Overview Test Case 2

- **CRM Wing-Body steady Coupled Aero-Structural Simulation**
- **Flow Conditions: $Ma_\infty = 0.85$; $Re_c = 5.0 \times 10^6$; $T_{static} = 100F/310.928K$**
- **MSC NASTRAN® Finite-Element Model supplied by NASA via CRM Website**
- **Compute static aero-elastic Deflections, starting from the undeformed Geometry**

- **Test Case 2a: Grid Convergence Study**
  - Grid Levels: L1 - L6 (four required, six desirable)
  - Flow Conditions: fixed $C_L = 0.5$ +/- 0.0001

- **Test Case 2b: Angle-of-Attack Sweep**
  - Grid Level: L3 or L4
  - Flow Conditions: α = [-1.50°, 2.50°, 2.75°, 3.00°, 3.25°, 3.50°, 3.75°, 4.00°, 4.25°]
    $C_L = 0.5$ +/- 0.0001

Overview Test Case 2

Data submitted by 6 Teams (3 DPW-6, 3 DPW-8)

- **CFD Grid Type:**
  - **unstructured (5)**
  - **overset (1)**
- **CFD Flow Solver:**
  - **Finite Volume (3)**
  - **Finite Differences (1)**
  - **Stabilized Finite-Element (2)**
- **Structural Model:**
  - **3D Volume Element Model (5)**
  - **equivalent Beam Model (1)**
- **Structural Solver:**
  - **linear static Analysis (4)**
  - **linear modal Analysis (2)**
- **Interpolation Method CFD ⇨ CSM:**
  - **nearest-Neighbor (3)**
- **Mesh Deformation Algorithm:**
  - **Radial Basis Functions (2)**
  - **Torsional Spring Analogy (1)**

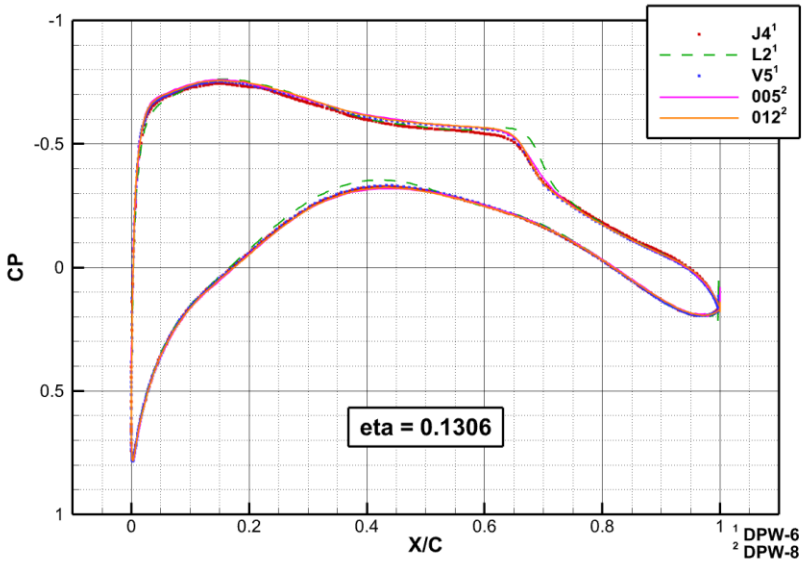
DPW6 only need Data from DPW8 Teams

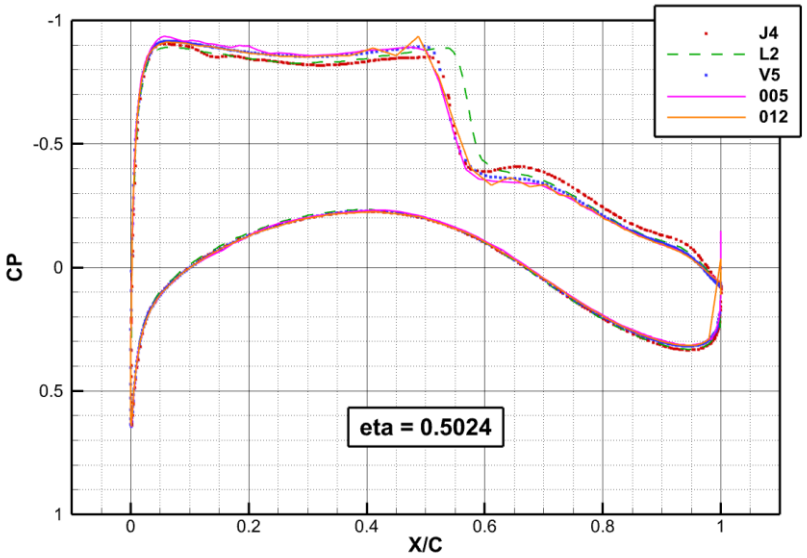
Test Case 2a (E)

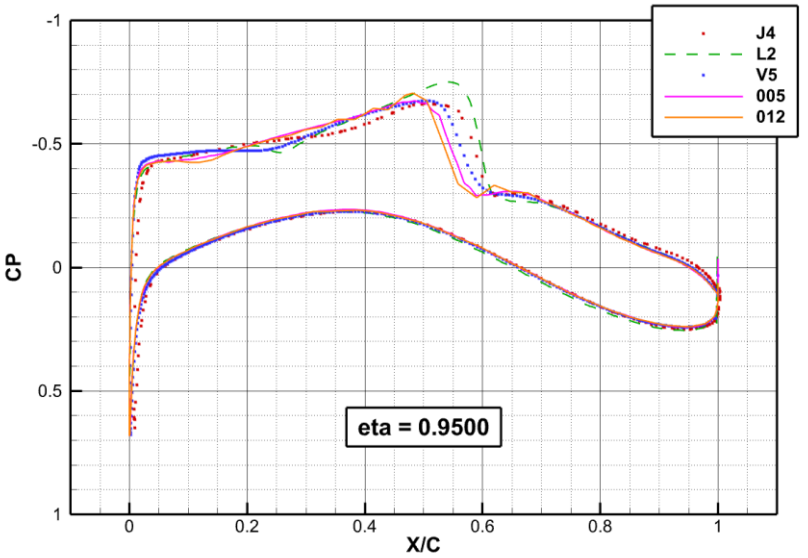
- Static Pressure Distributions -

Flow Conditions:

