Charles WMLES Buffet Predictions for CRM Configuration

DPW-8/AePW-4

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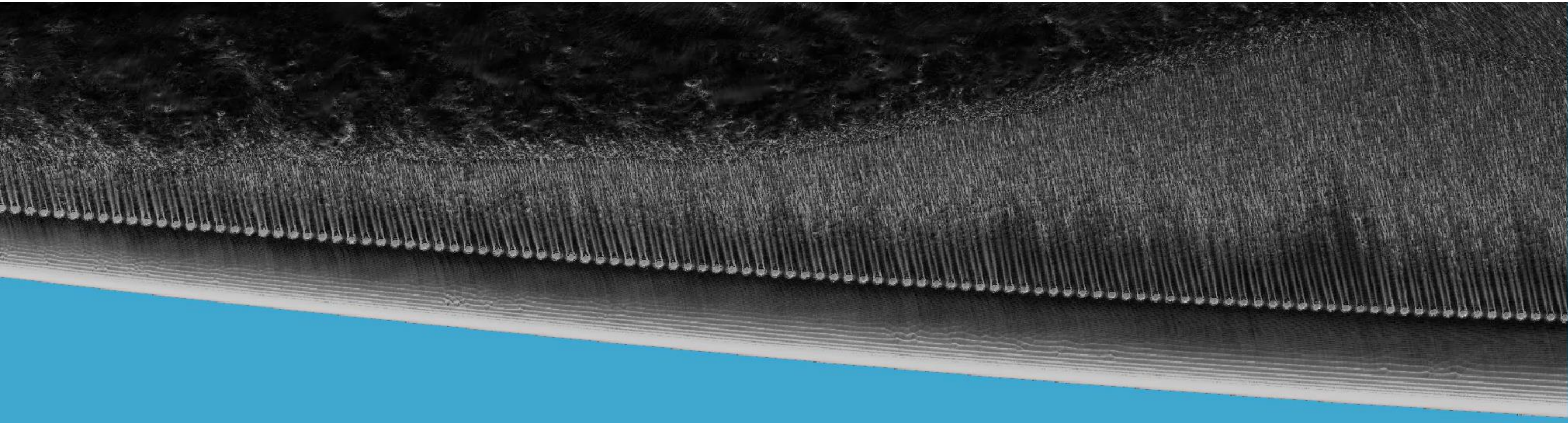
Prediction of Buffet on the 2.16% scale NASA CRM

Notes on the experimental setup

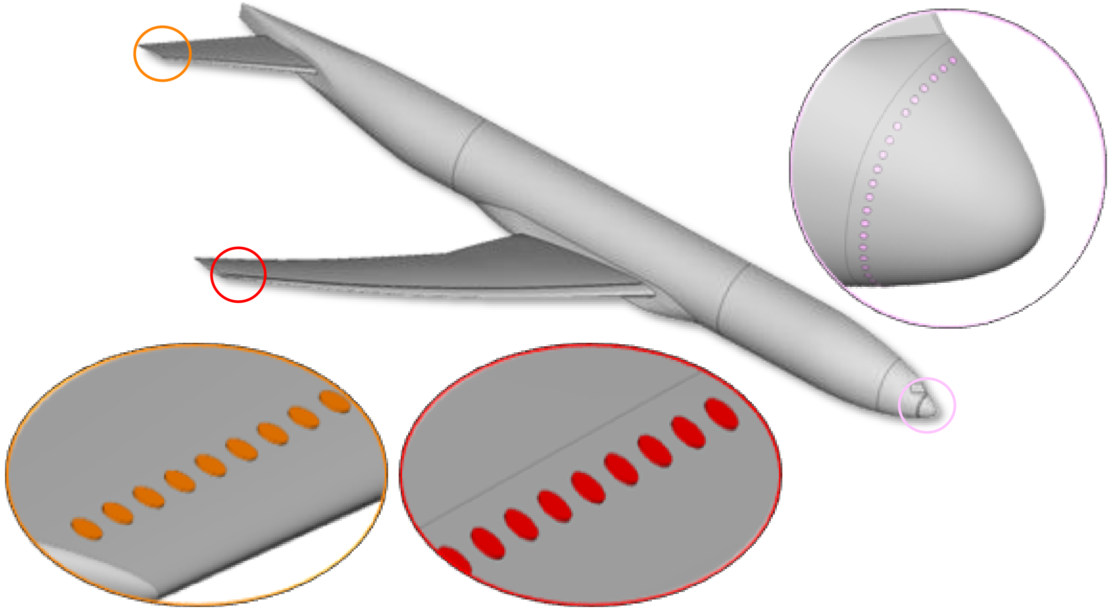
- Focus on DPW-8 Test Case 2
- Operation Conditions:
  - Re=1.5M, M=0.85
  - AoAs : 1.22, 2.29, 4.84, 5.89
    - Geometry is different for each AoA given the scanned model's deformation
- Uncertainty of setup from provided CAD:
  - Simulating as far-field (w/o 2 x 2m tunnel)
  - No sting

Methodology

- Compressible Flow Solver: **Fidelity Charles**
  - Low-dissipation numerics
  - 2nd order finite-volume method
  - Kinetic Energy and Entropy Preserving (KEEP)
  - Explicit RK time integration
  - GPU Accelerated
  - Wall Modeled:
    - Algebraic equilibrium wall model (EQWM)
    - 2nd Point matching EQWM (N2WM)
    - Sensor-based WM for transition (SBWM)
  - Subgrid-Scale Model:
    - Dynamic Smagorinsky model
  - Grid Generation: Stitch™
    - Custom grid generator for Fidelity Charles
    - Voronoi grids of hexagonal close-packed topology with near wall stranded meshes



Gridding Approach



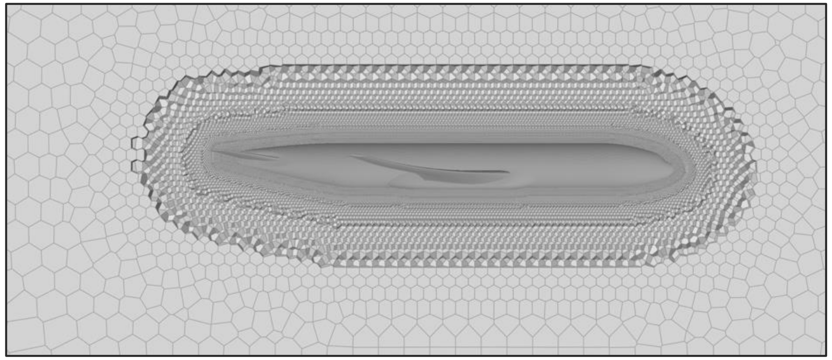
Trip	Aeronautical trip dot (CAD Cut)
Diameter [mm]	1.27
Distance (between dot centers) [mm]	2.54
Height (main wing) [mm]	0.11430 (inner-wing) 0.09906 (mid-wing) 0.08890 (outer-wing)
Location (main wing)	10% chord (upper and lower sides)
Height (horizontal stabilizers) [mm]	0.09906
Location (horizontal stabilizers)	10% chord (upper and lower sides)
Height (body) [mm]	0.08890
Location (body)	1.5% body length (azimuthally around the nose)

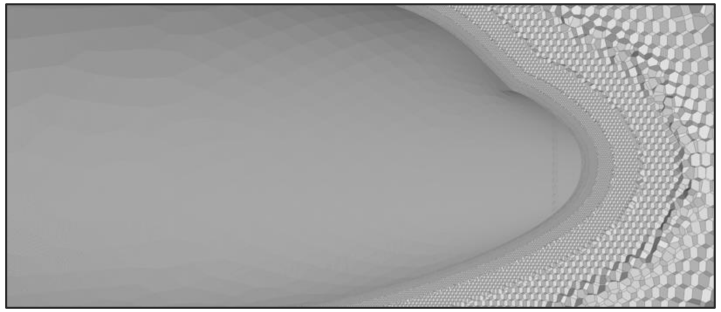
Surface Tessellation (Fidelity Pointwise)

