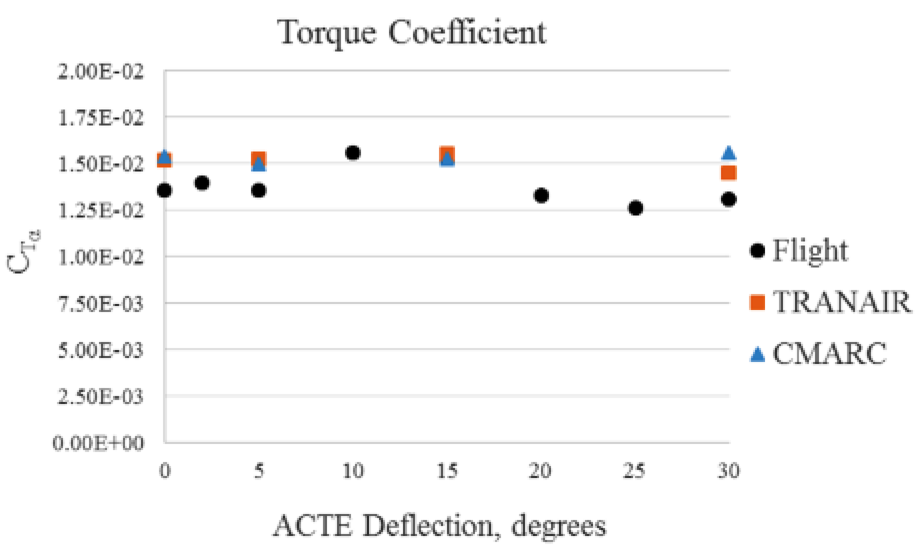
- Purpose for this work is to present NASA analysis processes for predicting normal force, bending moment, and torque loads on the GIII wing
- Study utilized TRANAIR and CMARC
- CFD-based simulations compared to flight data
- Predicted wing loads compared against calibrated strain gage wing load data
- CFD simulation matched the experimental CP profile well and, as expected, this led to good agreement in the predicted normal force
- ACTE flap setting 30 deg., CP did not match the flight data
- CFD-based analysis for ACTE flap setting 0, 5, and 15 deg, had good agreement with bending moment and torque, however, further analysis is necessary to have better results
- Addition of aerolasticity effects could possibly reduce the dissimilarities in bending moment and torque results
- Results of this study show that the CFD and inertia tools utilized for this analysis could be used for future studies of wing loads applications

# Back-Up

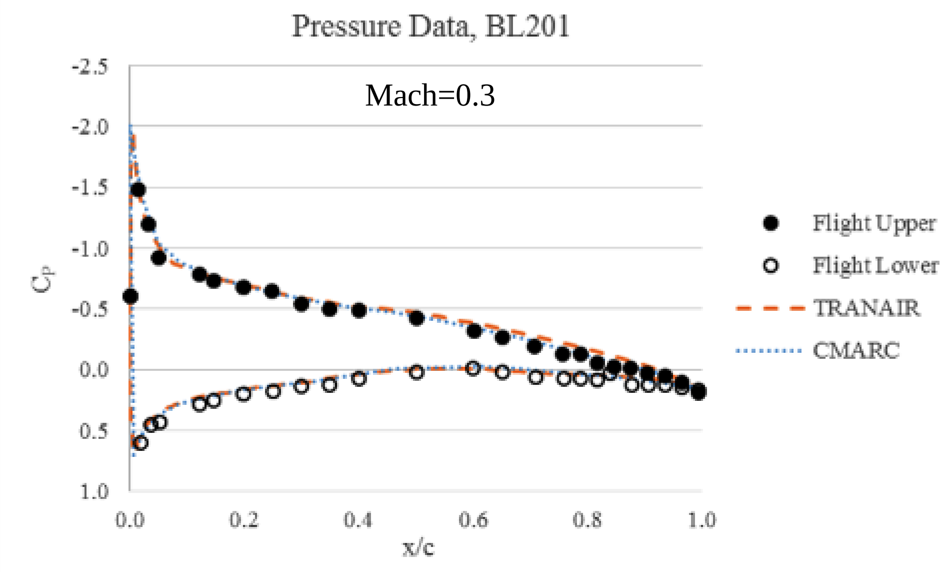
# Results, Wing Slope Coefficients, Mach=0.3 @ 10,000 ft.