- Ma = 0.85
- Re = 5.0×10^6
- C_L = 0.50 +/- 0.0001
- q_∞ = 1384 lb/sq.ft





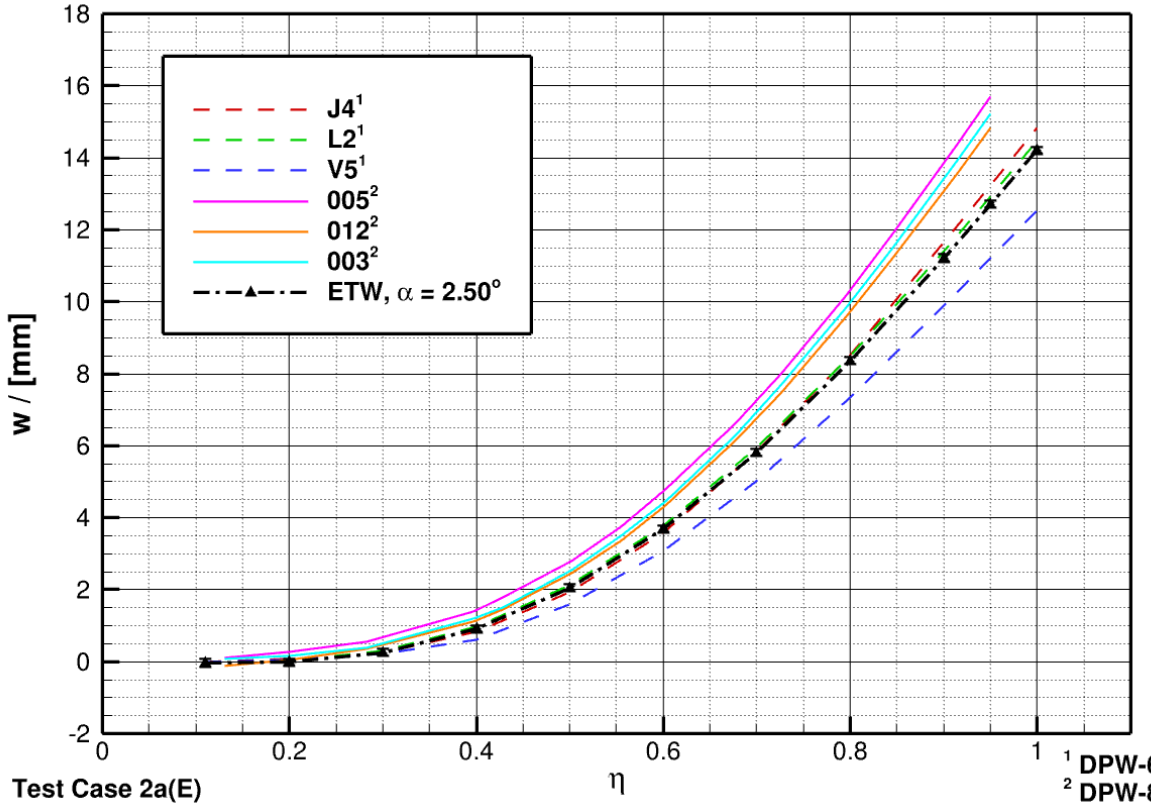


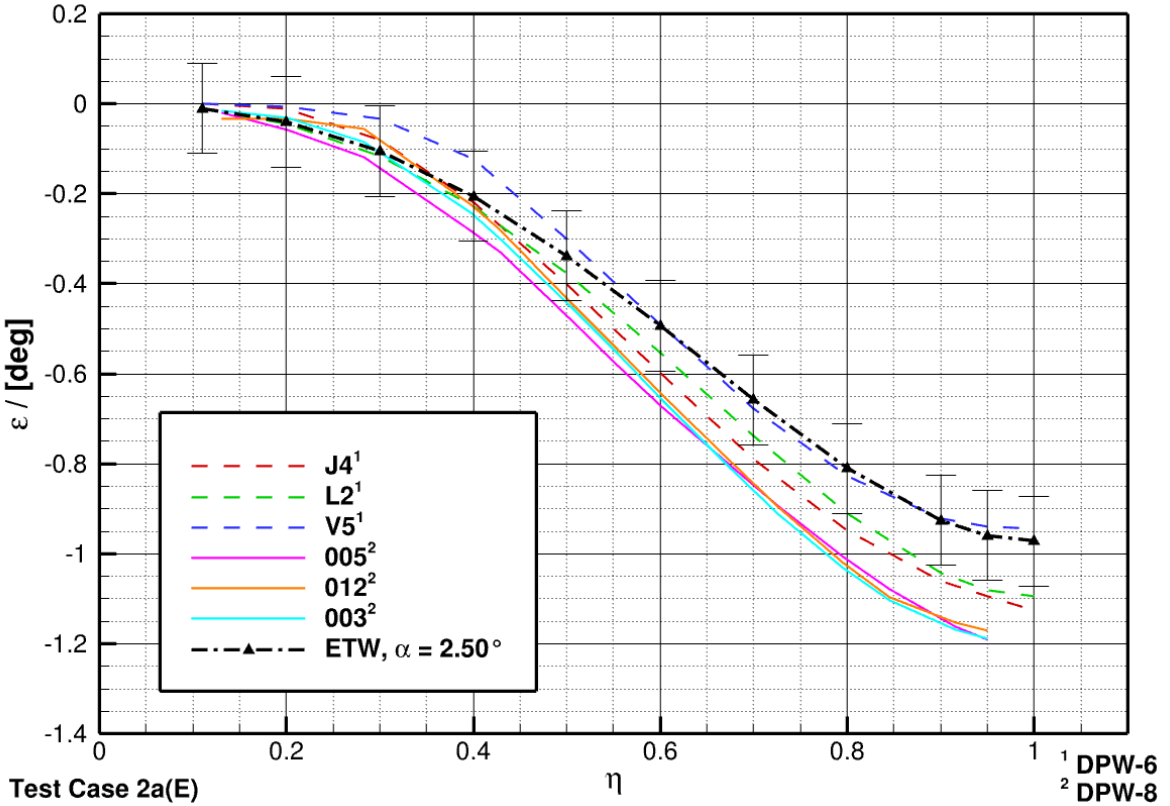
- Pressure Distributions match reasonably well on inboard Wing (no Deformation)
- Some Variation in Shock Location on outboard Wing, probably caused by Variations in Twist (⇨ next Slide)
- Only one Outlier

Reasonable to include DPW-6 Data in Analysis

Test Case 2a (E)
- Wing Deformation -

Flow Conditions:
- Ma = 0.85
- Re = 5.0×10^6
- C_L = 0.50 +/- 0.0001
- q_∞ = 1384 lb/sq.ft