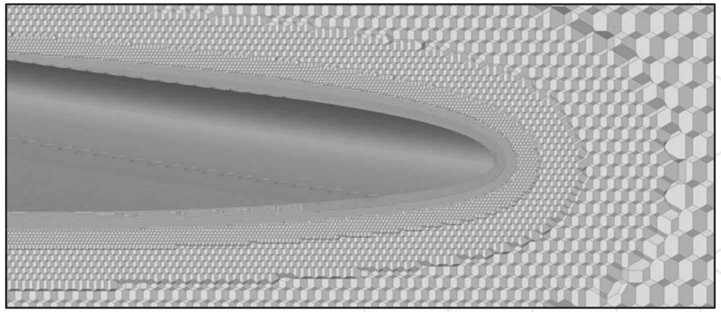
- Trip dots created and added to the original CAD data via a Glyph script (~5 minutes).
- Surface tessellation generated via the Automatic Surface Mesh tool (~5 minutes)
- Surface tessellation exported in *.sbin format to be used with Stitch (~1 minute)

Voronoi Volume Meshes (Stich)

- Stitch is the native mesh generator for Fidelity Charles.
- Generation of Voronoi volume meshes as detailed in previous slide.



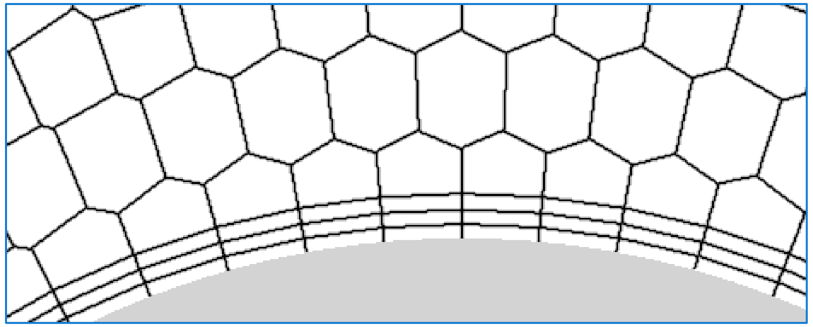




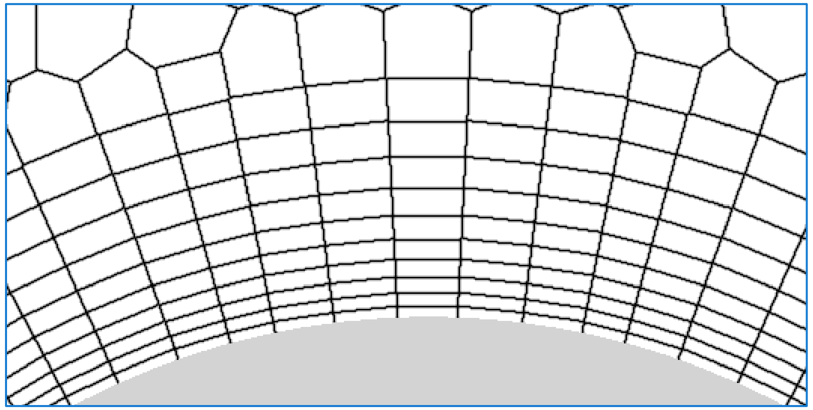
Gridding Approach

- We employ three different gridding approaches:
  - Adding higher-aspect ratio cells to the first wall cell (AR)
  - Boundary layer stranded mesh (SVP)
  - AR cells with physical trip dots (TR)
- Mesh level is a scaling based on :
  - $\Delta_L = \Delta_0 \left(\frac{1}{2}\right)^L$, where $\Delta_0 = MAC = 0.1513\ m$
- Resolutions include (LVL <streamwise>/<wall normal>)
  - LVL9/11 $\rightarrow$ 141 Mcvs, $y^+_{LE} \sim 24$, $y^+_{\eta=0.5} \sim 8$
  - LVL10/12 $\rightarrow$ 399 Mcvs, $y^+_{LE} \sim 12$, $y^+_{\eta=0.5} \sim 4$
  - LVL 11/13 $\rightarrow$ 609 Mcvs, $y^+_{LE} \sim 6$, $y^+_{\eta=0.5} \sim 2$
    - Local increase to wing LE, TE, upper surface, and wing tip
  - Up to LVL 13/15 $\rightarrow$ 884 Mcvs, $y^+_{LE} \sim 3$, $y^+_{\eta=0.5} \sim 2$
    - Uses a solution-based refinement technique (Agrawal et al.*) from Xfine mesh and excludes horizontal stabilizer and lower wing surface..
- **Note:** Trip dots set to LVL 13 w/isotropic cells ensuring enough resolution to be geometrically resolved

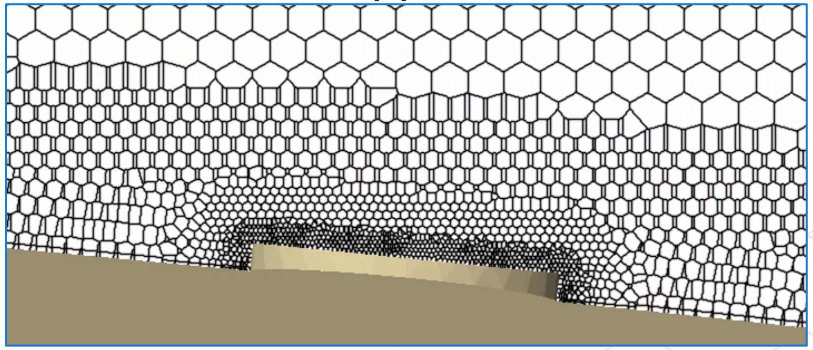
AR approach (4:1)



SVP approach (5:1)



TR approach

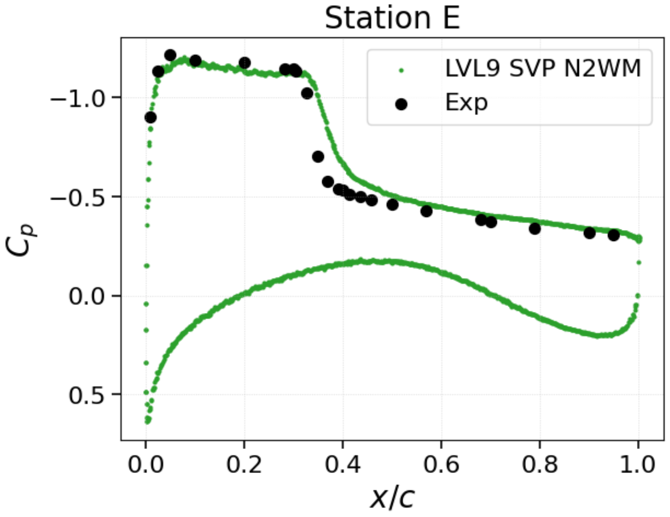


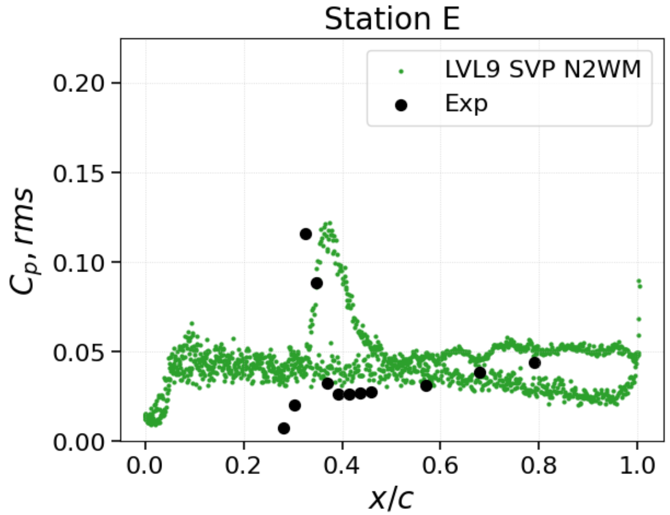
*Presentation on SBR method 6/10 @ 2pm in Hillcrest B