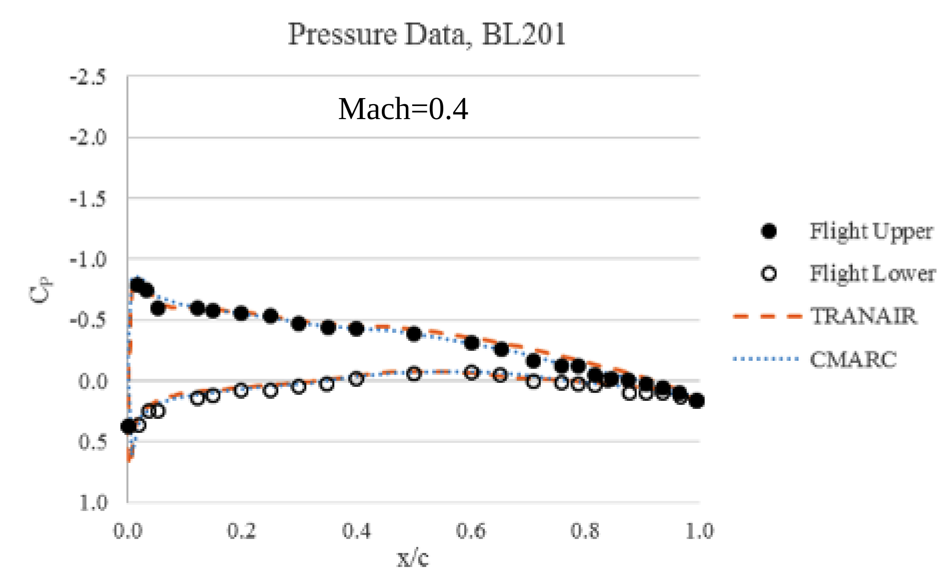


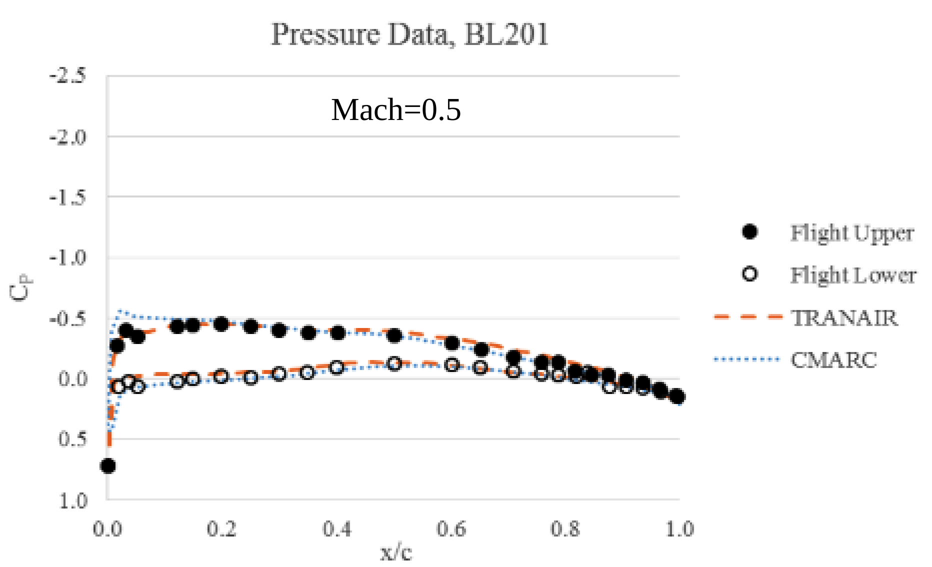



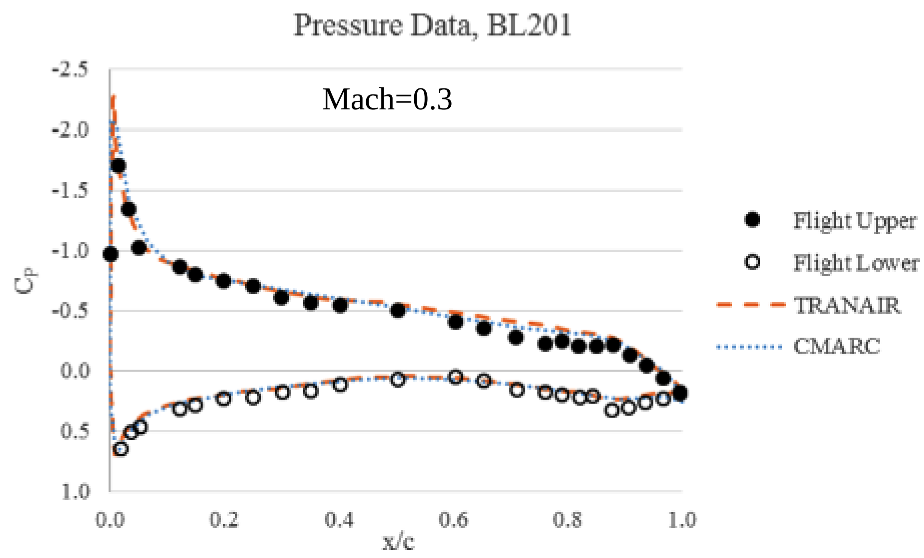
# Results, ACTE 0º @ 10,000 ft.