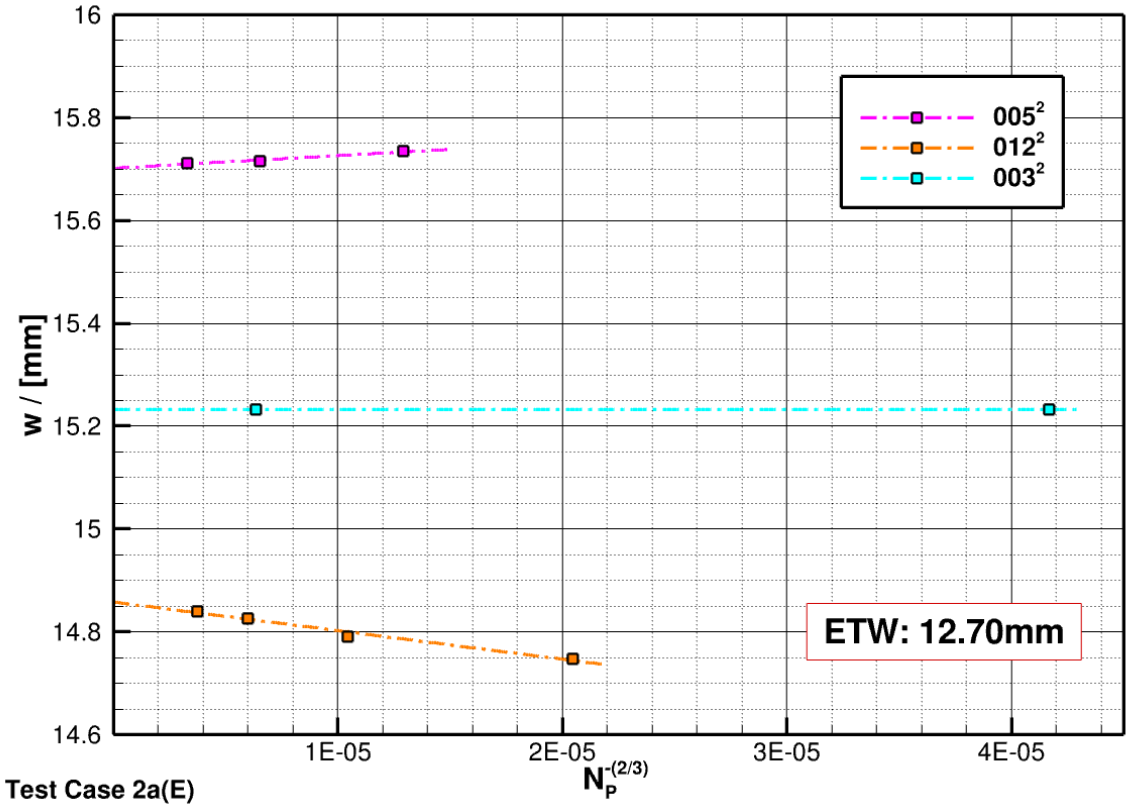


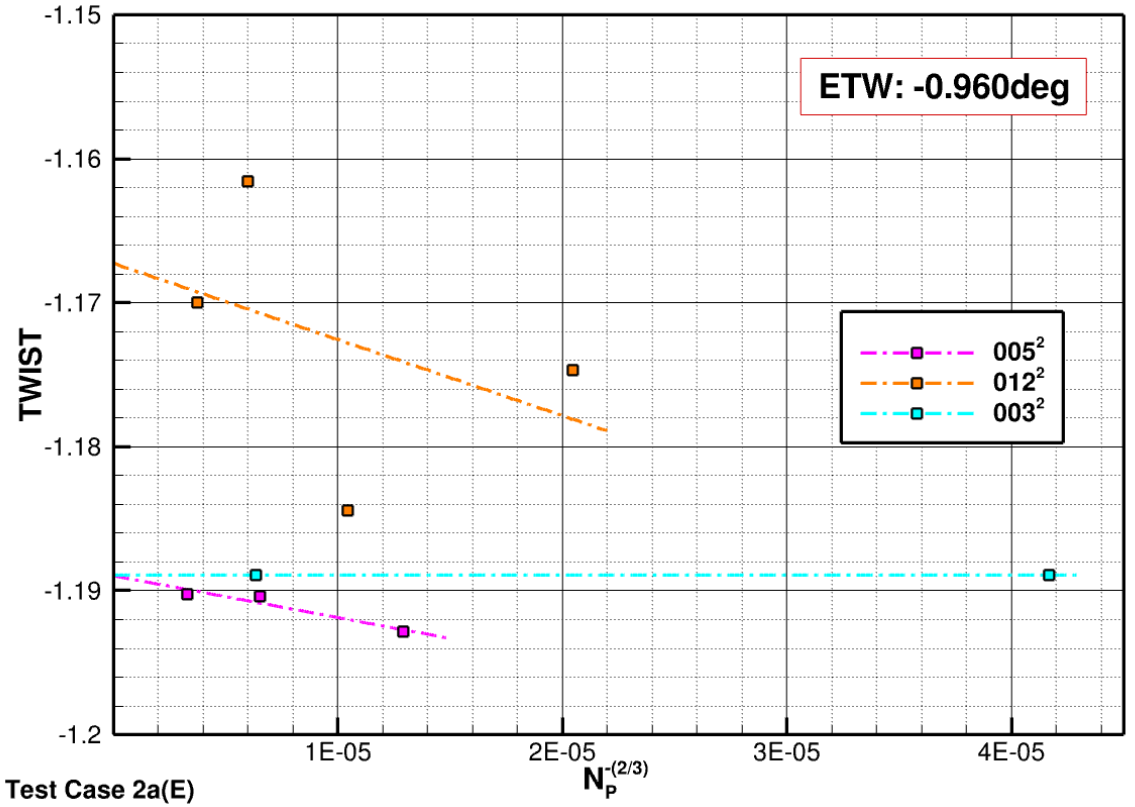
- Relatively large Deviations for DPW-8 Datasets (16-24%)
- ETW Measurement Accuracy: +/-0.1mm (+/-0.004in)

- Twist Deviation @ η = 0.95: $\Delta\varepsilon \approx$ 0.15-0.25deg
- ETW Measurement Accuracy: +/-0.1deg

Test Case 2a (E)
- Wing Deformation -

Flow Conditions:
- Ma = 0.85
- Re = 5.0×10^6
- C_L = 0.50 +/- 0.0001
- q_∞ = 1384 lb/sq.ft





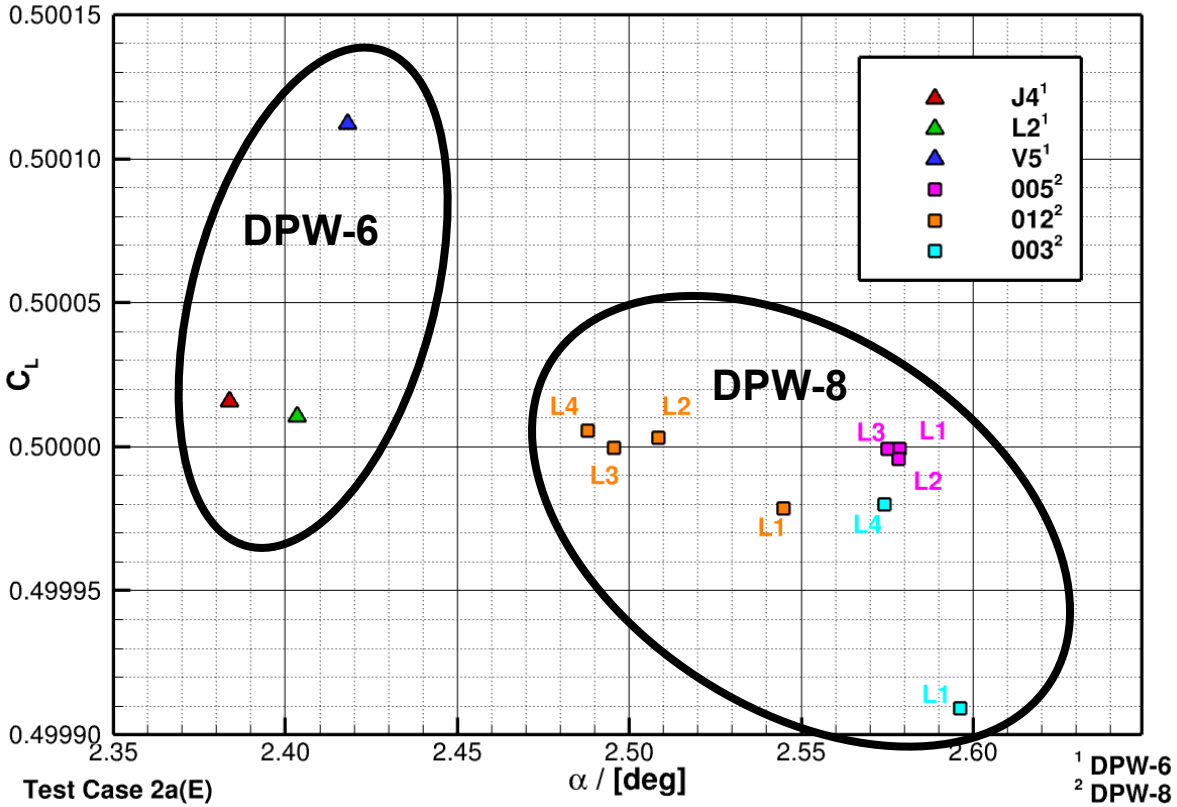
- **good Grid Convergence w.r.t. Wing Deformations**

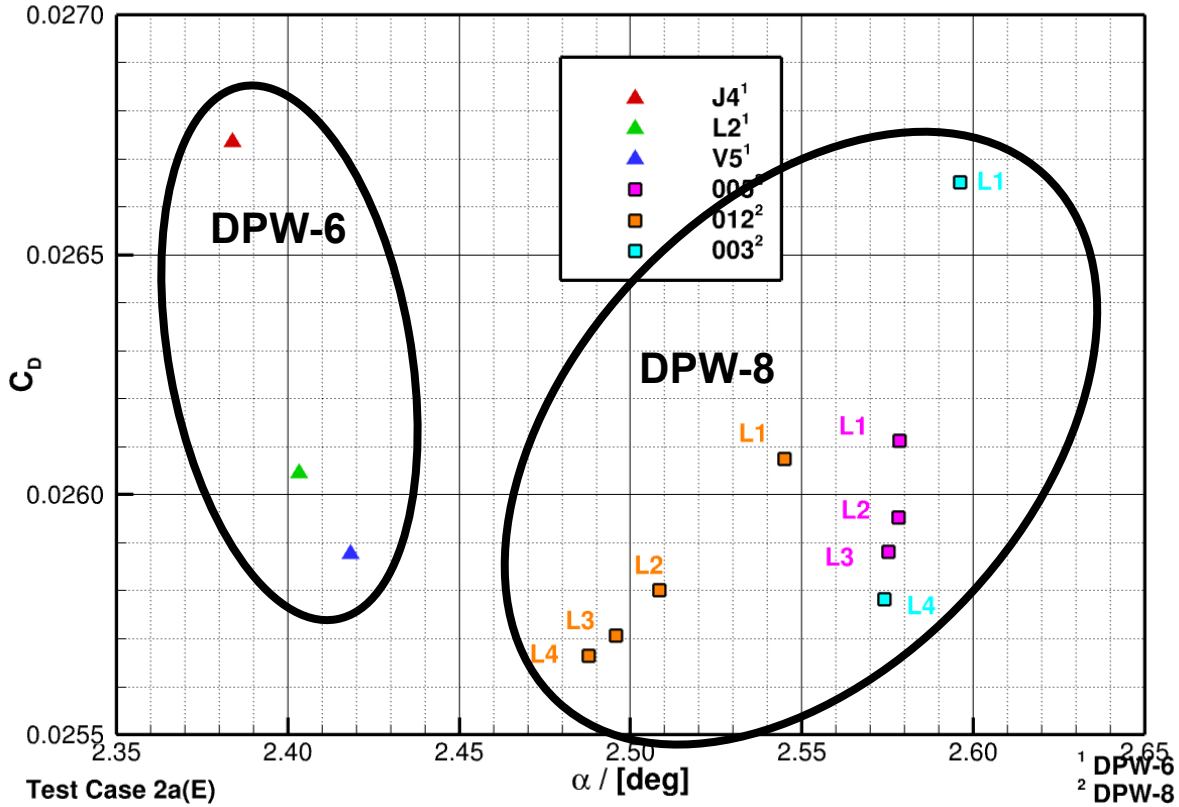
Test Case 2a (E)