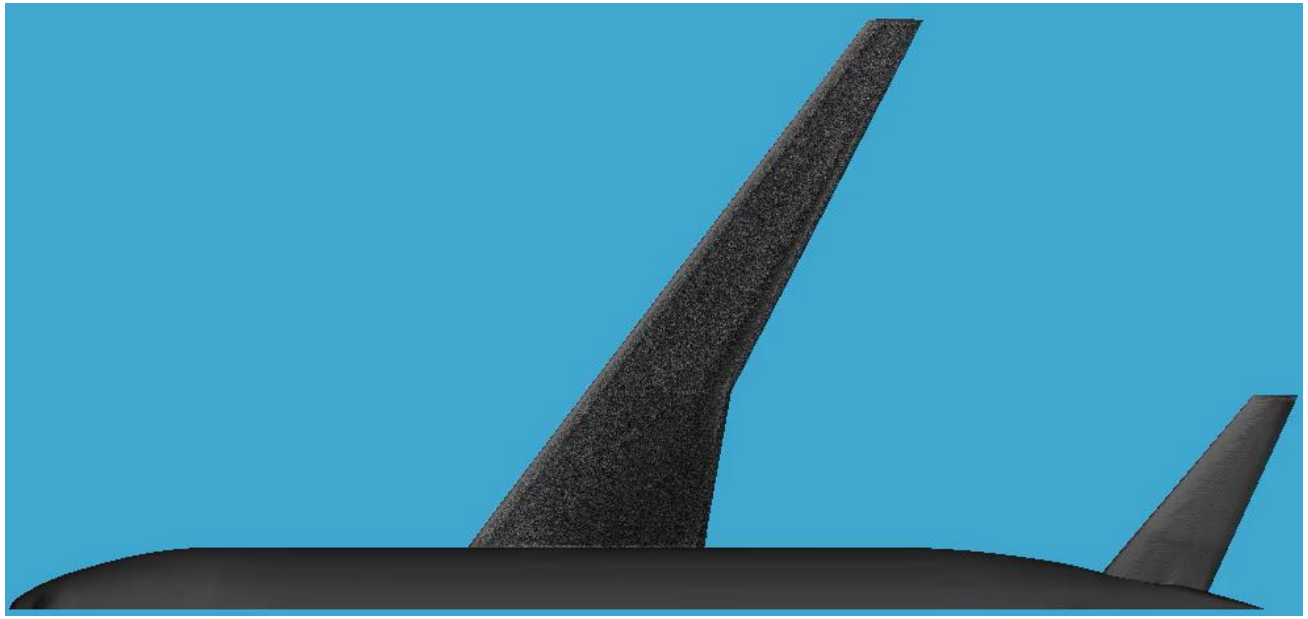
Near Wall Modeling Sensitivities

Grid Resolution and Wall Model Treatment, AoA=4.84 degrees

2nd Point Matching WM







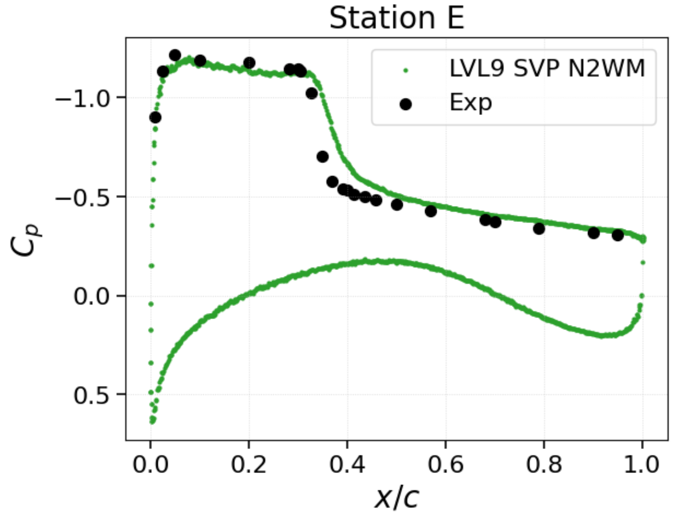
- Coarse grid + stranded mesh + 2nd point matching WM yields reasonable shock location and ok Cp,rms peak
- Upstream Cp value wildly over predicted
- Transition occurs instantly, but Cp,rms curve suggests delayed transition

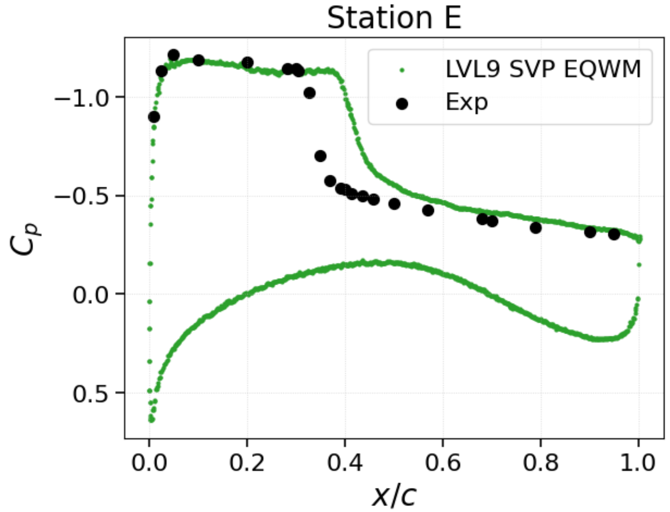
Near Wall Modeling Sensitivities

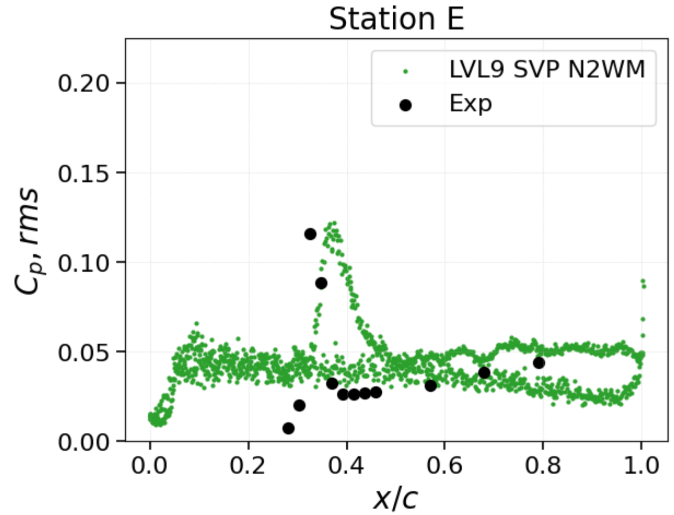
Grid Resolution and Wall Model Treatment, AoA=4.84 degrees