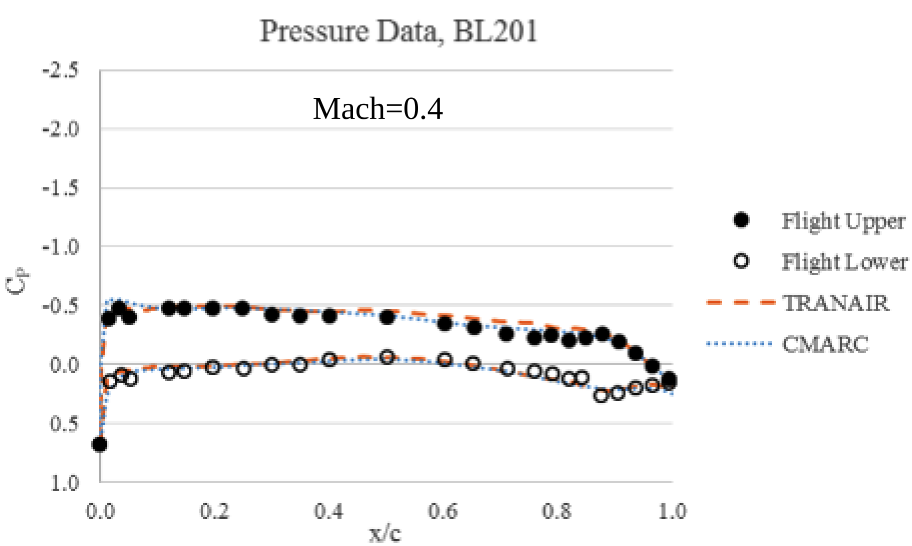


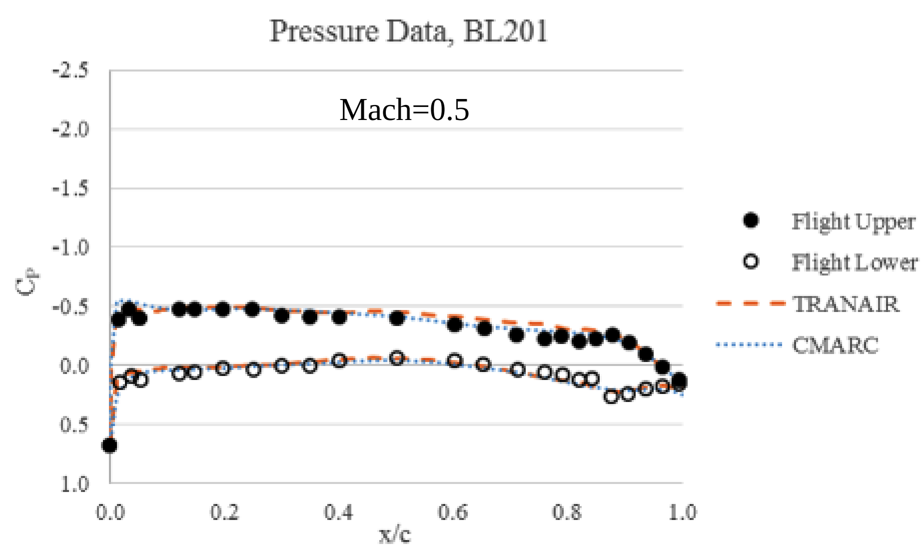



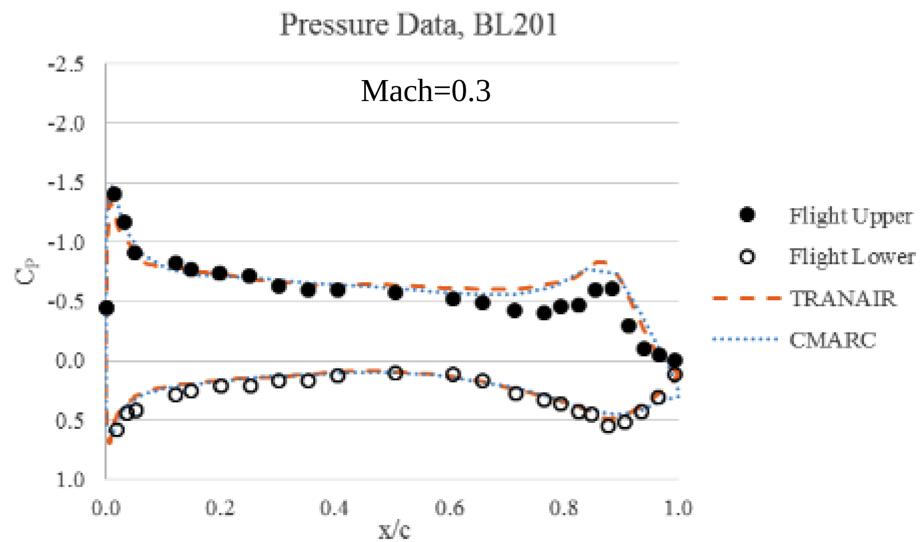
# Results, ACTE 5º @ 10,000 ft.