- Aerodynamic Coefficients -

Flow Conditions:

- Ma = 0.85
- Re = 5.0×10^6
- C_L = 0.50 +/- 0.0001
- q_∞ = 1384 lb/sq.ft



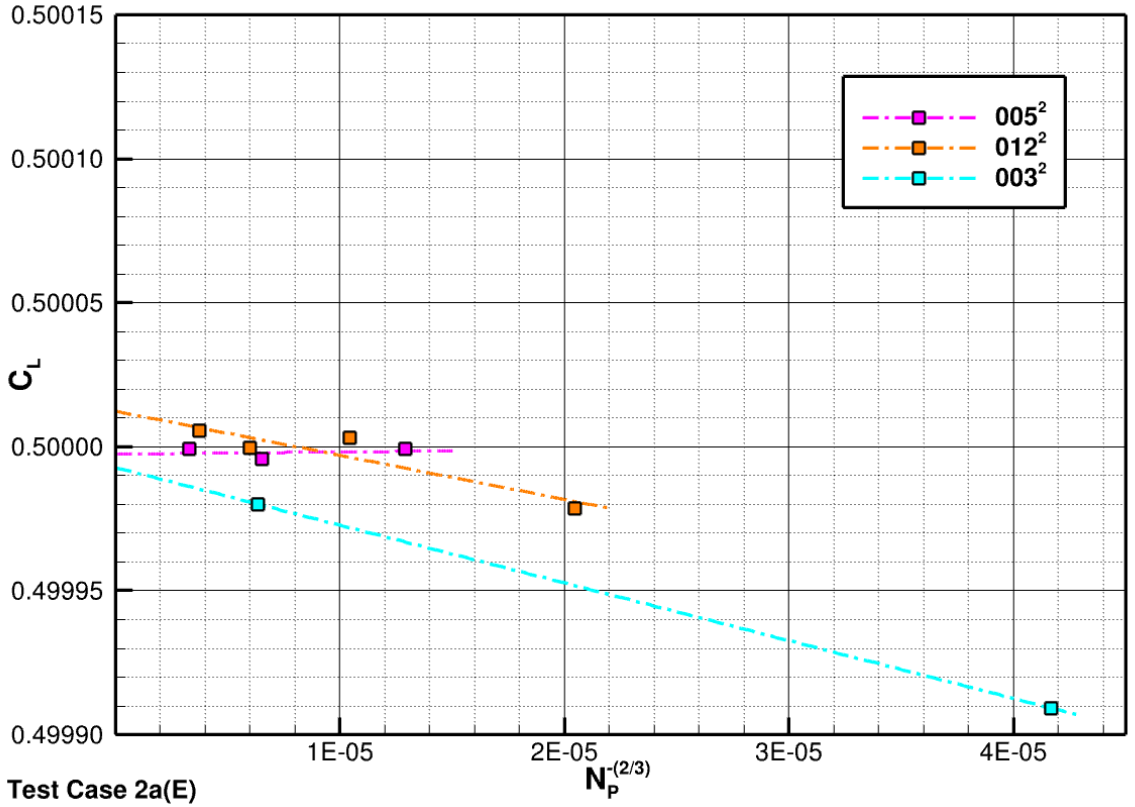


Test Case 2a (E)

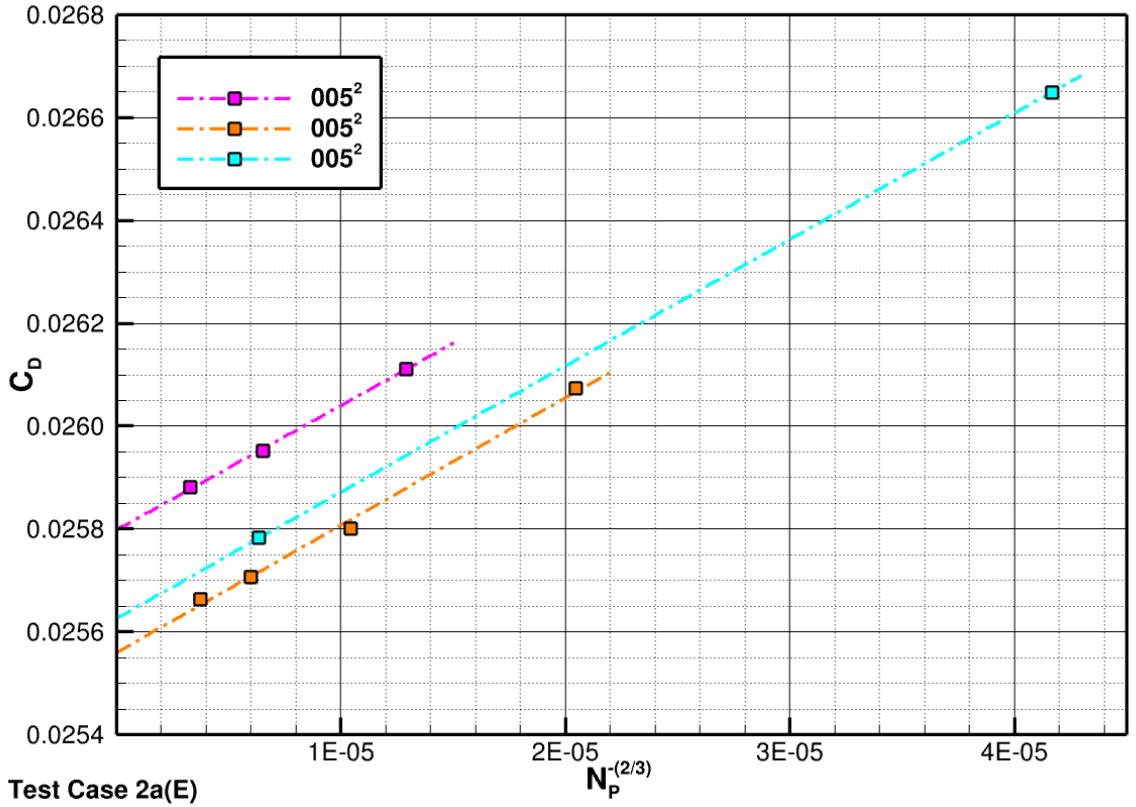
- Aerodynamic Coefficients -

Flow Conditions:

- Ma = 0.85
- Re = 5.0×10^6
- C_L = 0.50 +/- 0.0001
- q_∞ = 1384 lb/sq.ft



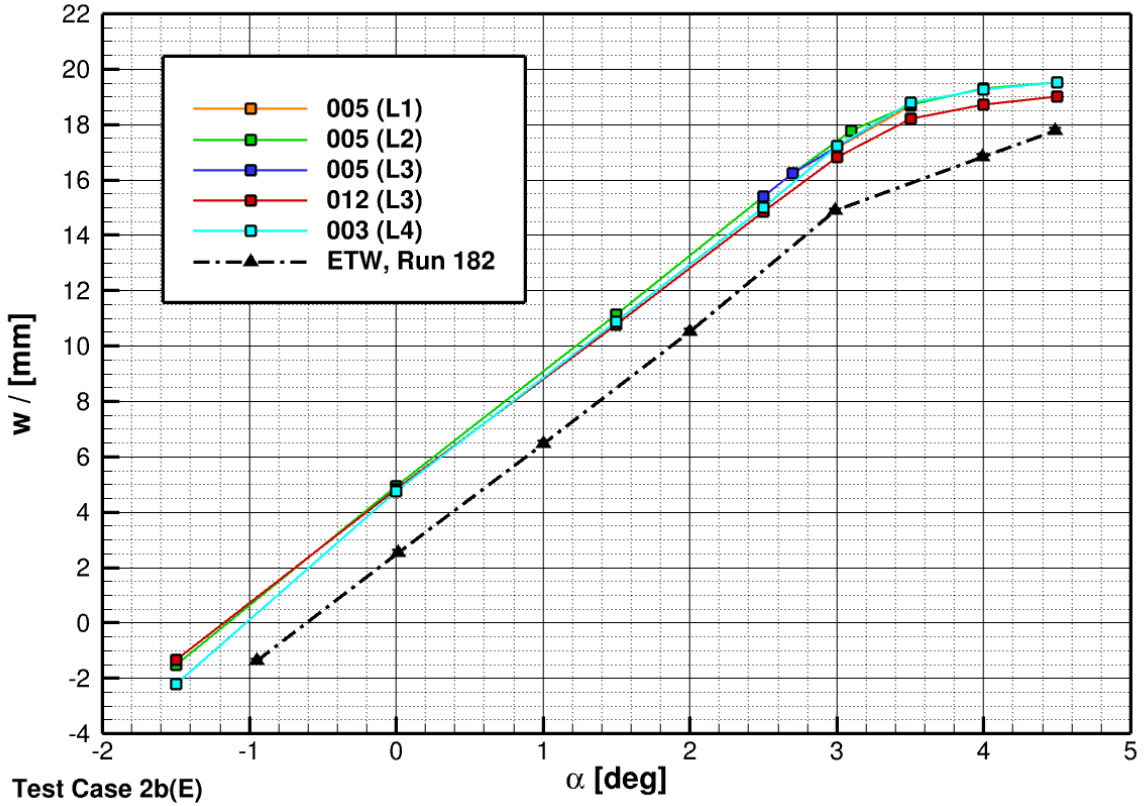
- good Grid Convergence for Lift



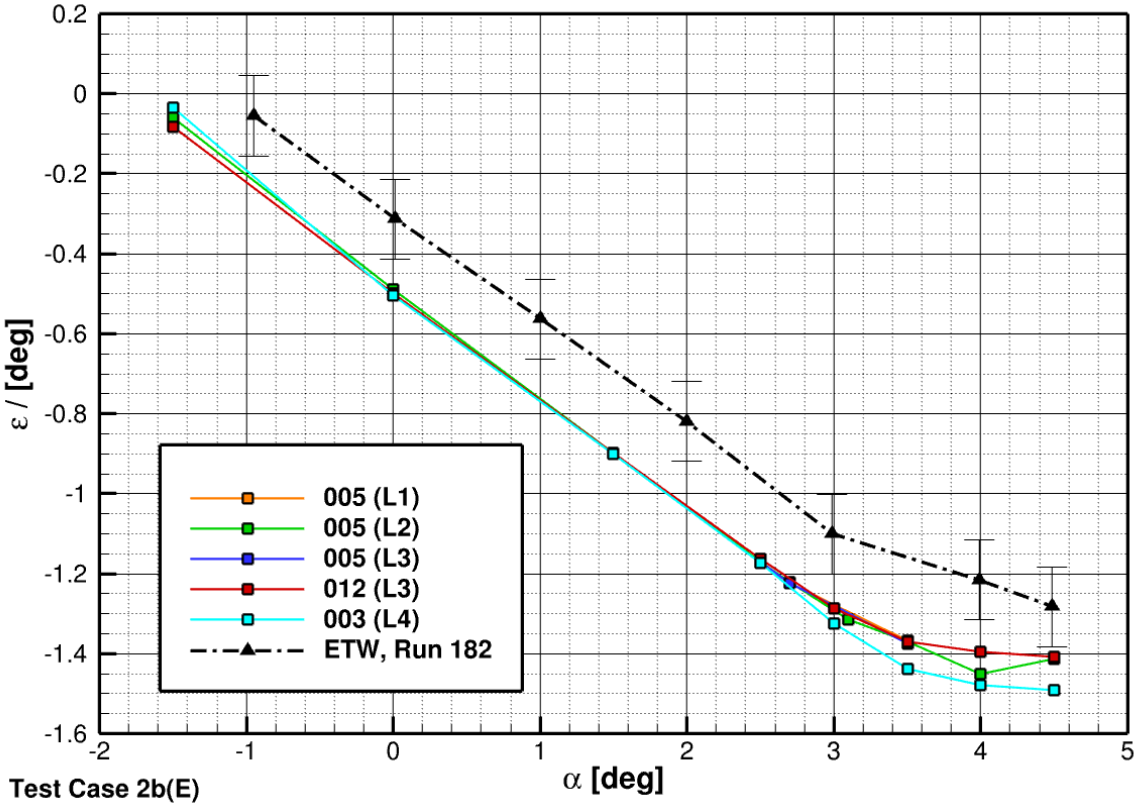
- minor Gradient in Drag Convergence

Test Case 2b (E)
- Wing Deformation -

Flow Conditions:
- Ma = 0.85
- Re = 5.0 x 10^6
- α = [-1.50, ..., 4.25]°
- q_∞ = 1384 lb/sq.ft



- approximately constant Offset due to Sting Effect



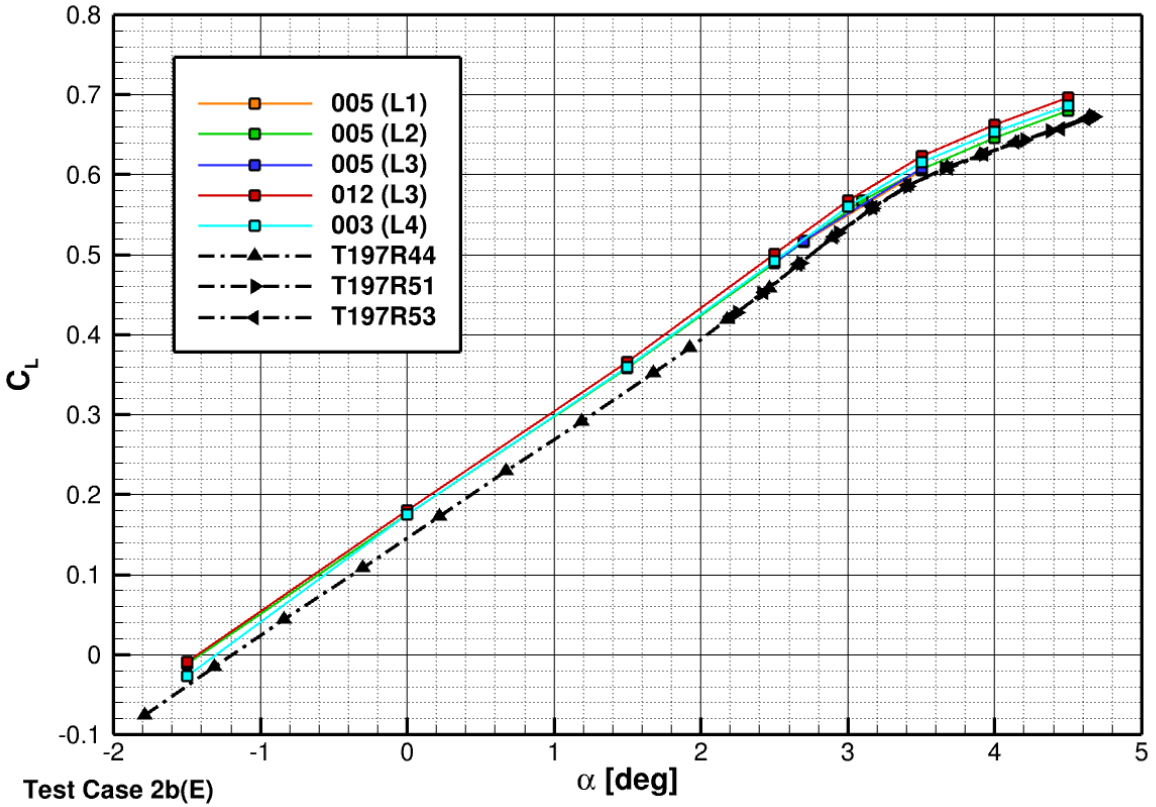
- almost constant Offset $\Delta\varepsilon \approx$ 0.16-0.18deg