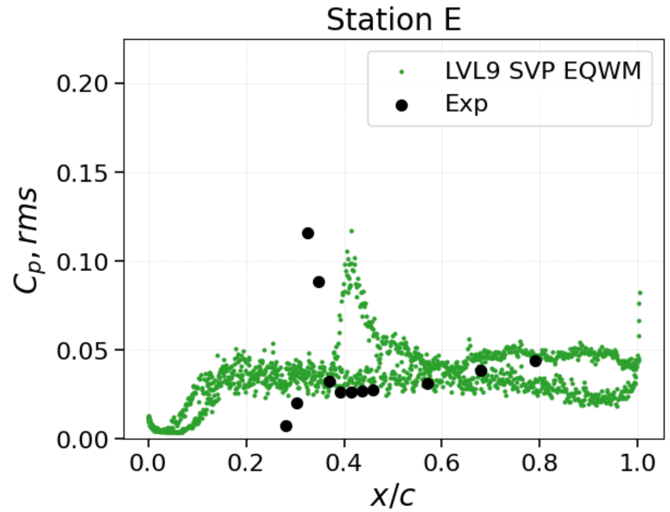
2nd Point Matching WM

EQWM









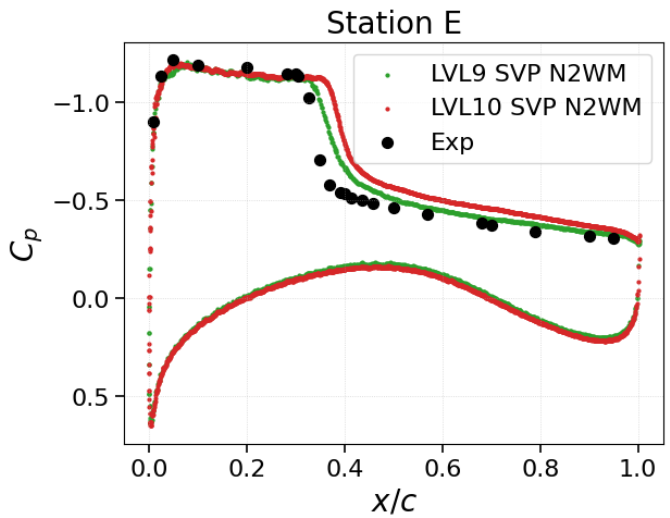
- EQWM had a further downstream shock position location compared to experiment
- Upstream boundary layer remains laminar further downstream

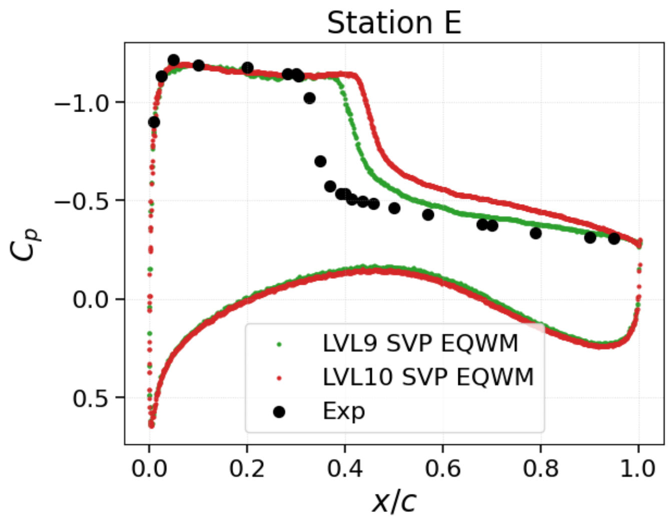
Near Wall Modeling Sensitivities

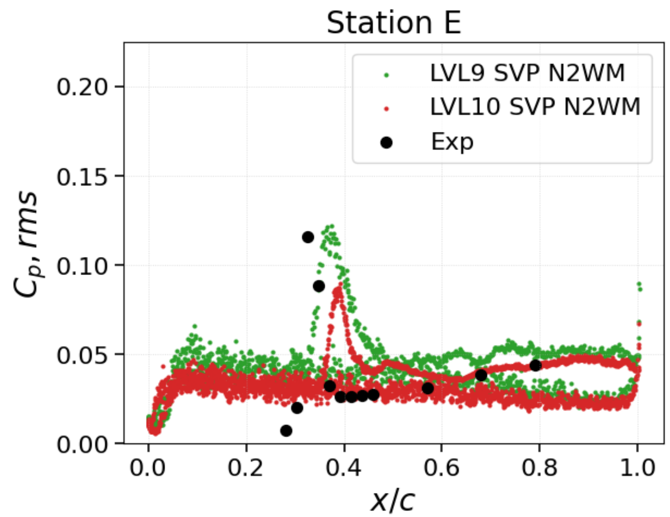
Grid Resolution and Wall Model Treatment, AoA=4.84 degrees

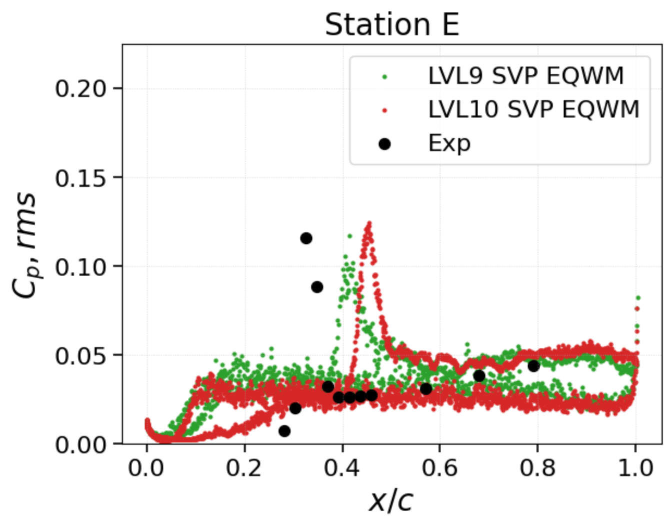
2nd Point Matching WM

EQWM









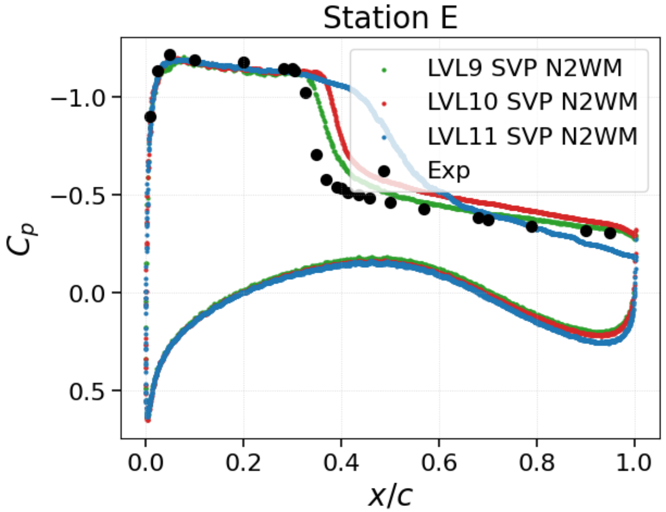
- 2nd point matching is more robust to shock location from grid
- EQWM improves upstream RMS value prior to the shock.

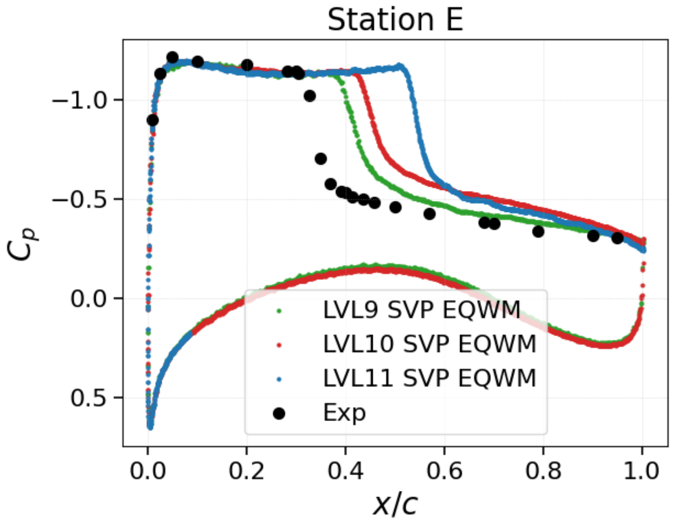
Near Wall Modeling Sensitivities

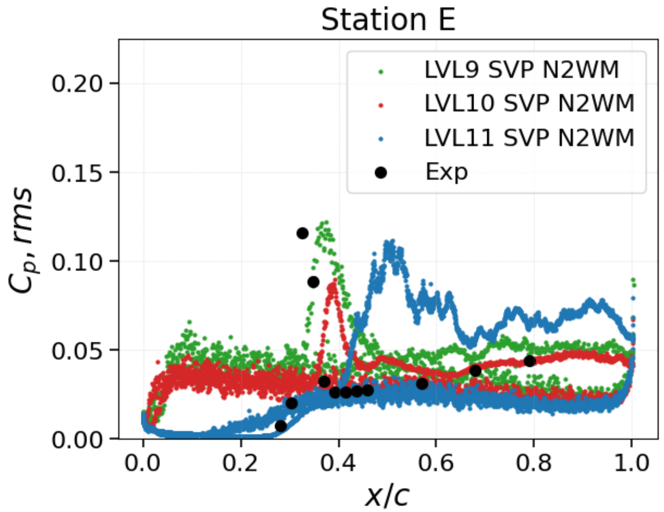
Grid Resolution and Wall Model Treatment, AoA=4.84 degrees