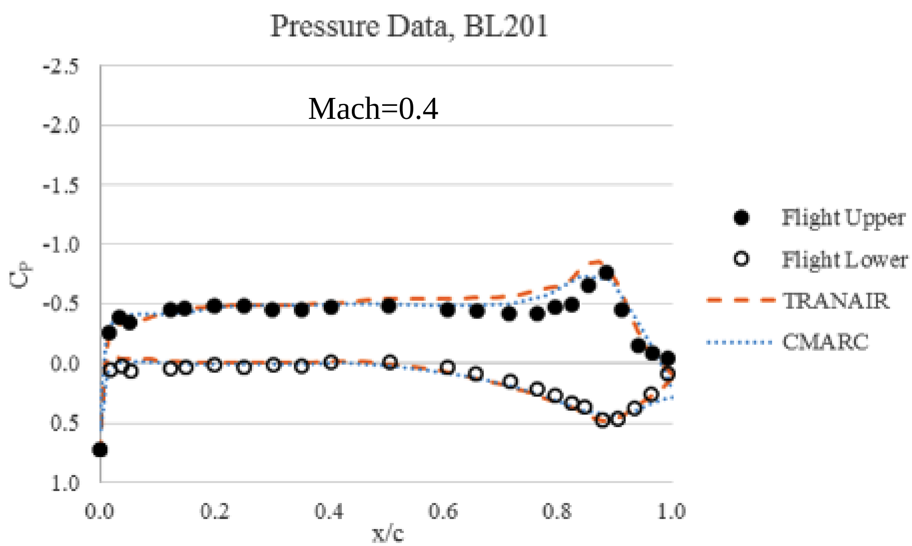


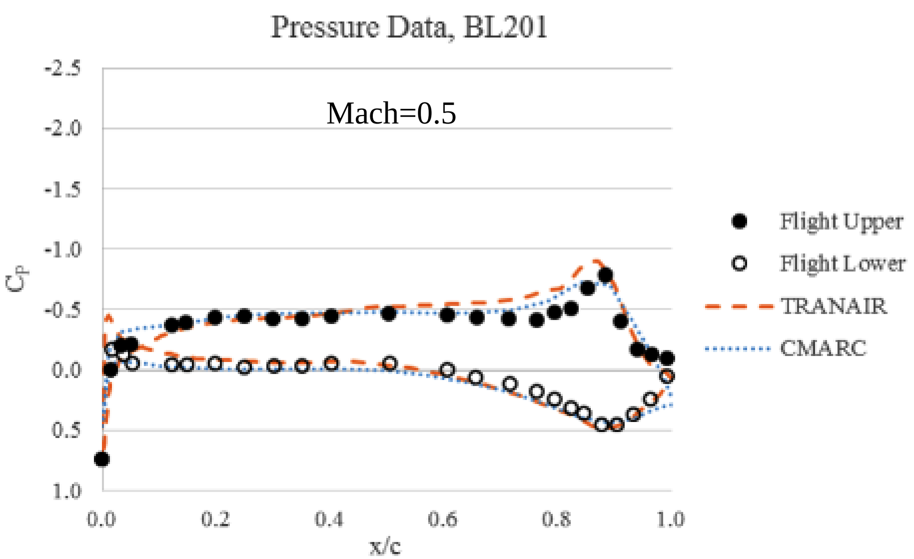



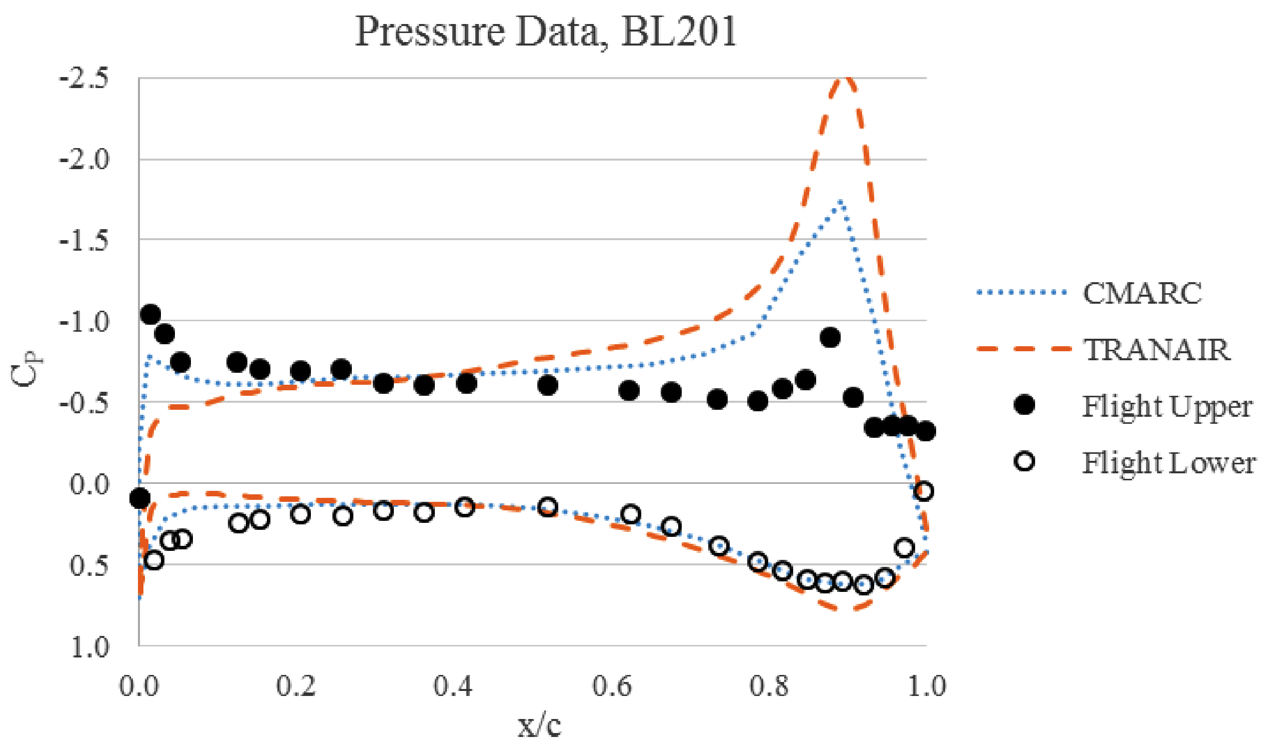
# Results, ACTE 15º @ 10,000 ft.



