Curvilinear LAVA RANS Results on HLPW4 2D Multi-Element Airfoil Geometry*

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Overview/Agenda

- Problem Summary
- LAVA Flow Solver Characteristics
- Mesh Information
  - Mesh Size & Relevant Parameters
  - Surface Spacings
  - Wall-normal Spacings
- Results
  - Load Convergence (C_L , C_D , $C_{M,y}$)
  - Pressure & Skin Friction Profiles
  - 1D Slices of U/U_{REF}, W/U_{REF}, and μ_T/μ_{REF}
  - Mach & Eddy Viscosity Ratio Contours
- Conclusions

Problem Summary

- **Case 3: Turbulence Model Verification and SRS Capability Study**
  - Constructed from a section of the HL-CRM geometry
  - HLPW4 requests 2D study with standard SA model to demonstrate accurate and consistent implementation
  - Used to verify consistency between LAVA Unstructured and Curvilinear codes

- Mach: 0.2
- T_{REF}: 272.1 [K]
- Reynolds #: 5.04 million
- AOA: 16 [deg]

LAVA Curvilinear Solver Characteristics

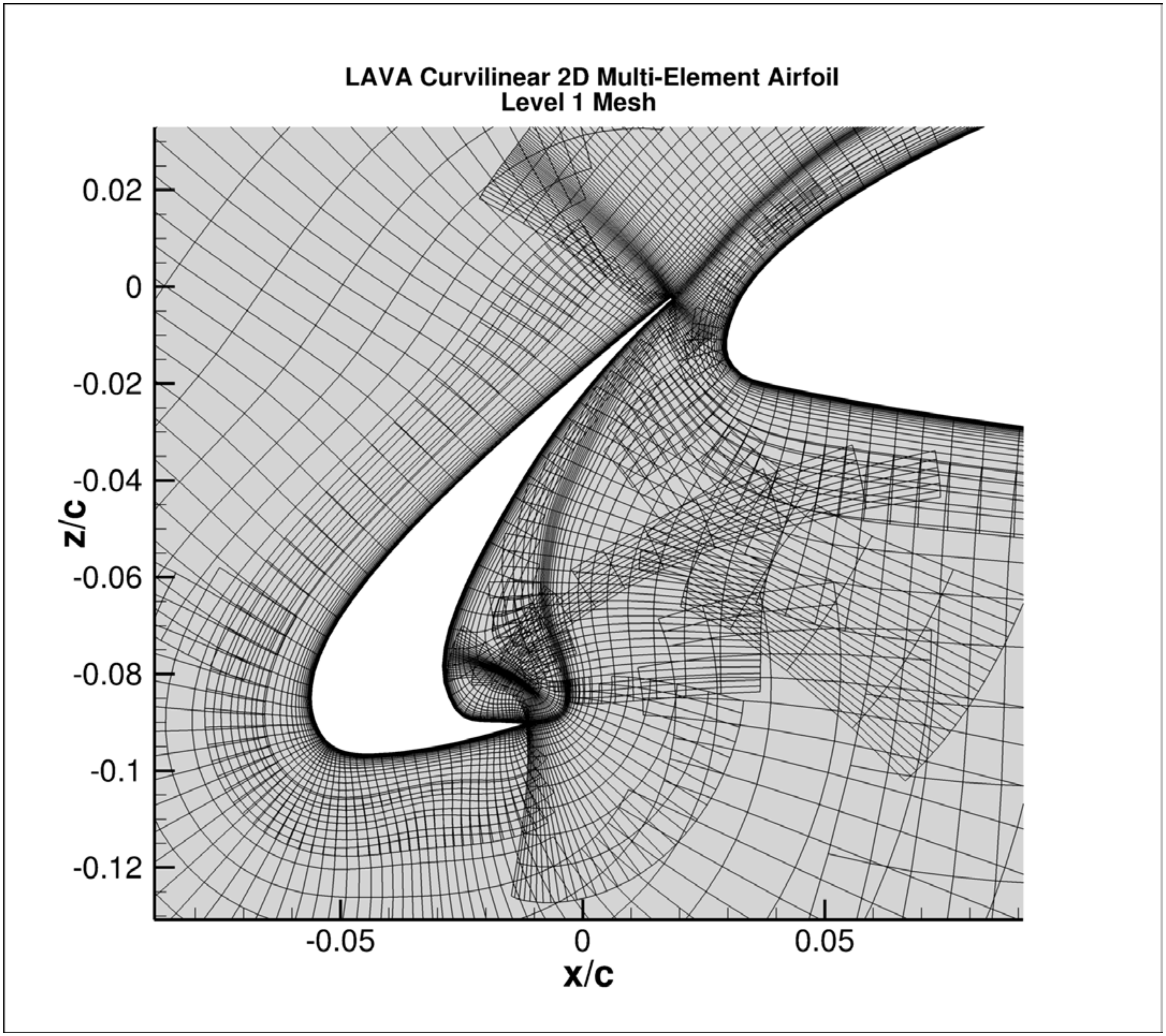
- Structured Overset Grid
- Flux Scheme: Upwind
- Limiter: none
- Turbulence Model: SA-neg
- Prandtl Number: 0.72
- Gas Model: Ideal, calorically perfect (C_p = 1005.0 J/(kg·K))
- Viscosity: Sutherland's Law
- Time Integration: Implicit Steady
  - CFL_{START} = 0.1
  - CFL_{LIMIT} = 1000
- Linear Solver: GMRES with ILU Preconditioning

Mesh Information

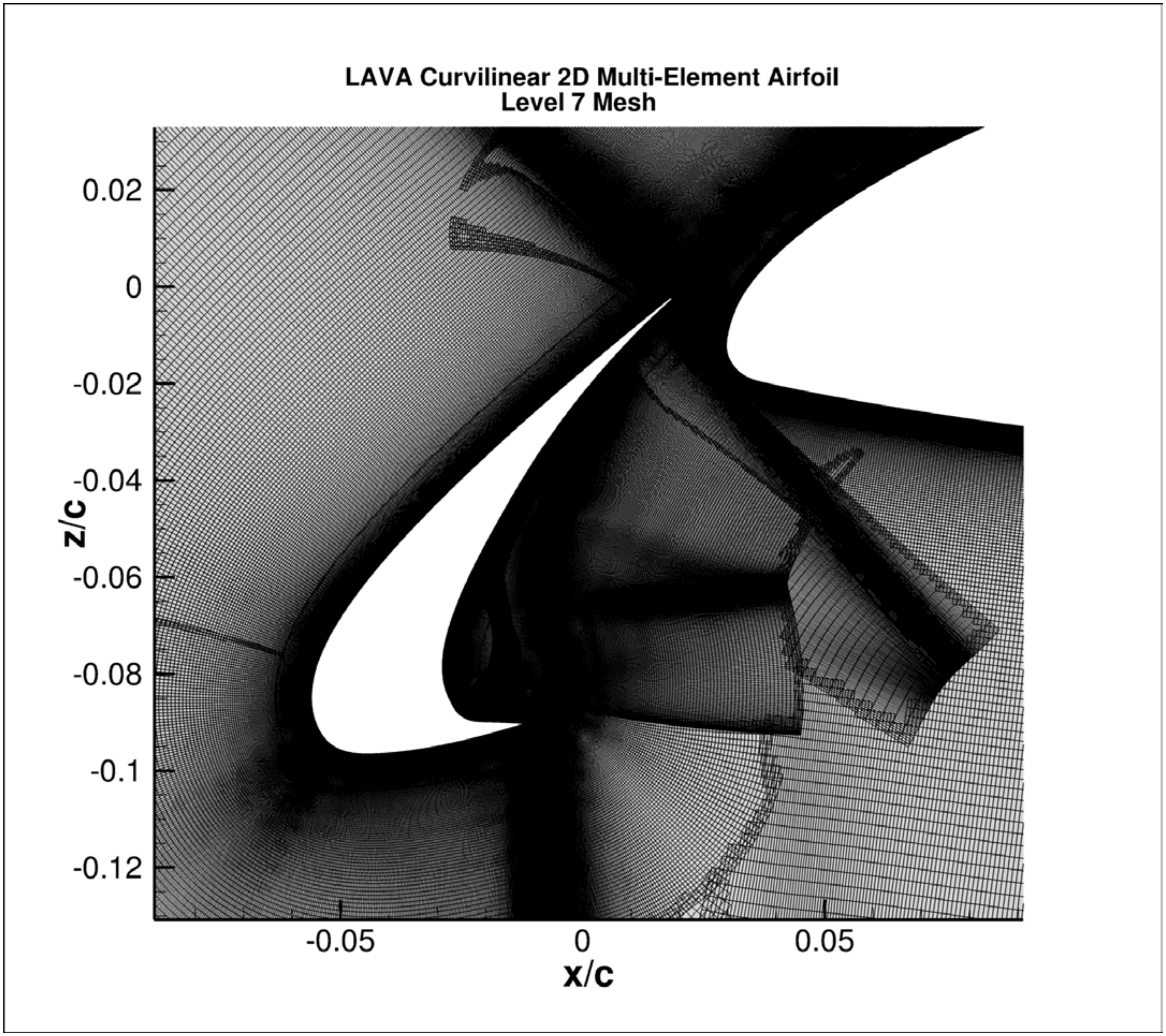
- 2D overset structured meshes (extruded 2 cells in spanwise direction)
- Wake refinement grids included
- Airfoil element surface grids were grown a particular distance into the volume as a single piece and then split up into several sections to avoid high AR grid cells
- Surface/volume stretching ratios and number of TE points were chosen to be consistent with workshop guidelines