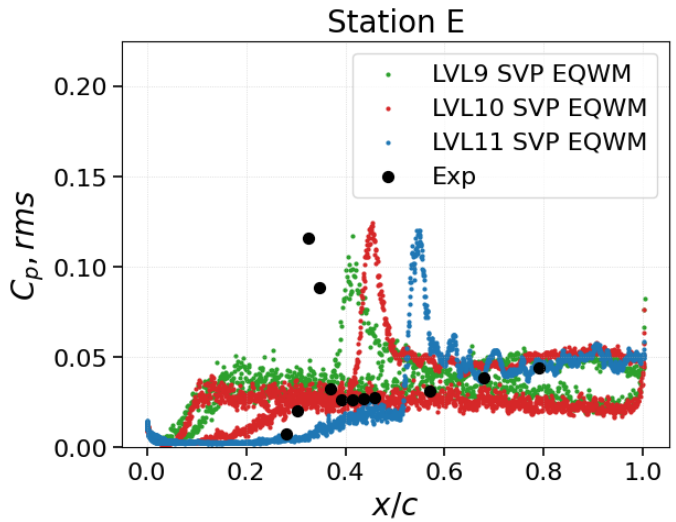
2nd Point Matching WM

EQWM









- At LVL11, both shock positions shift to the right.
- The region of laminar flow appears to have grown significantly

Note: 2nd point has fewer statistics at LVL11

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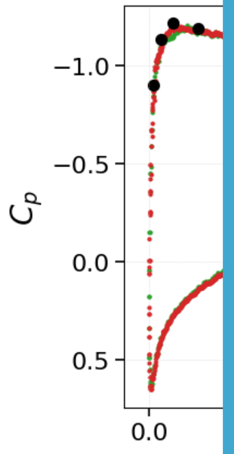
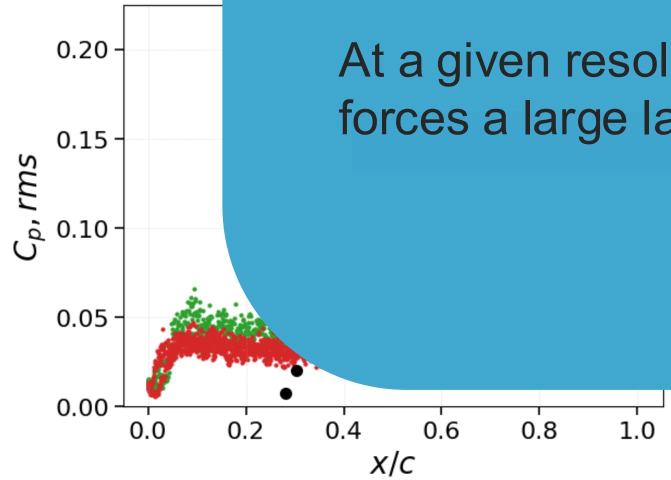
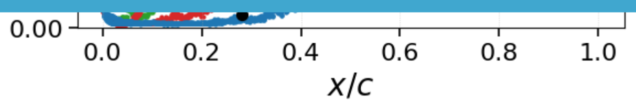
Near Wall Modeling Sensitivities

Grid Resolution and Wall Model Treatment, AoA=4.84 degrees

2nd R







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r flow
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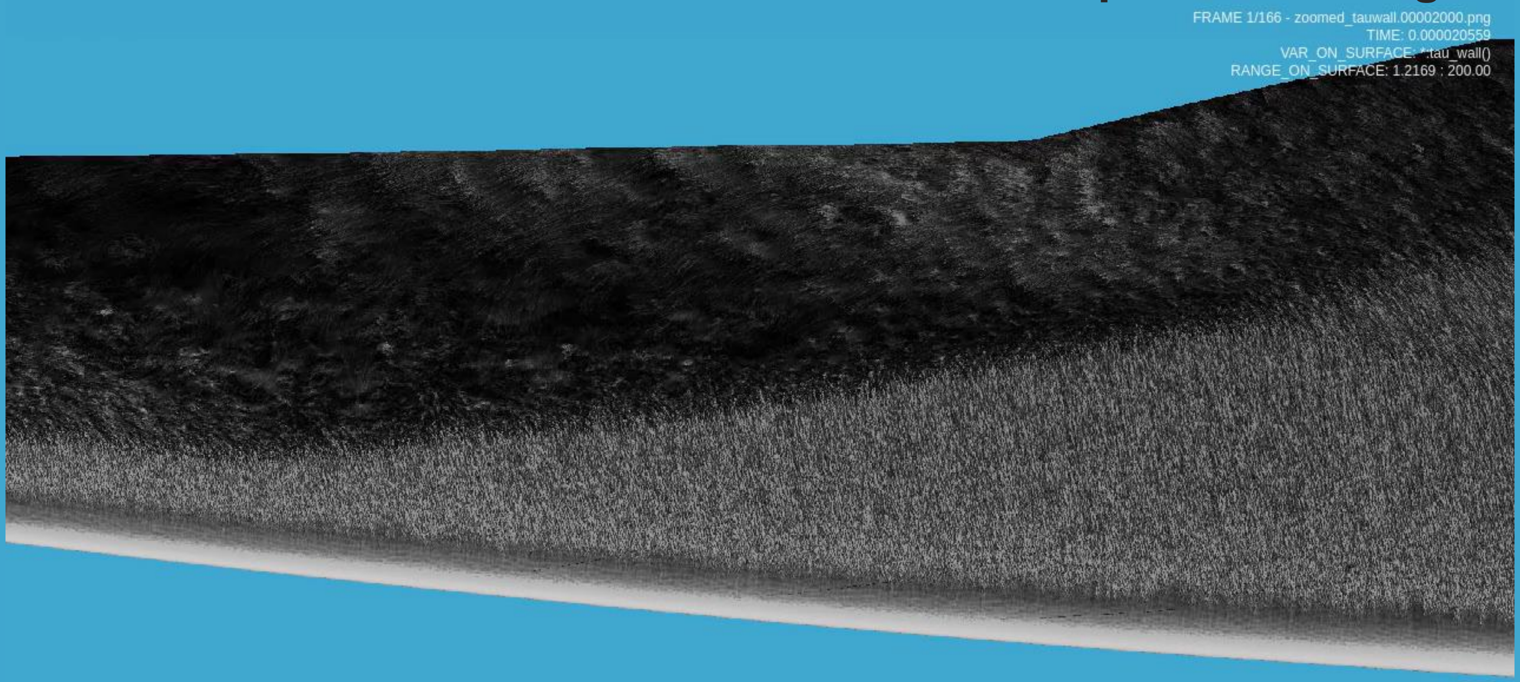
Increased resolution from LVL10->11 w/2nd point matching



At a given resolution, the boundary layer begins to be better resolved and forces a large laminar region. This motivates the use of two things:

1. **Geometrically resolved trip dots**
2. **A transition-sensor wall model**

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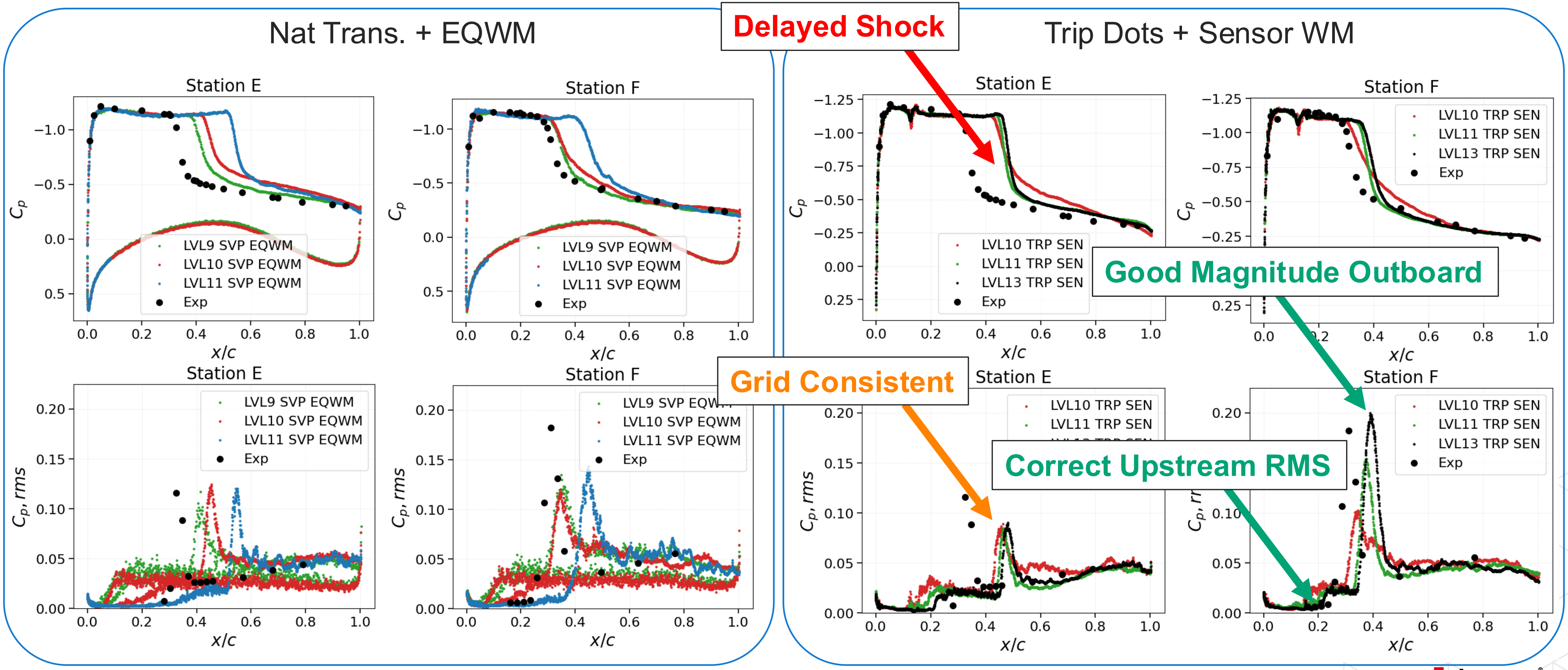
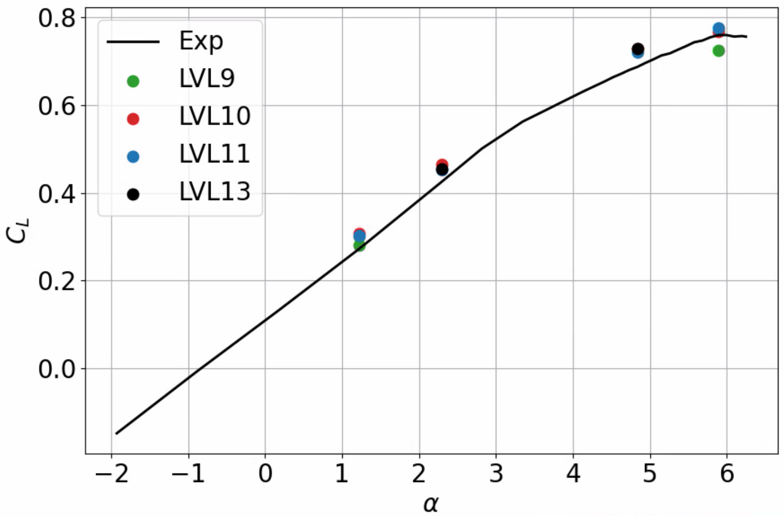
Near Wall Modeling Sensitivities