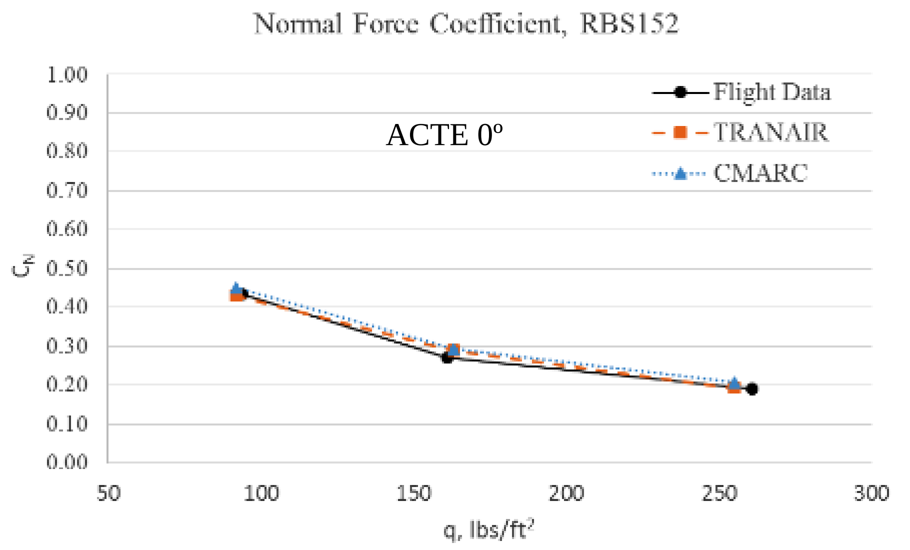



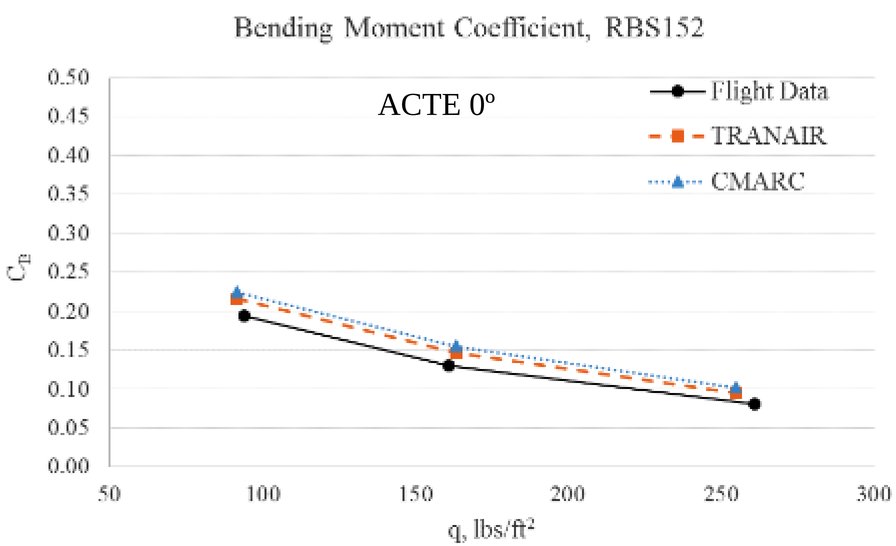
# Results, ACTE 30º, Mach=0.3 @ 10,000 ft.



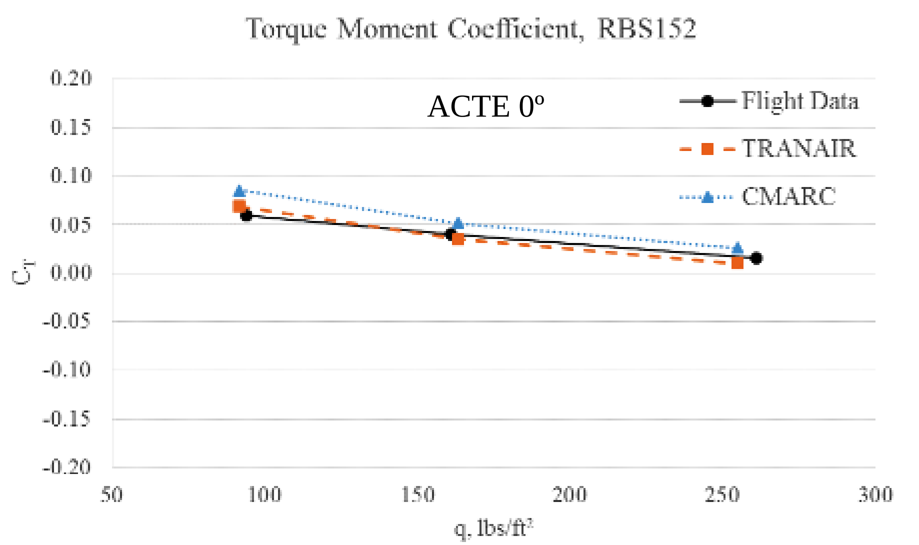
# Results



Normal Force Coefficient, RBS152
ACTE 0º
Flight Data
TRANAIR
CMARC
$C_N$
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
50
100
150
200
250
300
q, lbs/ft²