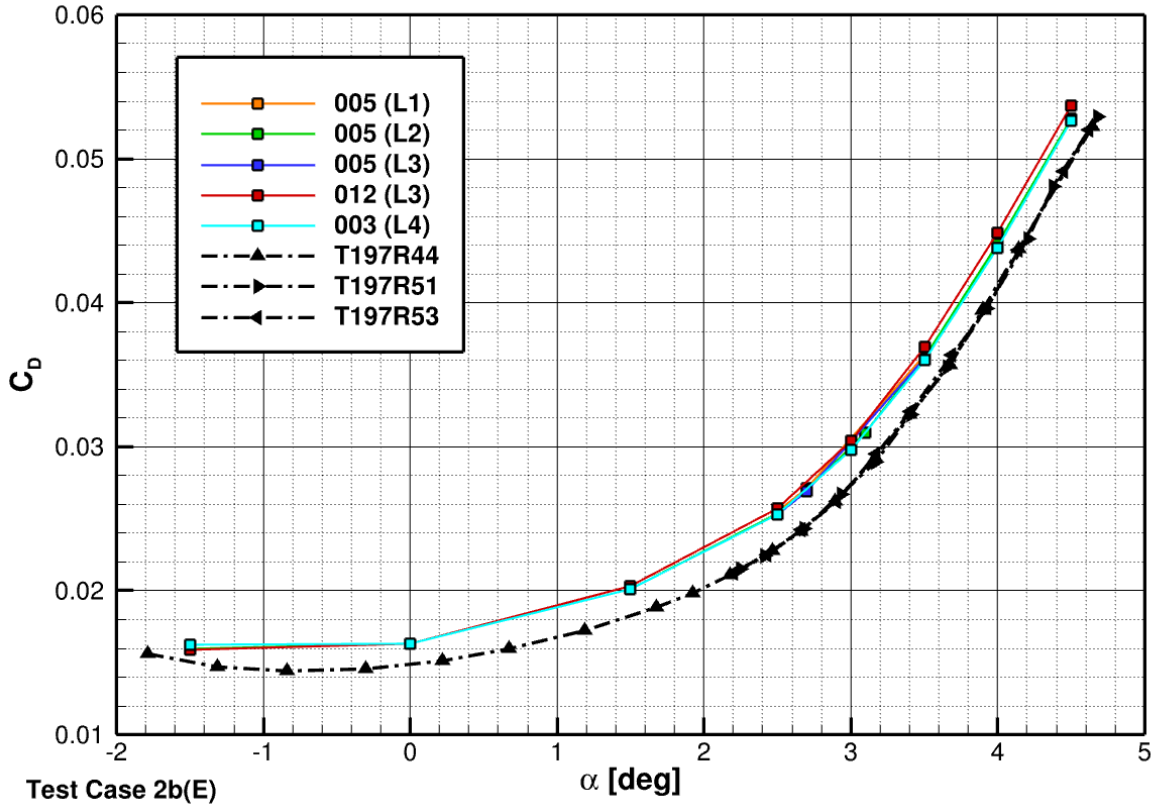
Test Case 2b (E)

- Aerodynamic Coefficients -

Flow Conditions:

- Ma = 0.85
- Re = 5.0 x 10^6
- α = [-1.50, ..., 4.25]°
- q_∞ = 1384 lb/sq.ft





- constant Offset possibly due to missing Tail Sting in CFD (⇨ Slide No. 6 from Ed's Presentation)

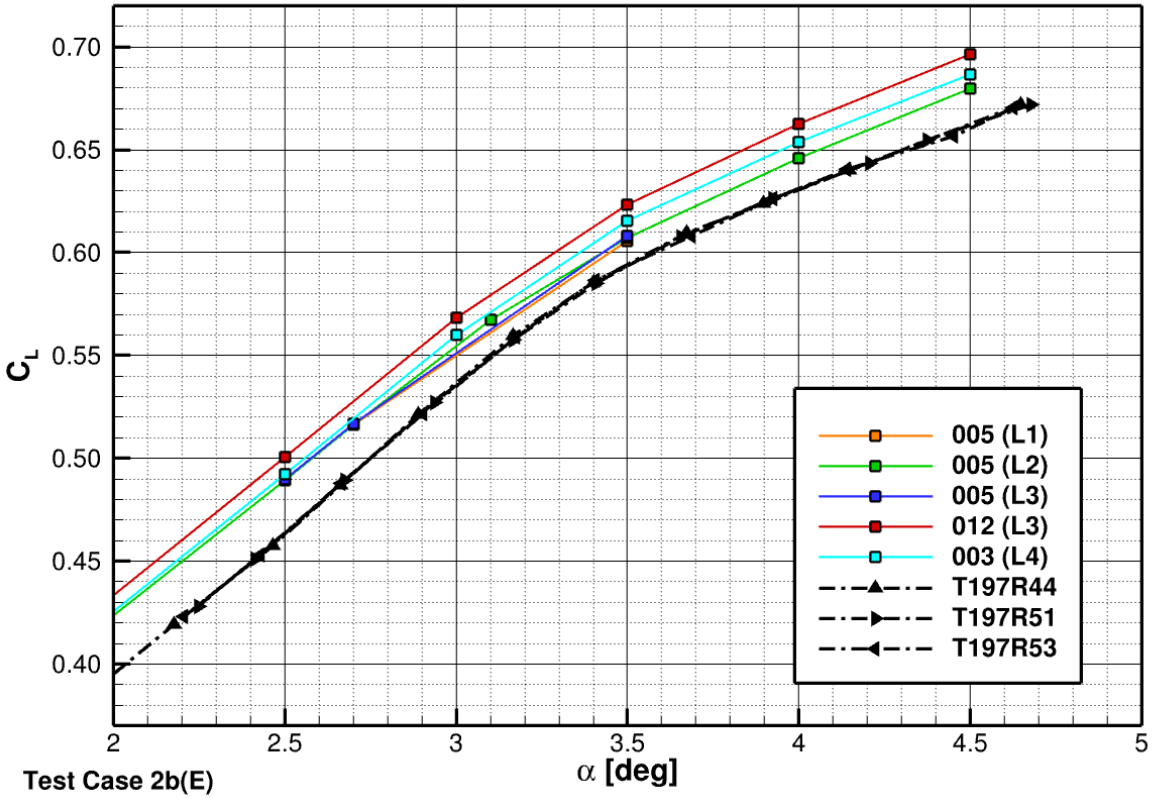
- good Agreement between Participants
- Offset to measured Data partially caused by fully turbulent RANS Computations