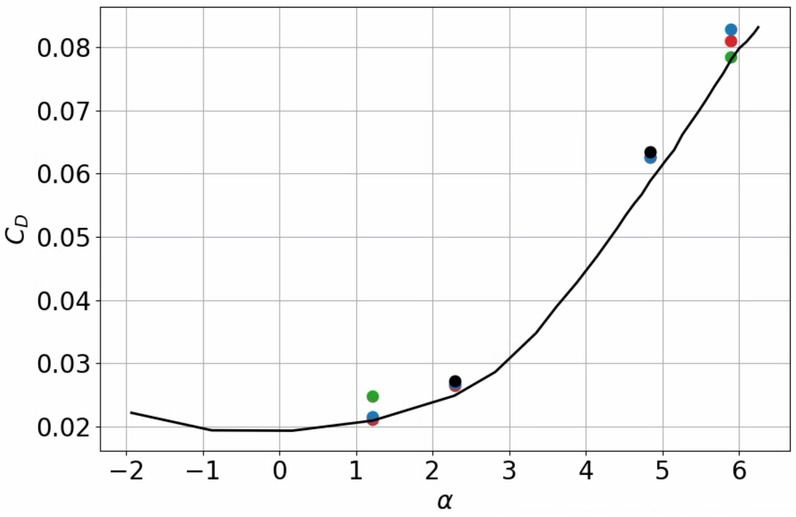
Effect of Trip Dots + Sensor WM

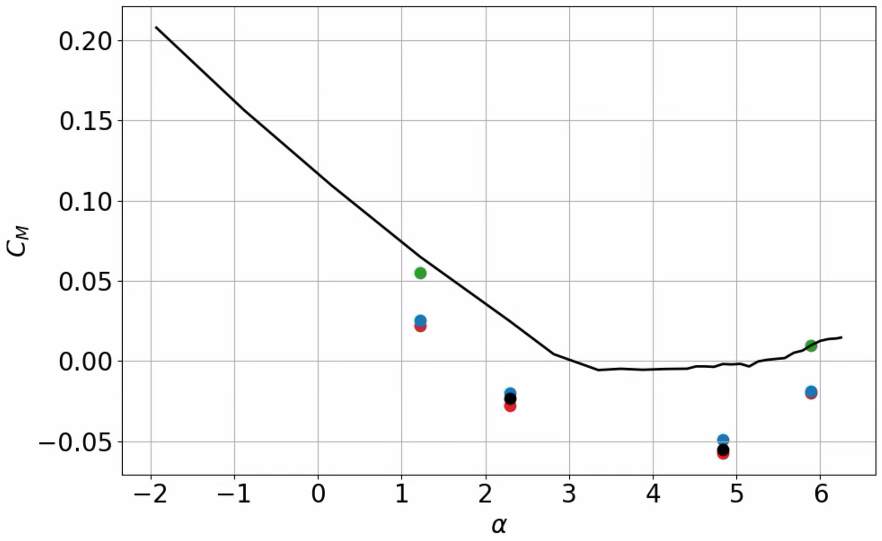


Forces and Moments

Angle of Attack Sweep with Trip Dots and Sensor-Based Wall Model







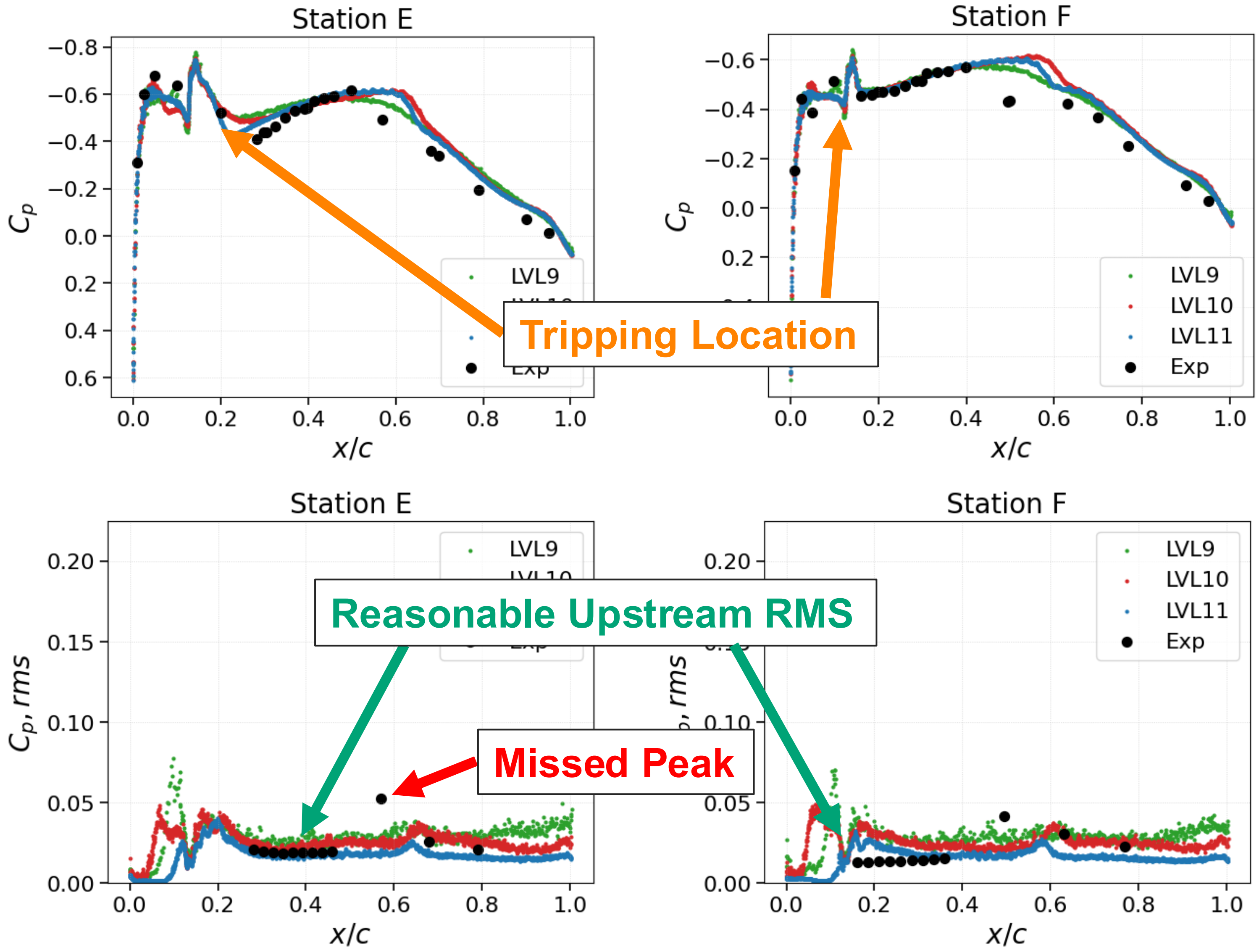
- Forces and moments do not differ much from grid to grid for the trip dots with sensor-based wall model approach.

- Lift/Drag yield reasonable results while moment is largely underpredicted
  - Note : Moment issues are consistent with transonic cases found in the literature*

*Goc et al., 2024

Mean and RMS Pressures

AoA = 1.22



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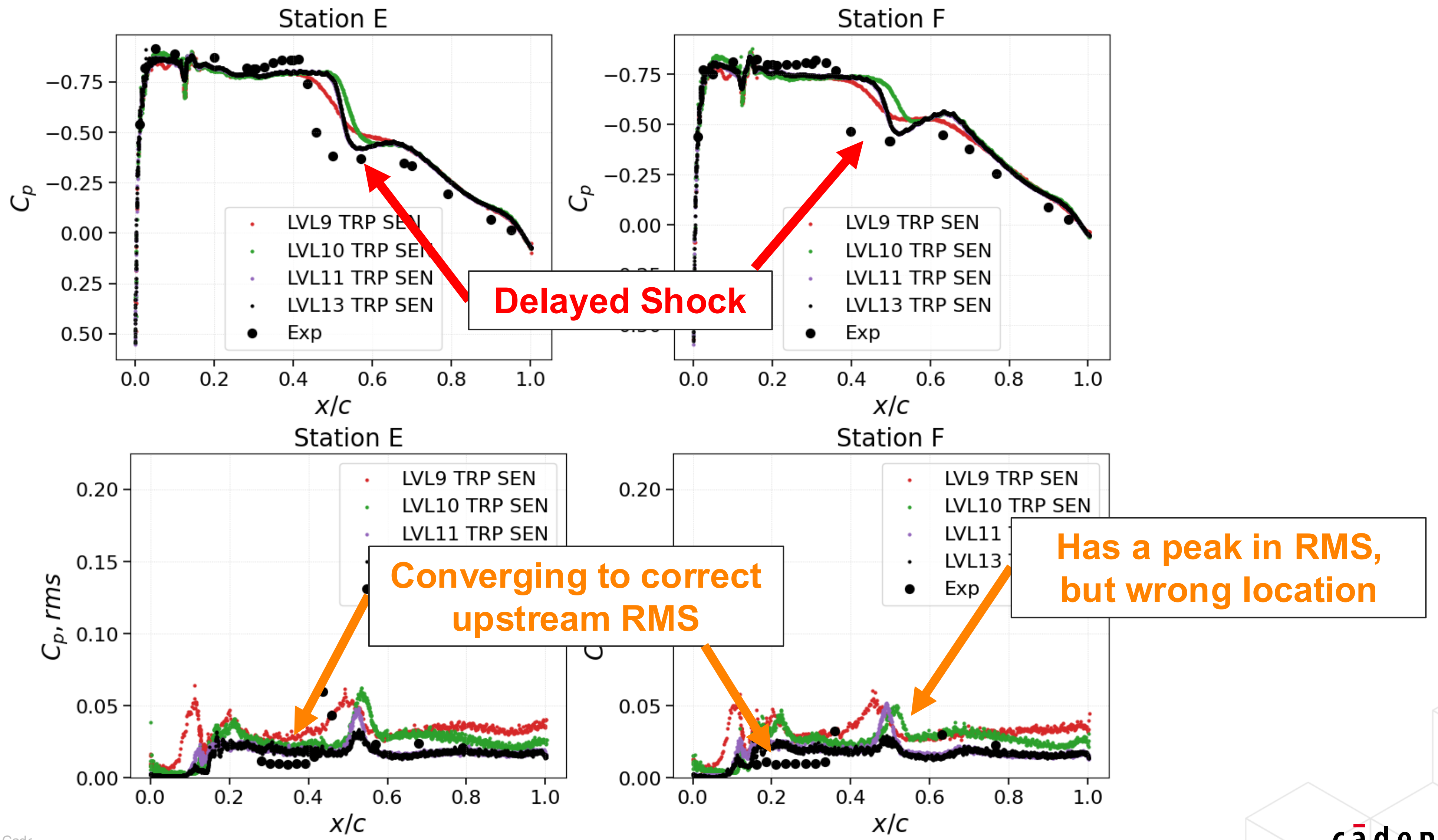
Mean and RMS Pressures