Refinement Level	Total # of Nodes	# of Compute Nodes	Max Surface/Volume Stretching Ratio	# of TE Points
1	204,270	138,241	1.250	5
2	430,212	298,691	1.167	7
3	742,818	517,558	1.125	10
4	1,621,926	1,145,576	1.084	15
5	3,132,165	2,226,630	1.059	21
6	6,537,678	4,695,184	1.041	30
7	13,314,846	9,705,608	1.029	44

Mesh Information (cont.)



Mesh Information (cont.)



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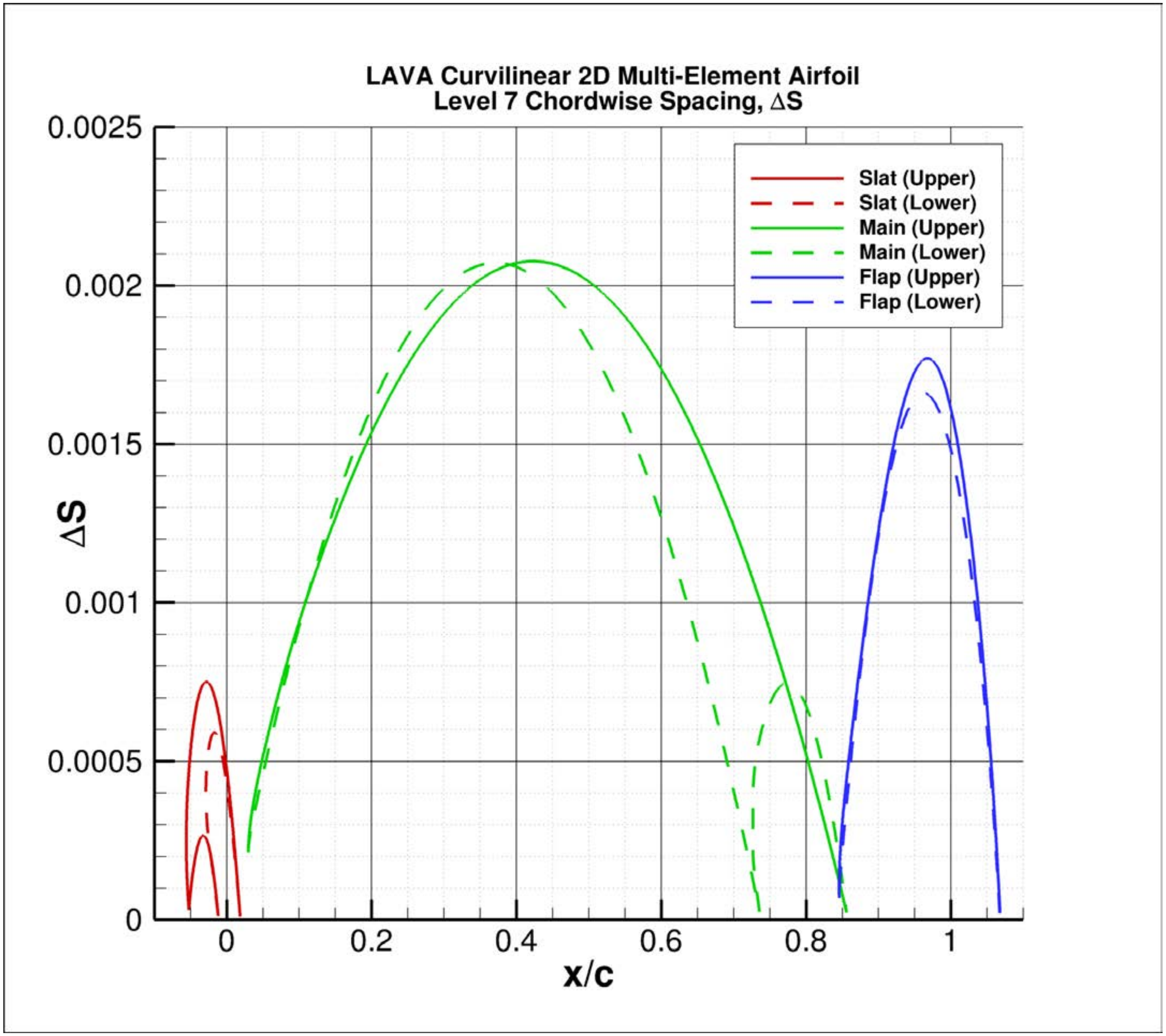

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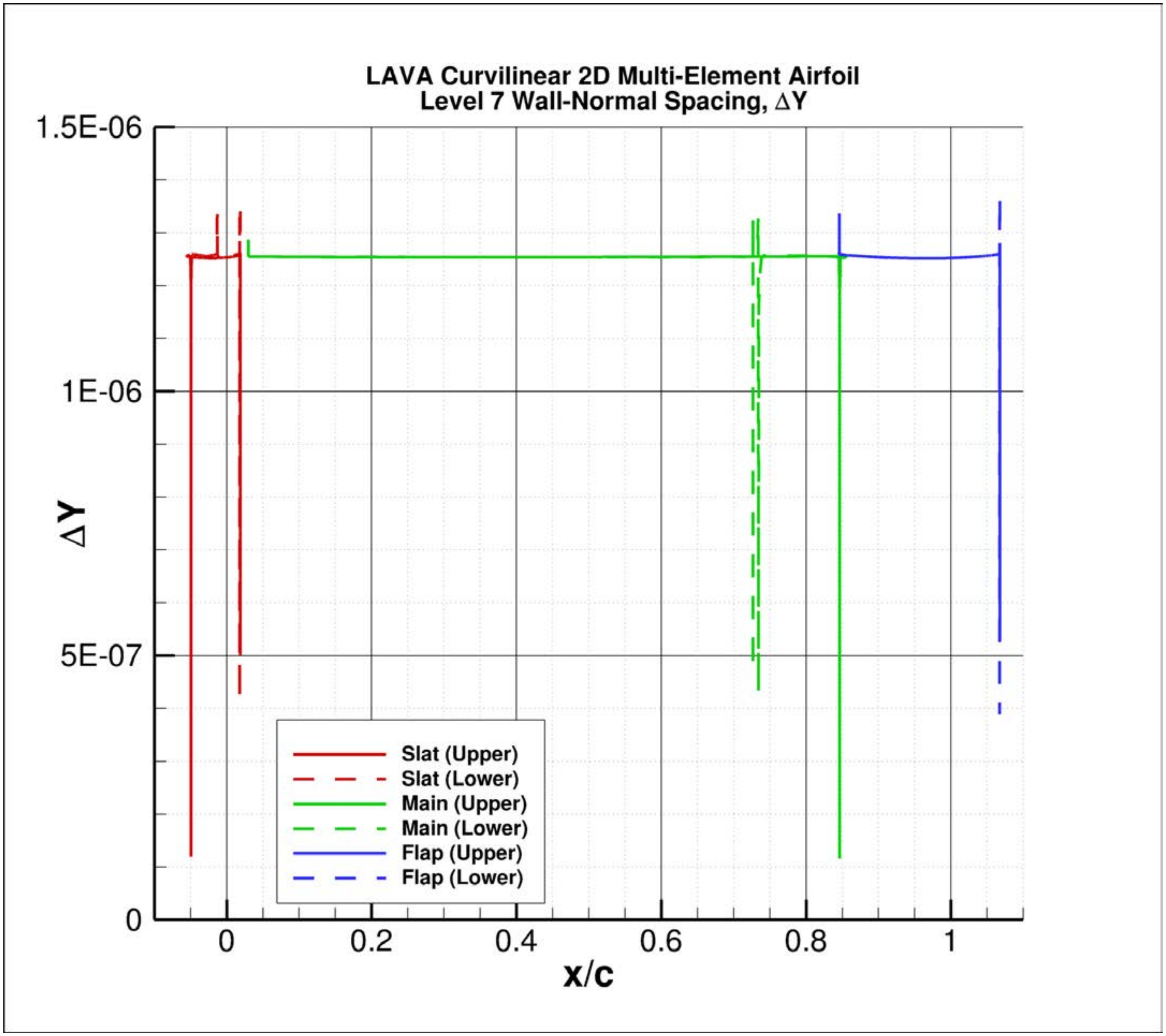