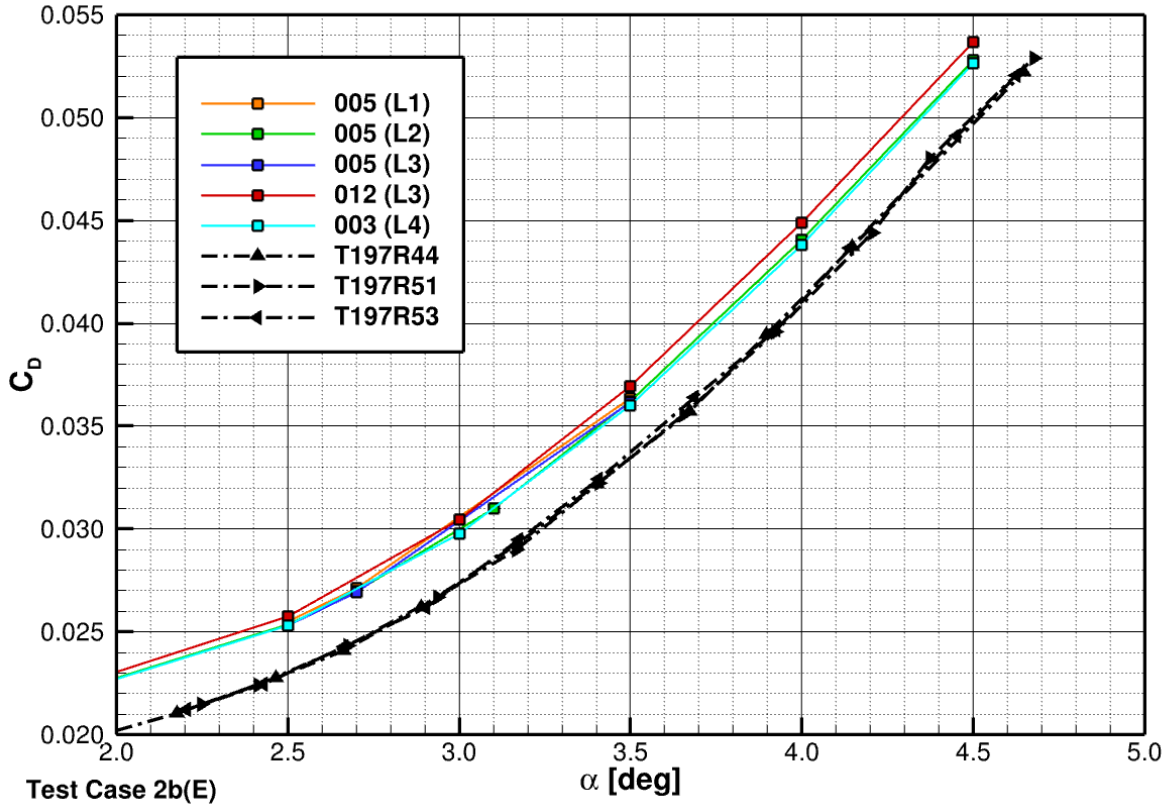
Test Case 2b (E)

- Aerodynamic Coefficients -

Flow Conditions:

- Ma = 0.85
- Re = 5.0×10^6
- α = [-1.50, ..., 4.25]°
- q_∞ = 1384 lb/sq.ft





- nonlinear Region starting at $\alpha \approx 3.0$deg captured correctly in both Lift and Drag
- 005: very small Differences between Grids (~1 Lift Count, ~2 Drag Counts)

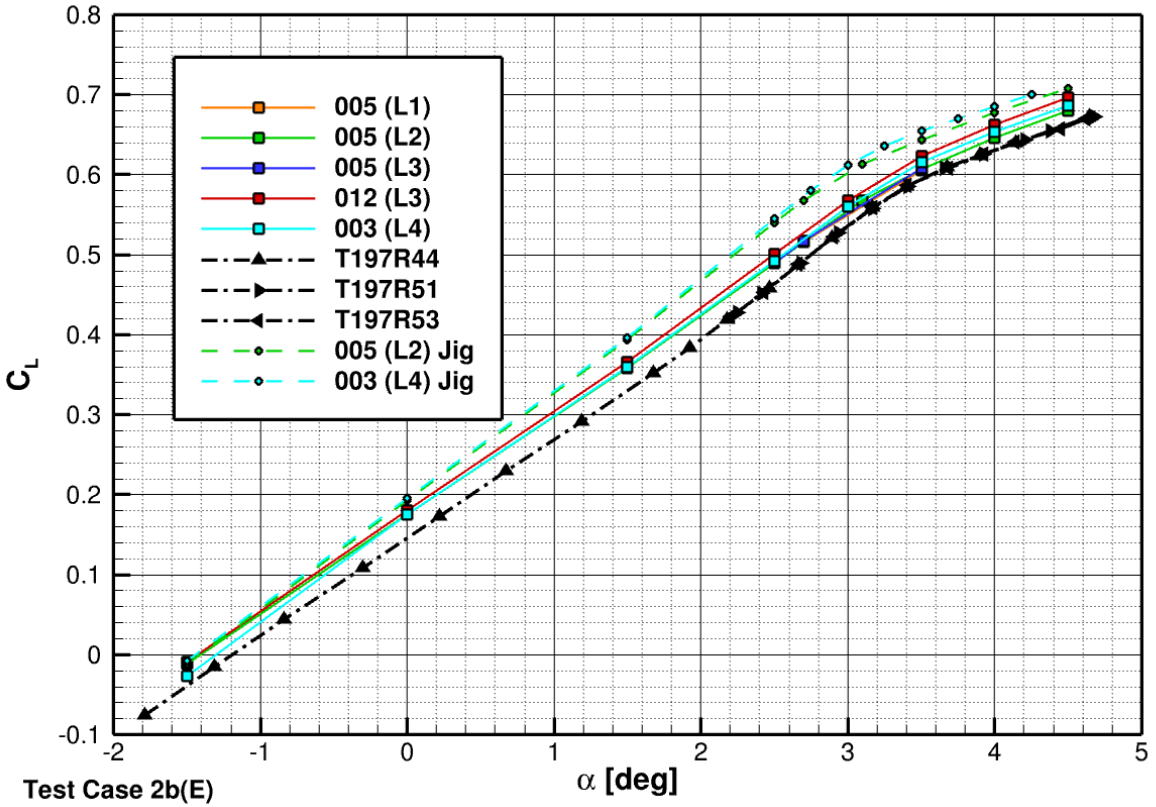
Conclusions

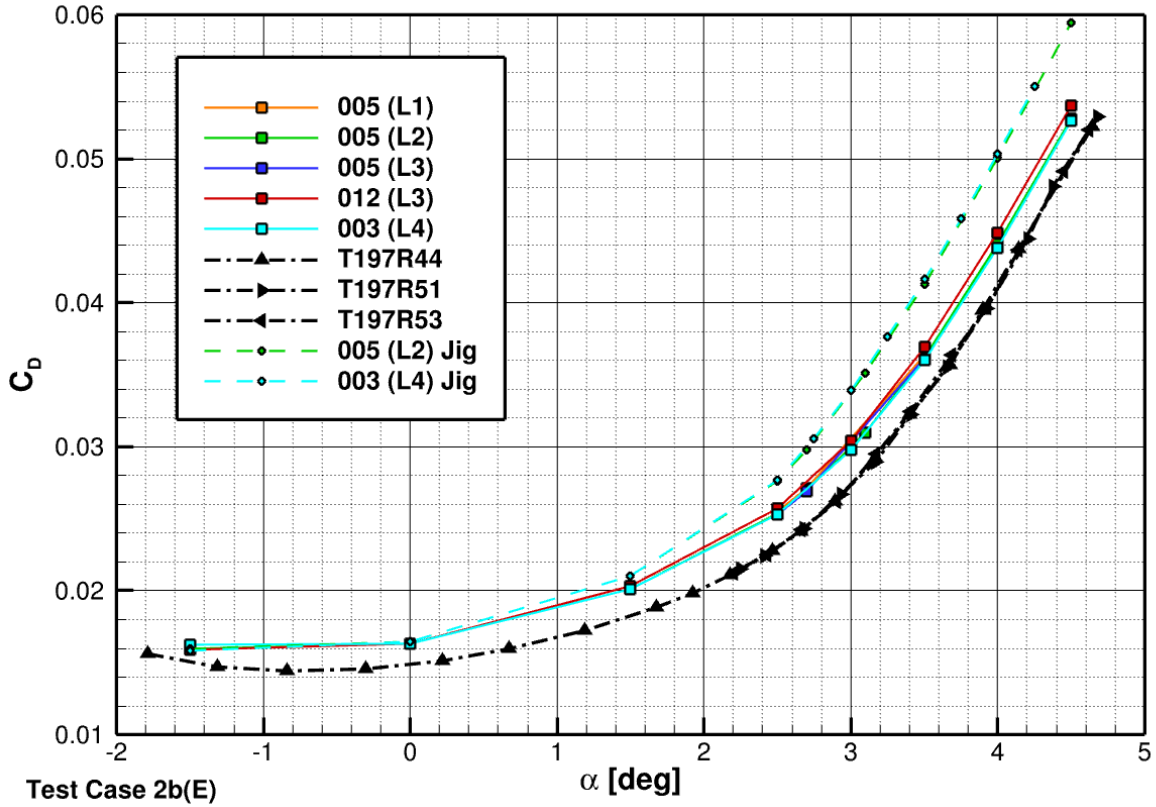
- Generally good Agreement between Teams and w.r.t. experimental Data
- DPW-6 Data included in Test Case 2a(E)
- Good Grid Convergence w.r.t. both Wing Deformations and aerodynamic Coefficients
- Minor Variations in Twist Distribution and chord-wise Shock Location, mainly on outboard Wing
- Lift overpredicted due to missing Sting in CFD Simulations
- Drag overpredicted due to fully turbulent RANS Computations
- Not enough Data for Statistics