AoA = 2.29



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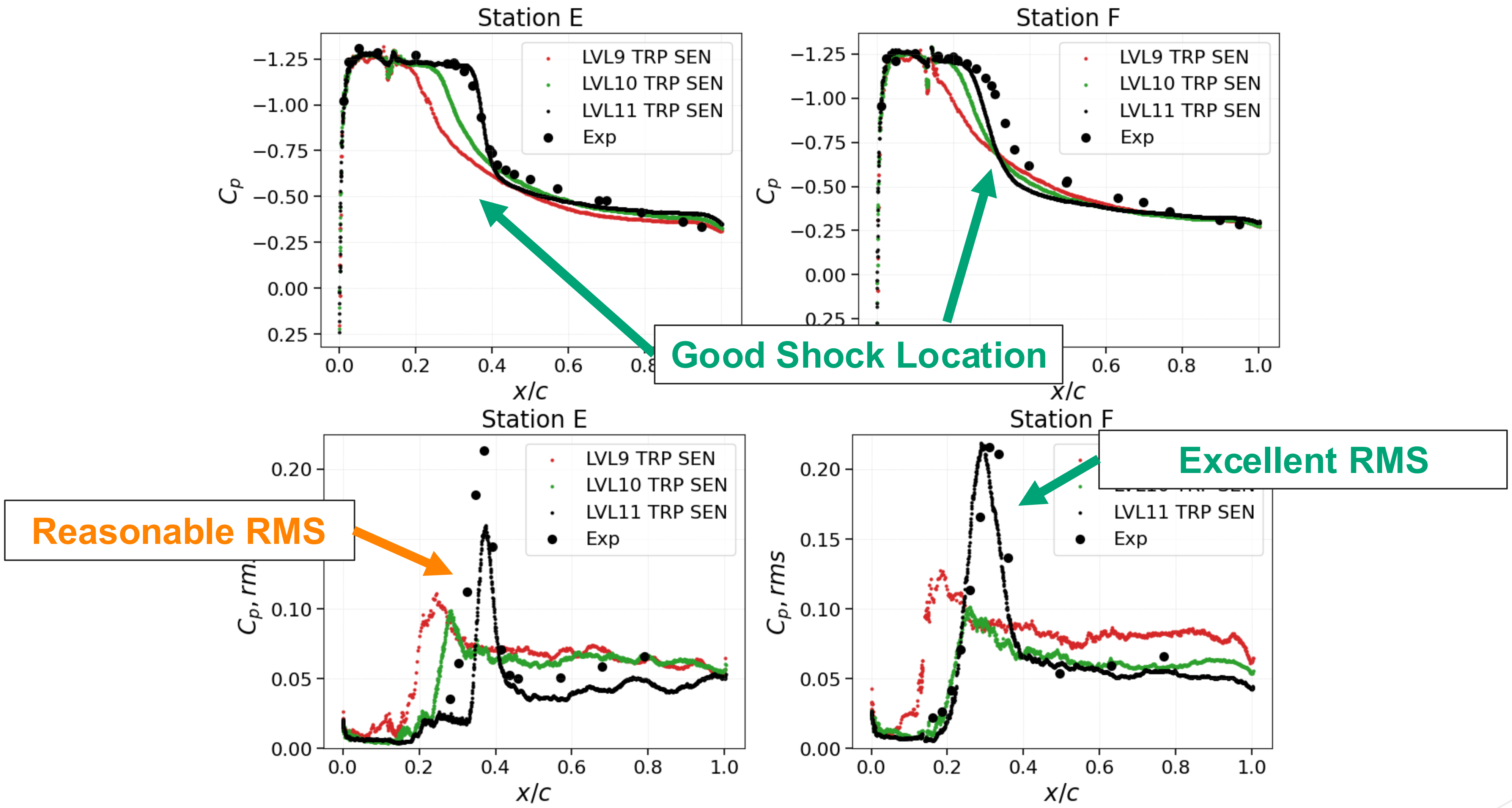
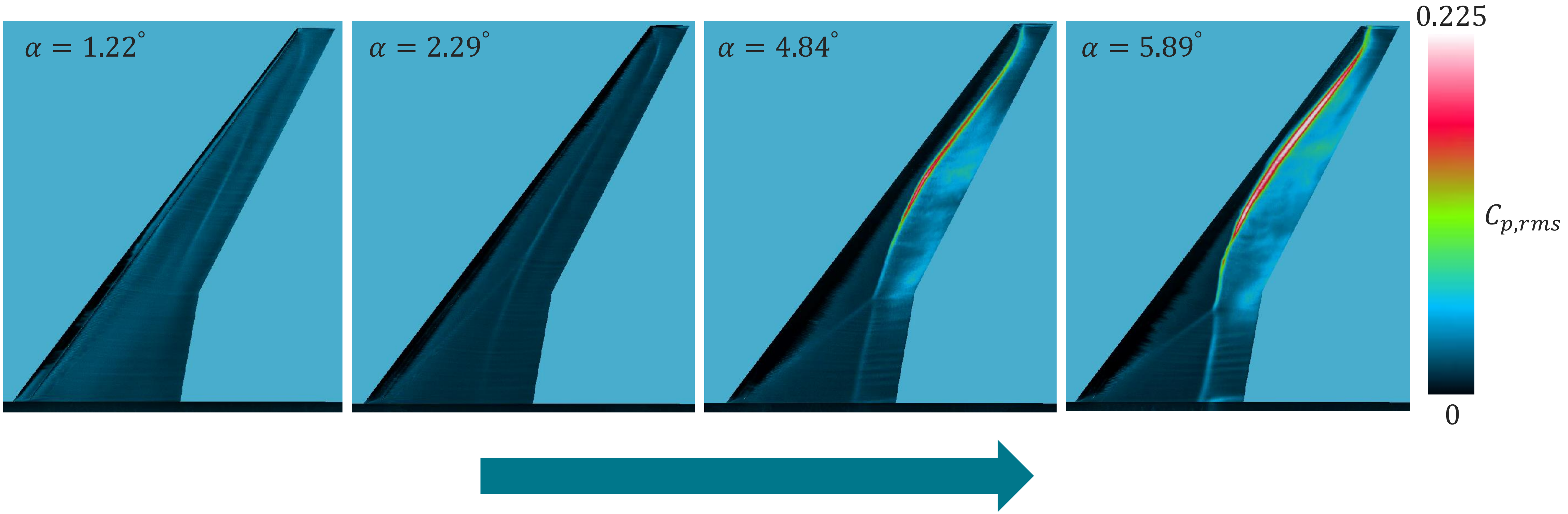
Mean and RMS Pressures

AoA = 5.89



Comparison of RMS Values



Increasing angle of attack shows increased peak *RMS* values as expected

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Key Conclusions and Open Questions

- **Key Conclusions:**
  - Stranded mesh with a coarse grid and 2nd-point matching predicts reasonable shock location; however, **shock shifts downstream with refinement**, indicating sensitivity to near-wall treatment
  - 2nd-point matching induces **early boundary-layer tripping near the leading edge** until the laminar region is sufficiently resolved
  - **Trip dots with sensor-based wall modeling** show consistent behavior across grid levels
  - Accurate RMS prediction at the leading edge requires **resolving the upstream boundary layer**
- **Open Questions:**
  - What is the impact of **wind tunnel effects** (sting, confinement, turbulence intensity) on shock position?
  - Do sensor-based wall model settings influence shock location?
- **Requests from Workshop:**
  - Provide trip dot CAD geometry or, at minimum, precise (x,y,z) coordinates for each trip dot
  - Provide additional CAD geometry for case with sting and additional details for the wind tunnel setup

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