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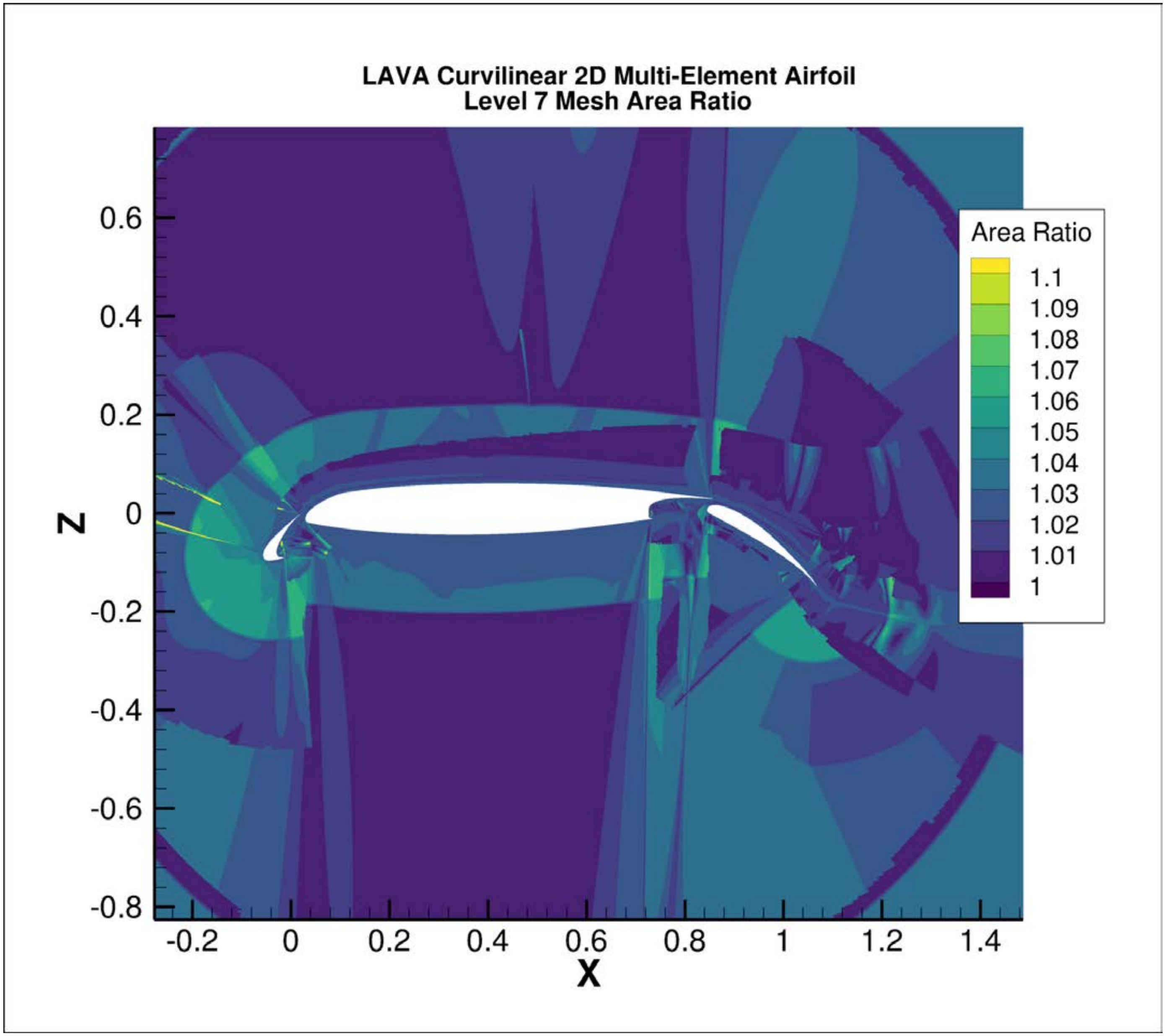