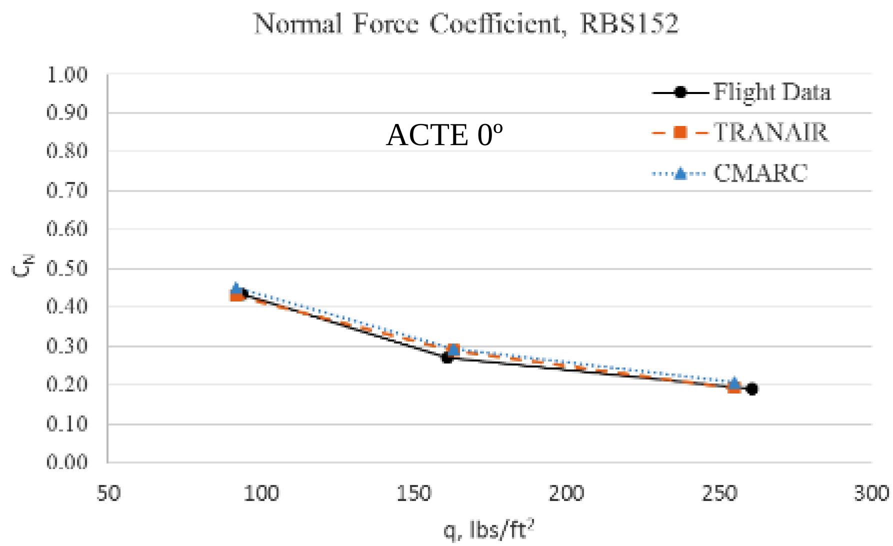



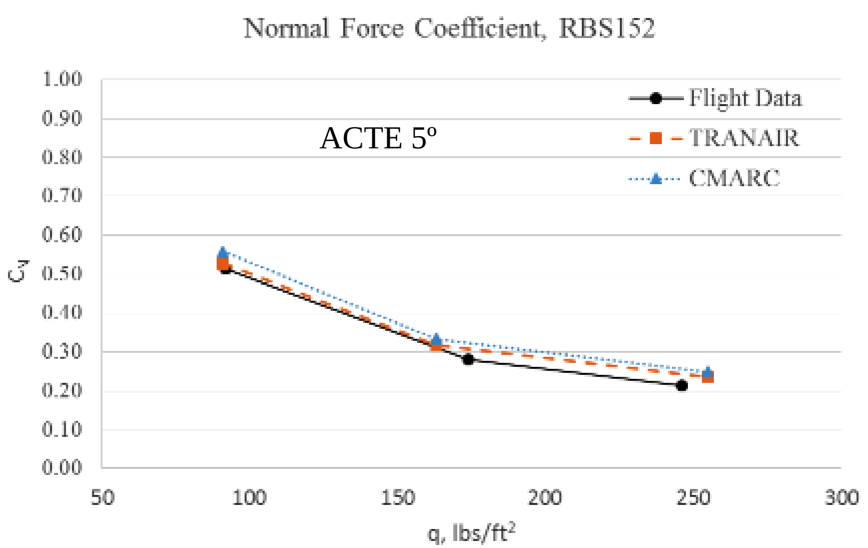
Bending Moment Coefficient, RBS152
ACTE 0º
Flight Data
TRANAIR
CMARC
$C_B$
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
50
100
150
200
250
300
q, lbs/ft²

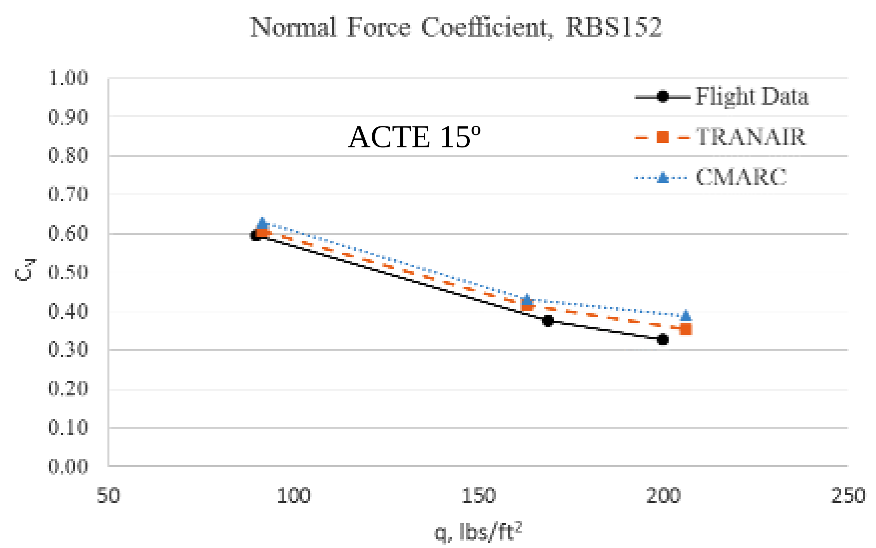



Torque Moment Coefficient, RBS152
ACTE 0º
Flight Data
TRANAIR
CMARC
$C_T$
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
50
100
150
200
250
300
q, lbs/ft²