Test Case 2b (E)
- Aerodynamic Coefficients -

Comparison to rigid jig geometry

Flow Conditions:
- Ma = 0.85
- Re = 5.0 x 10^6
- α = [-1.50, ..., 4.25]°
- q_∞ = 1384 lb/sq.ft

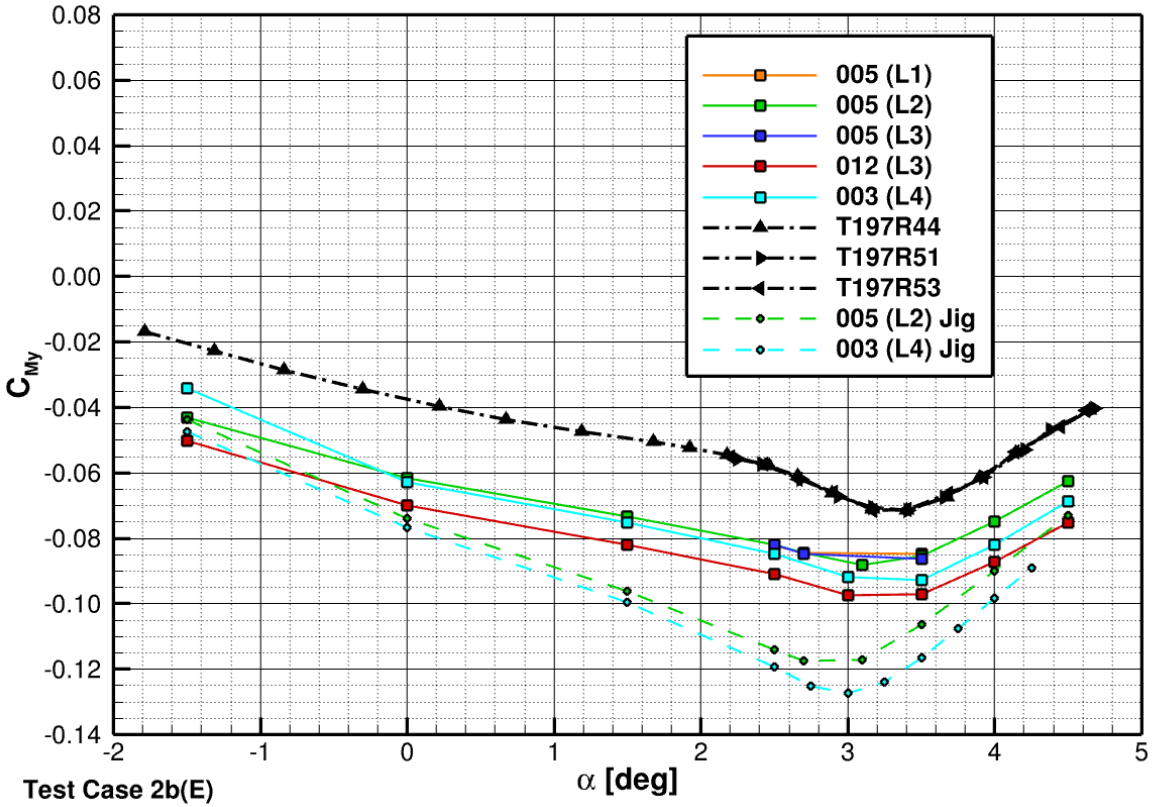


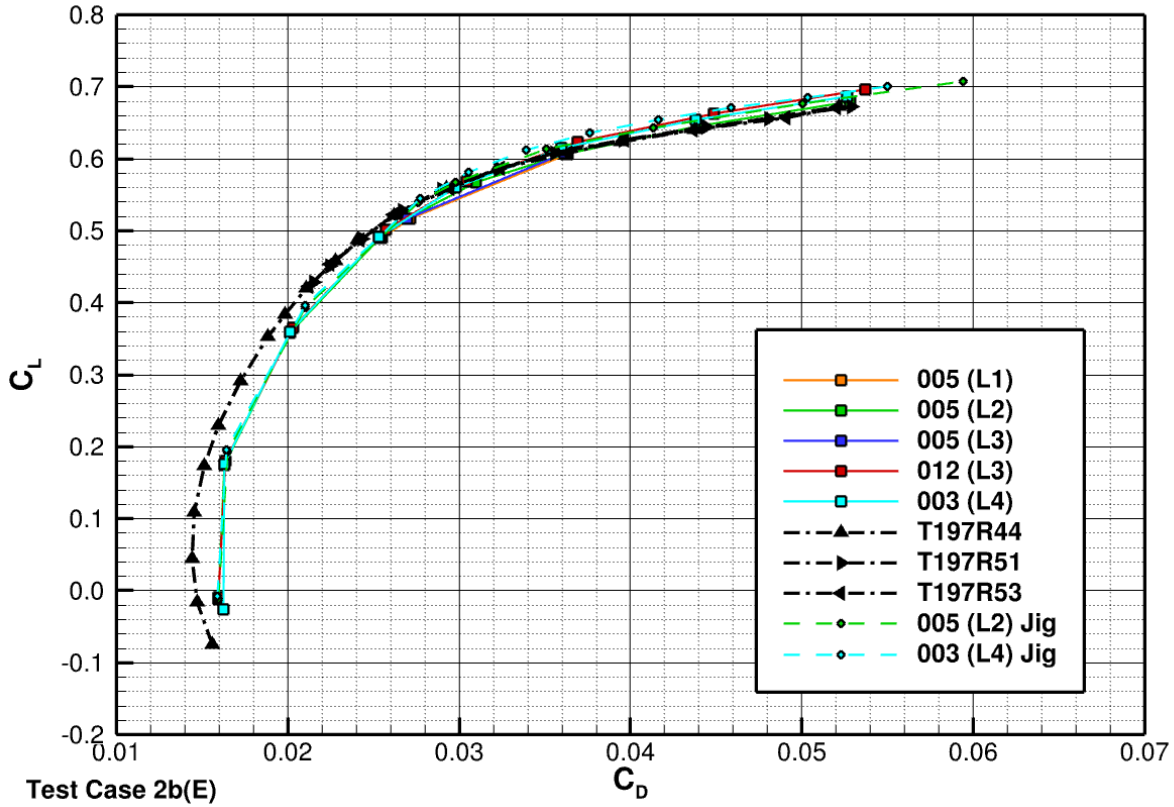


Test Case 2b (E)
- Aerodynamic Coefficients -

Comparison to rigid jig geometry

Flow Conditions:
- Ma = 0.85
- Re = 5.0 x 10^6
- α = [-1.50, ..., 4.25]°
- q_∞ = 1384 lb/sq.ft





Test Case 2b (E)
- Aerodynamic Coefficients -

Comparison to rigid jig geometry

Flow Conditions:
- Ma = 0.85
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- q_∞ = 1384 lb/sq.ft