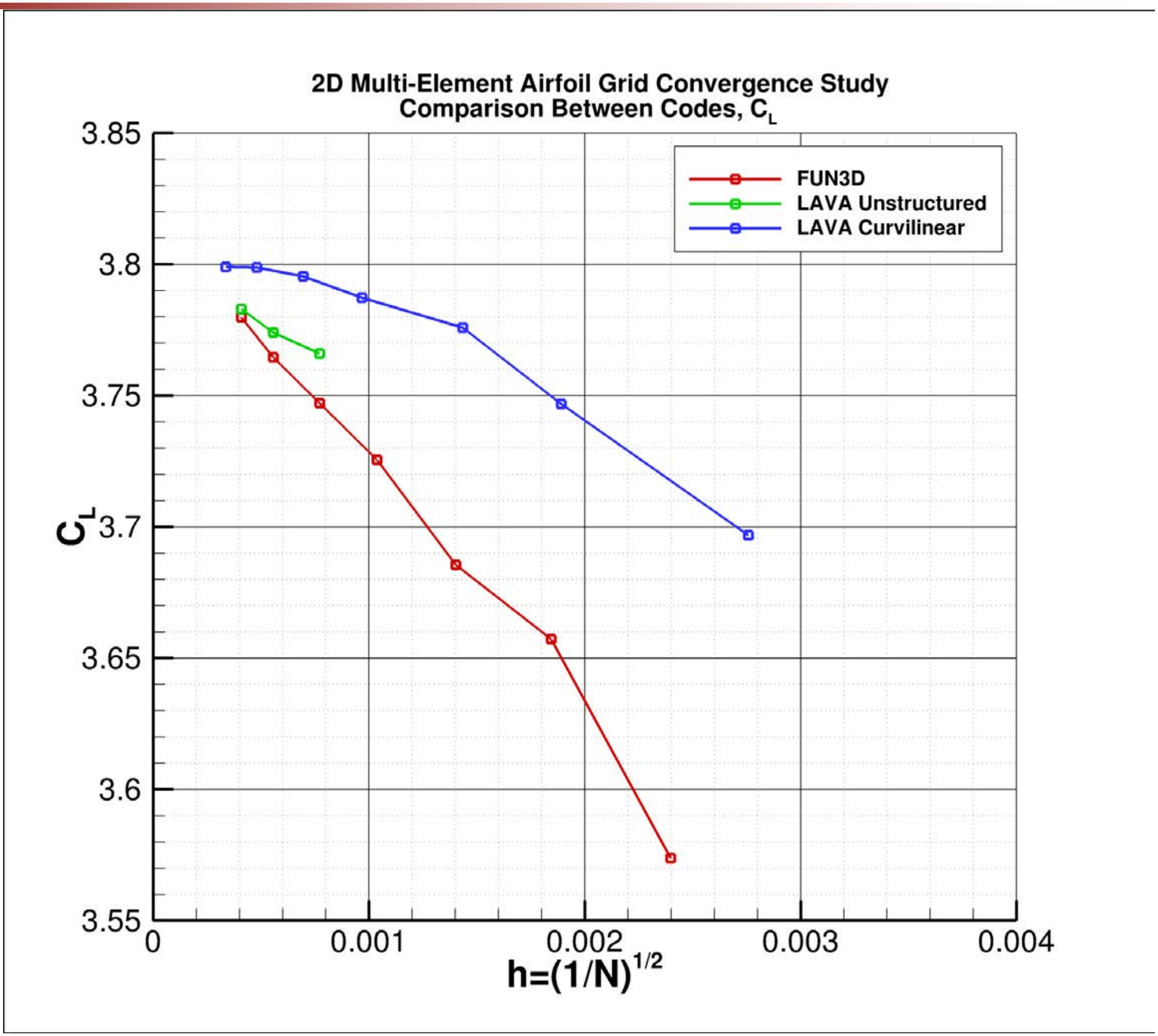
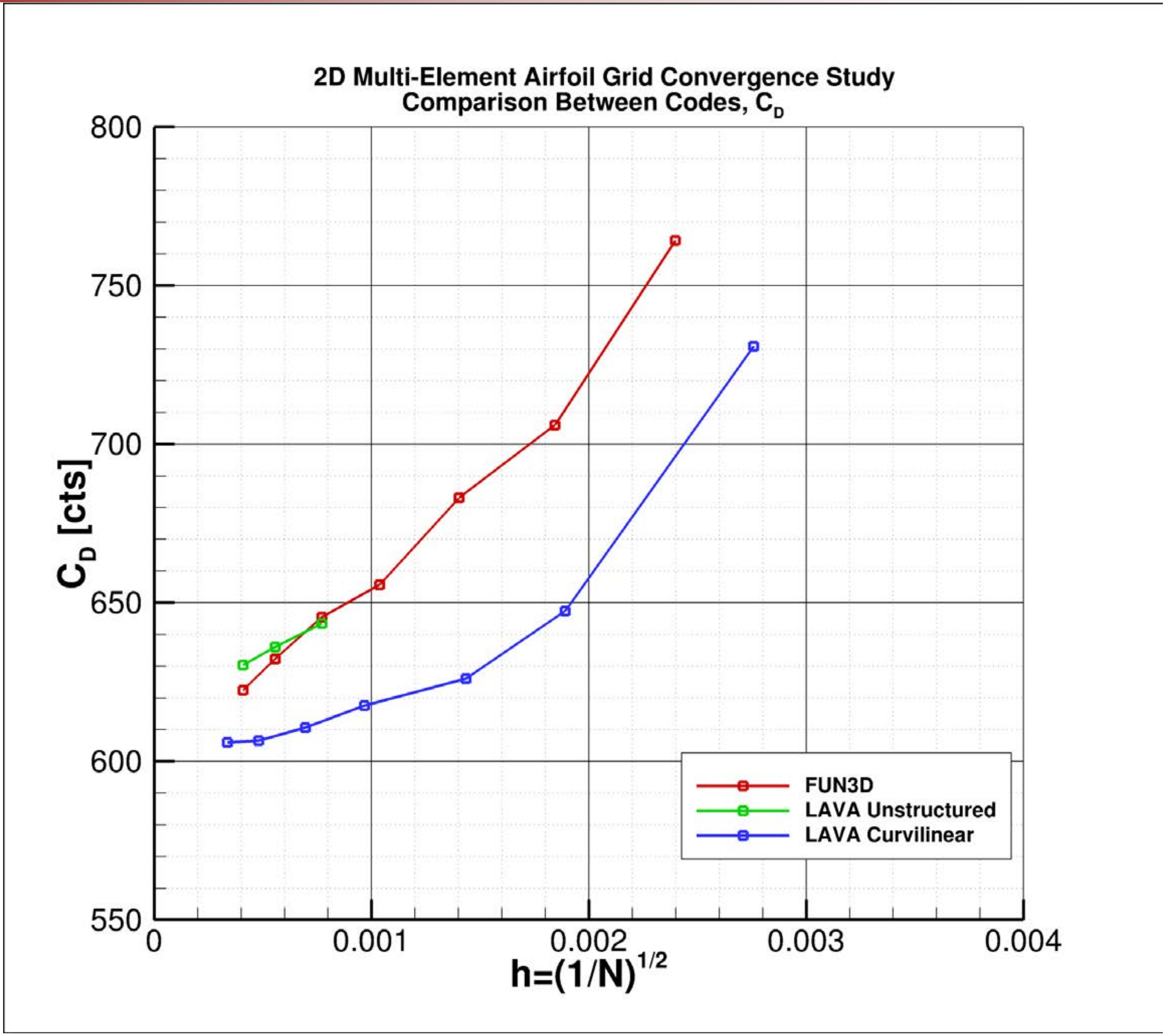