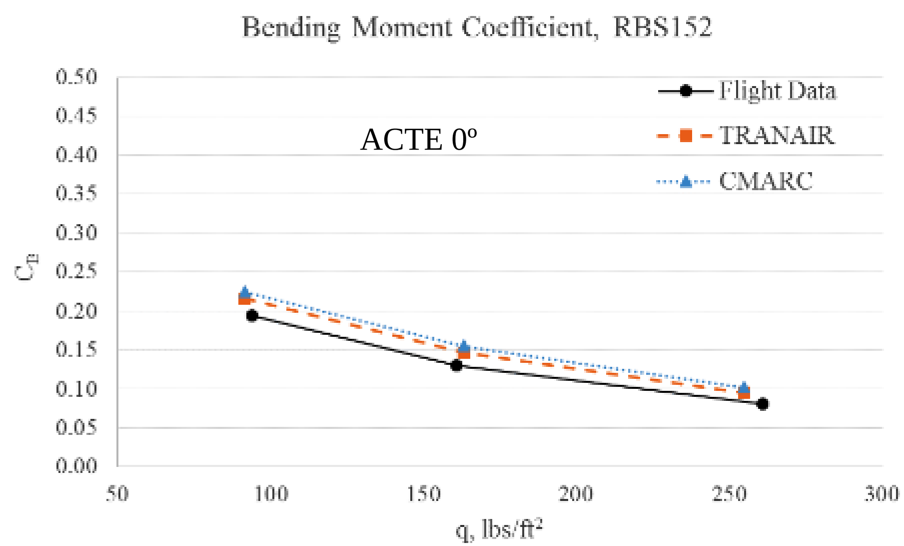
# Results, Normal Force Coefficient

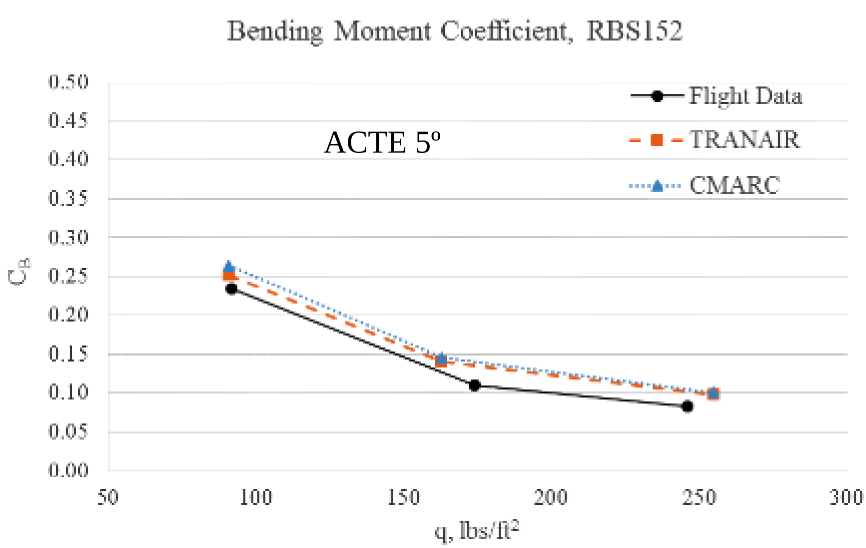


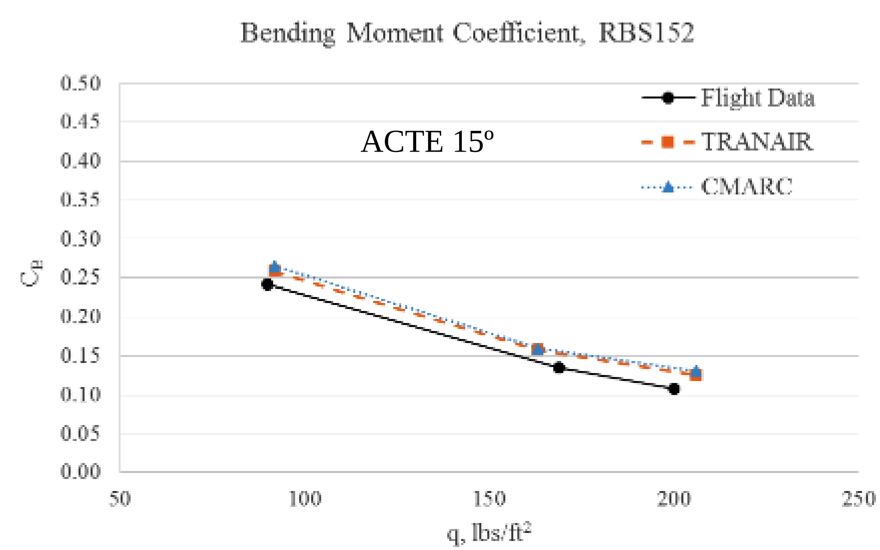



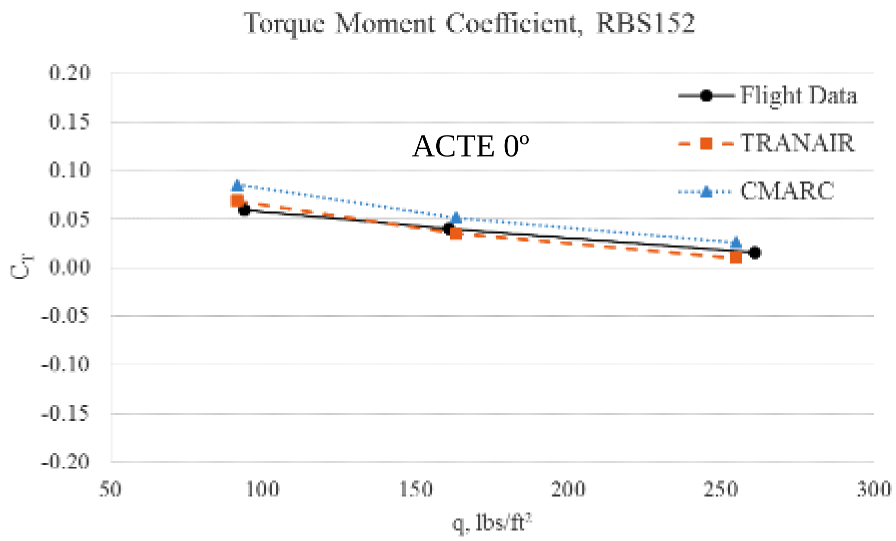