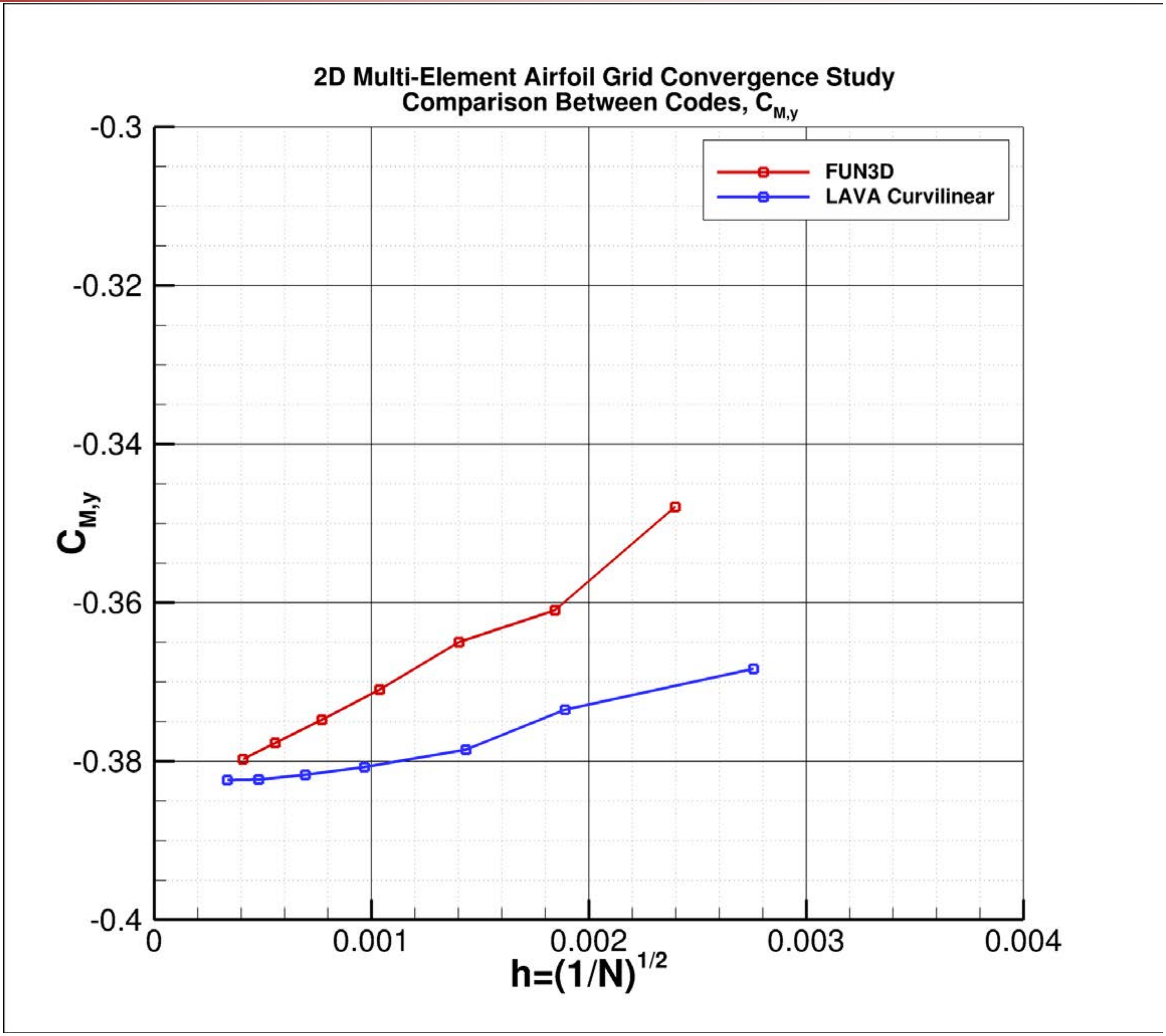
Grid Convergence Study: C_L



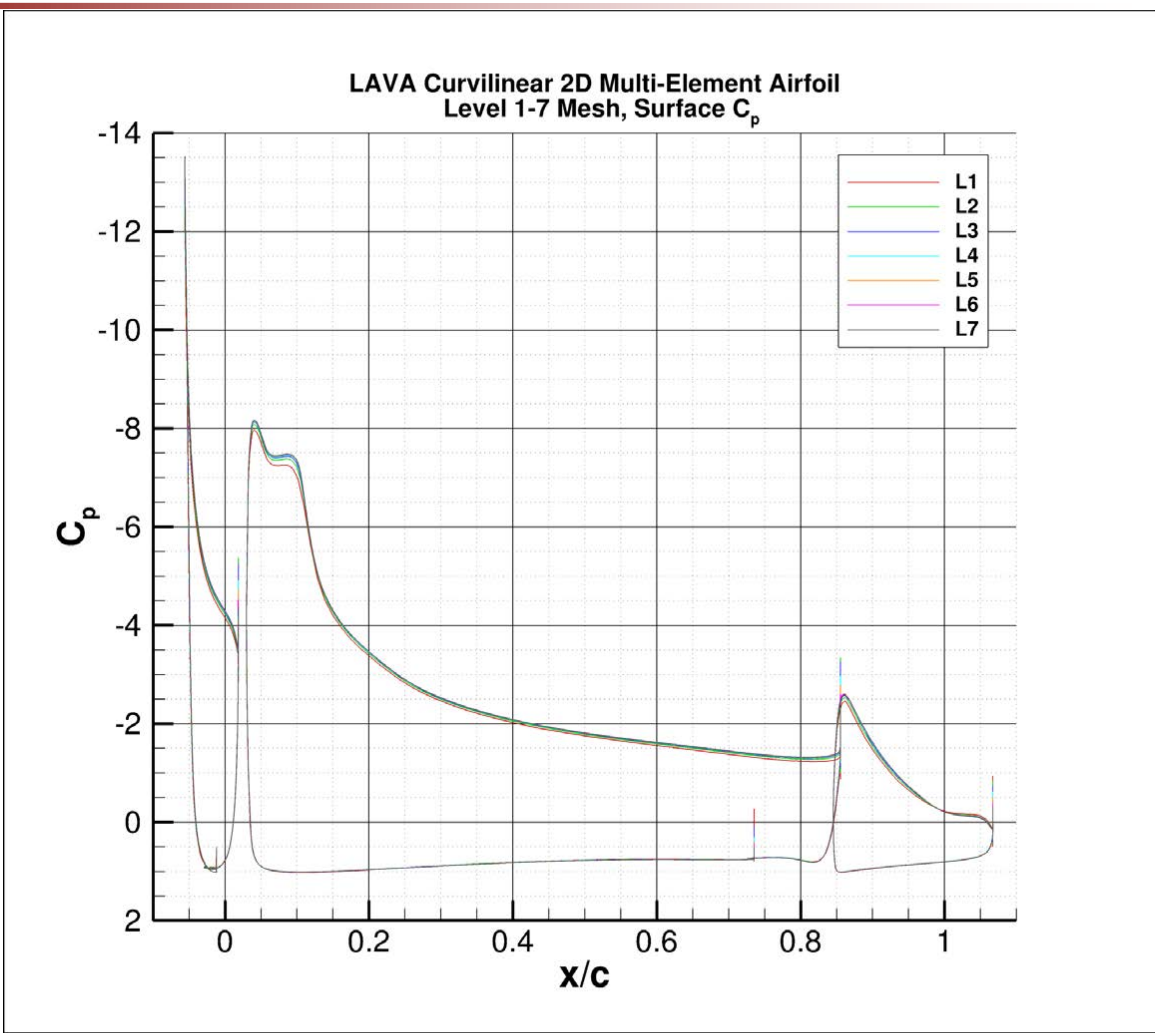
Grid Convergence Study: C_D



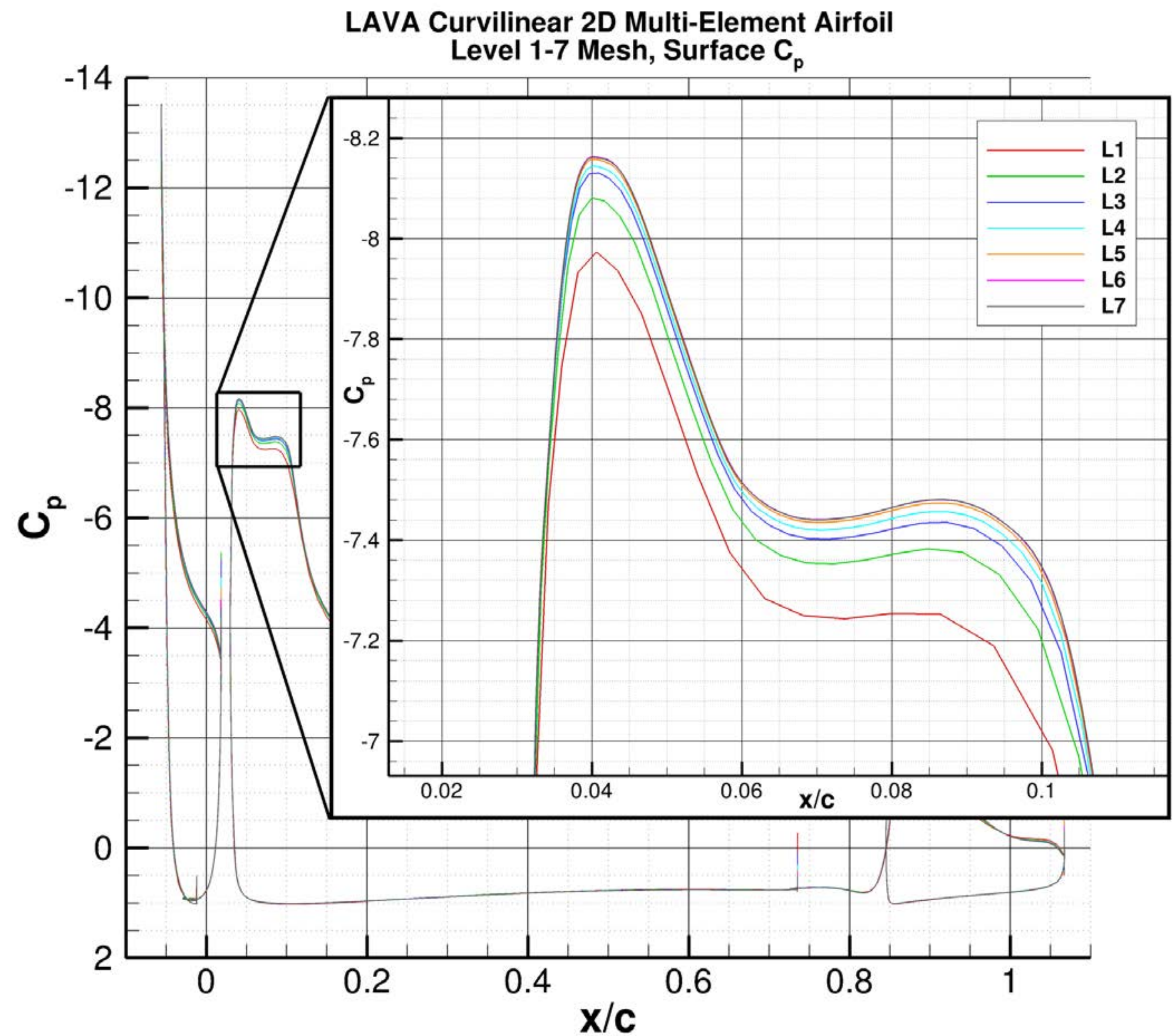
Grid Convergence Study: $C_{M,y}$



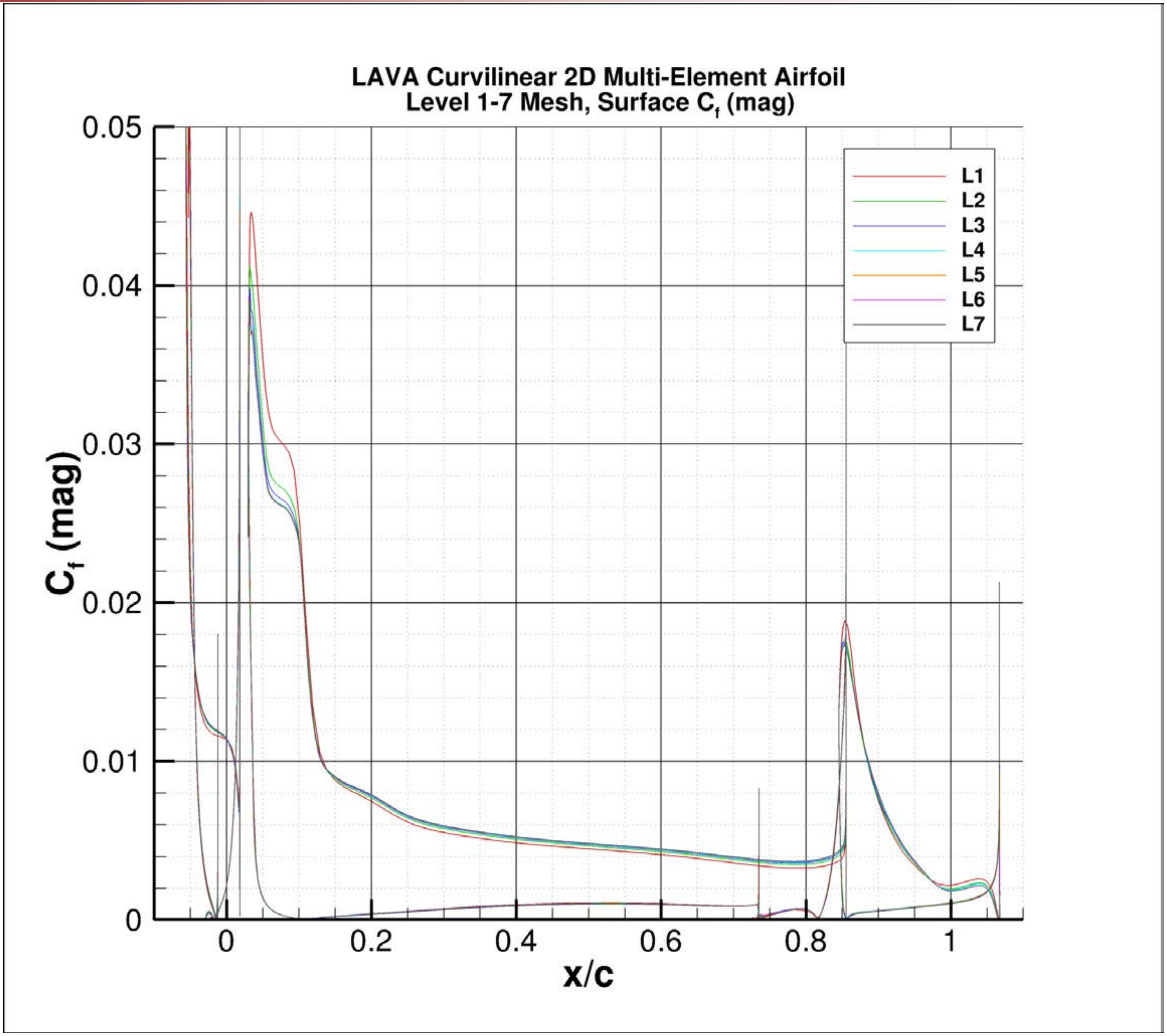
LAVA Curvilinear Results: C_p



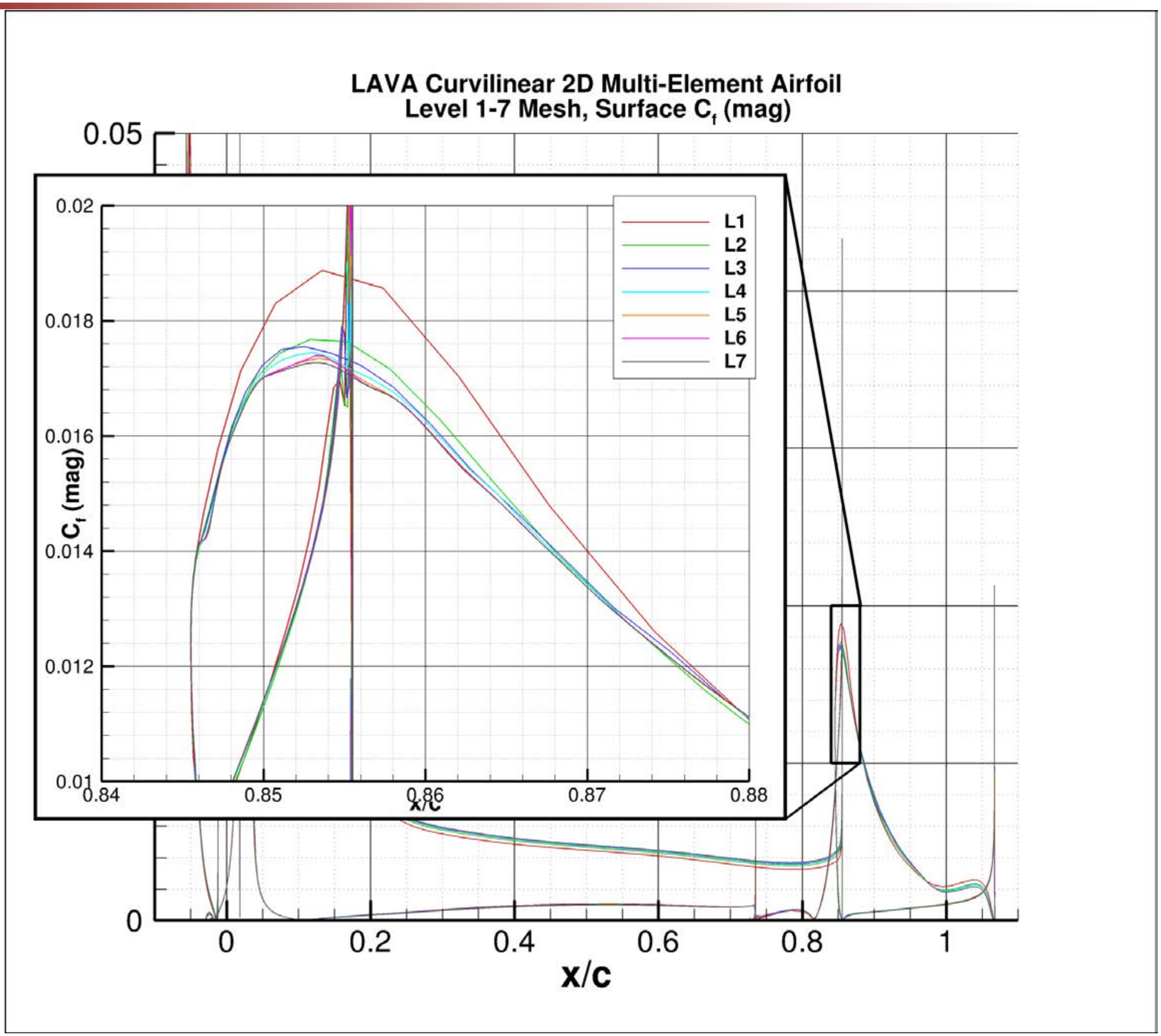