# Results, Bending Moment Coefficient

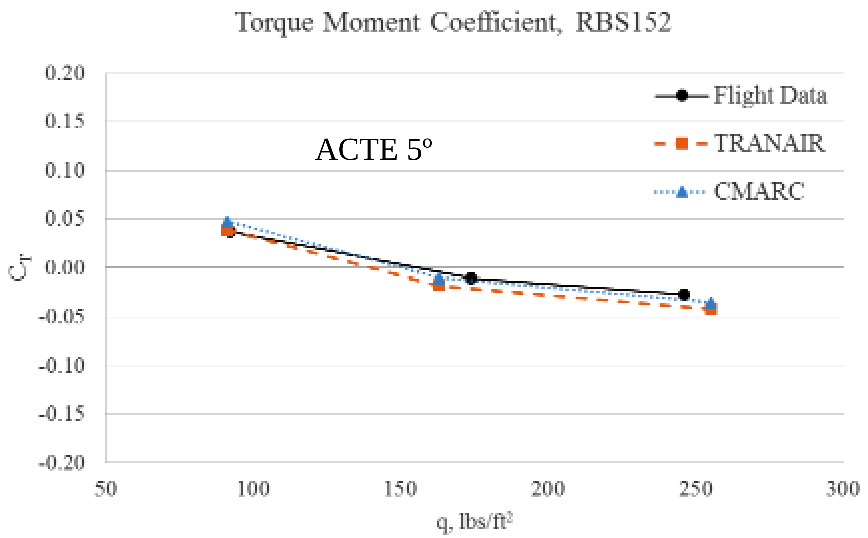


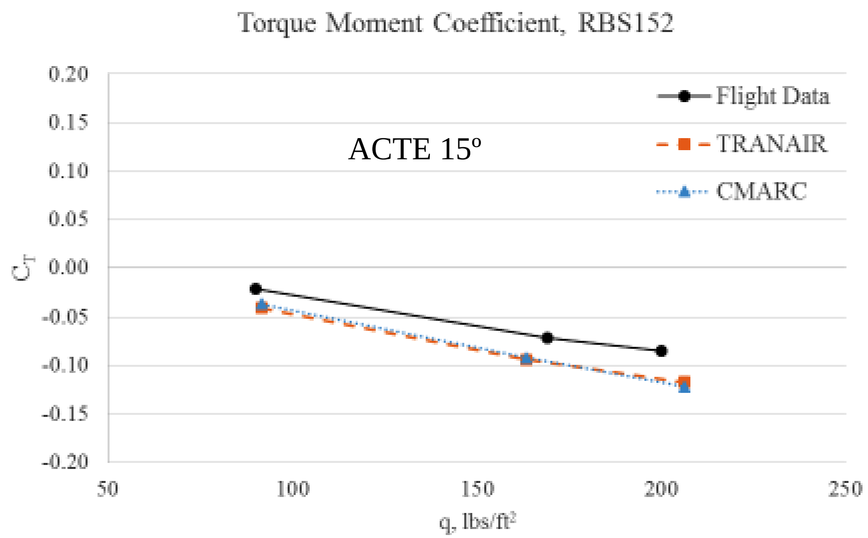



# Results, Torque Moment Coefficient



# Results, Wing Slope Coefficients, Mach=0.3 @ 10,000 ft.