LAVA Curvilinear Results: C_p



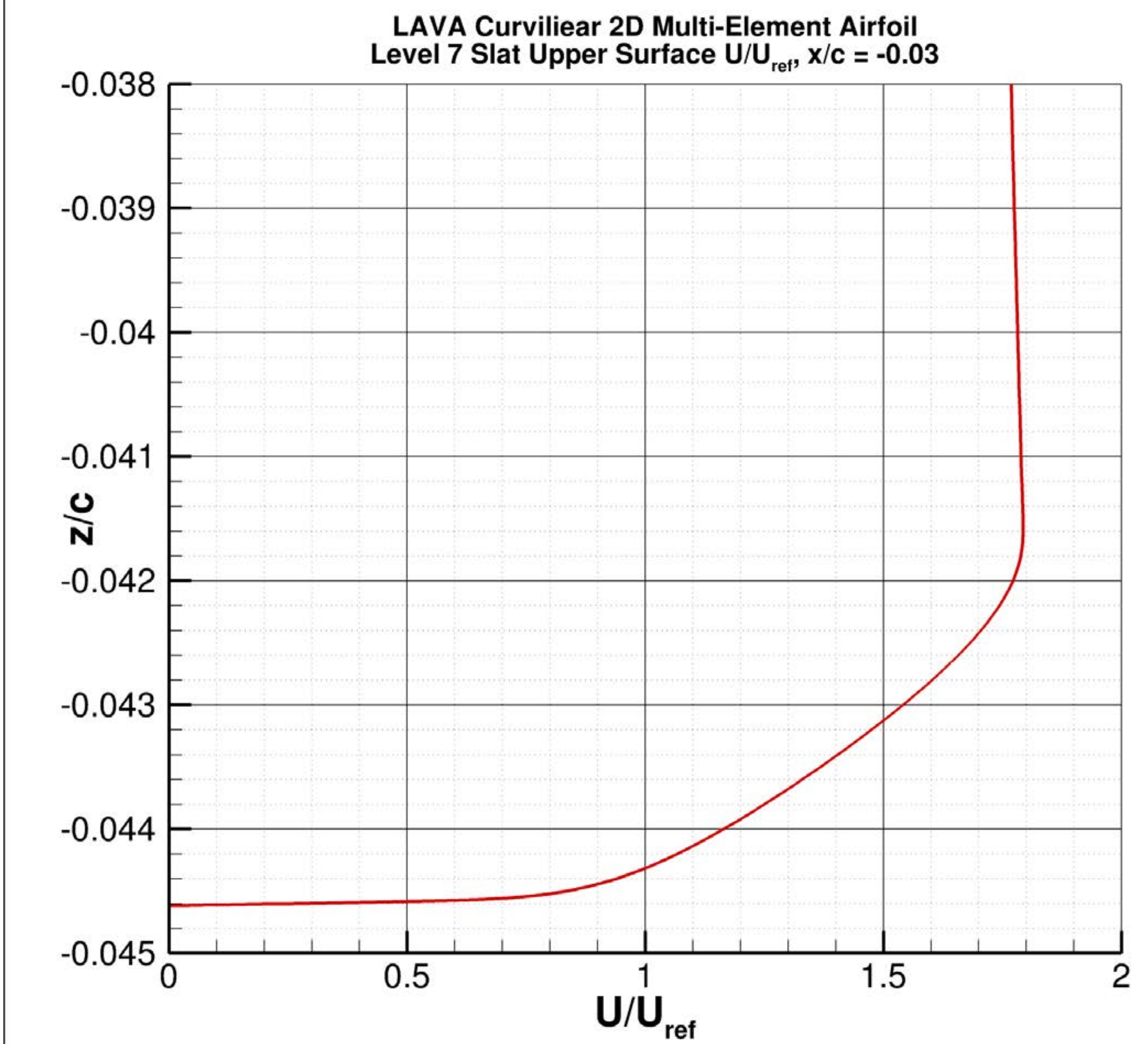
LAVA Curvilinear Results: C_f (mag)



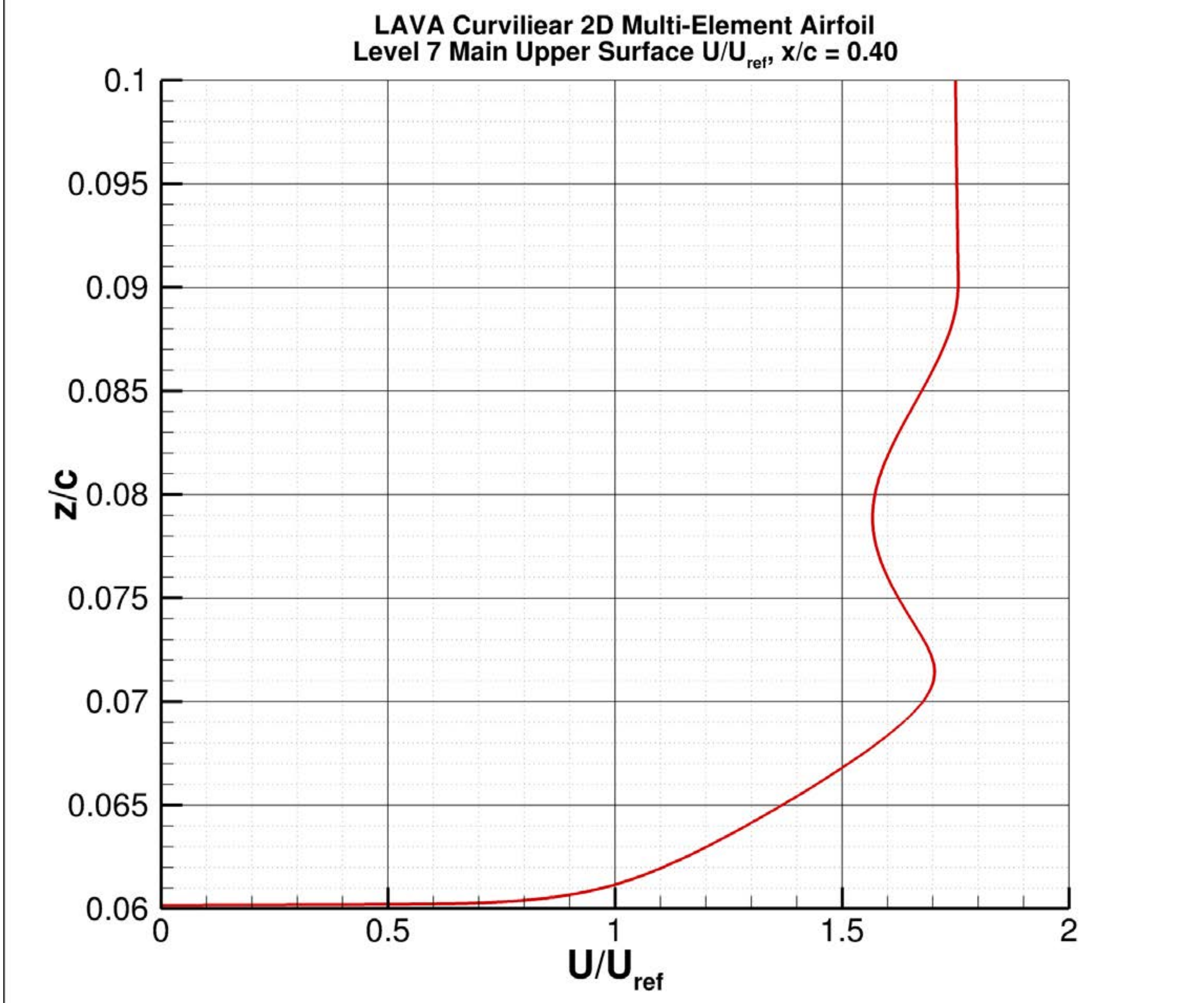
LAVA Curvilinear Results: C_f (mag)



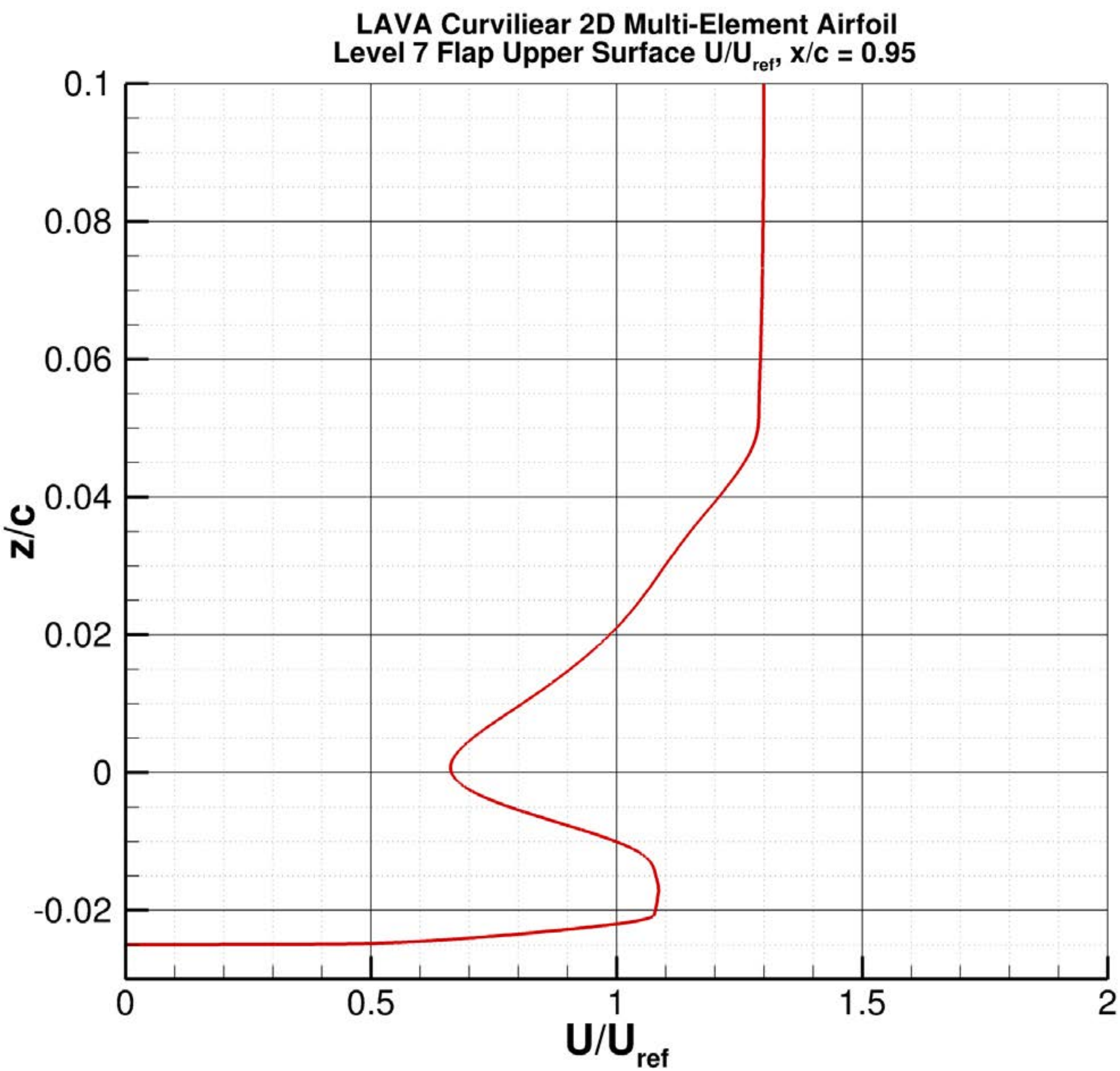
LAVA Curvilinear Results: *U* 1D Slices



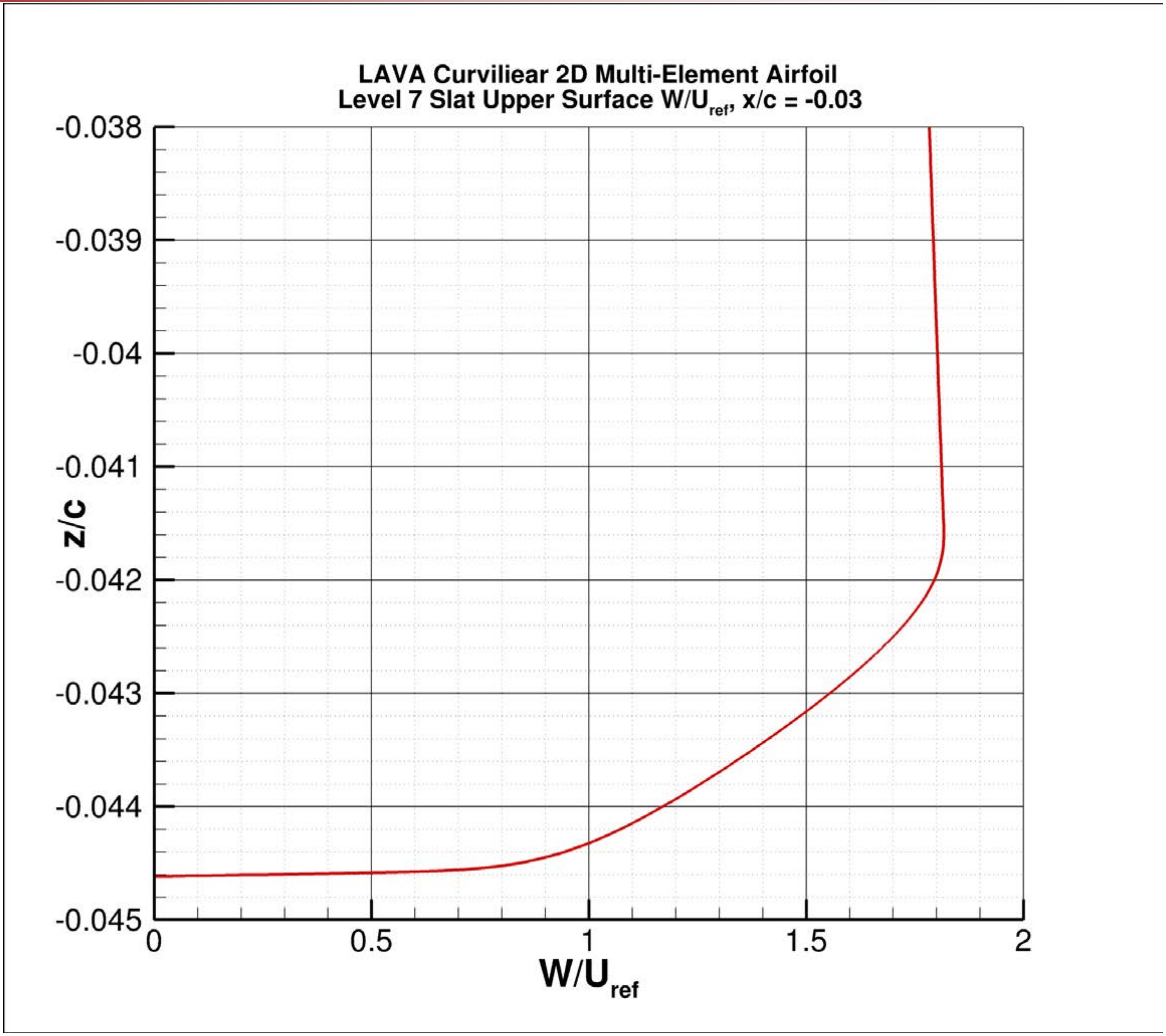
LAVA Curvilinear Results: *U* 1D Slices



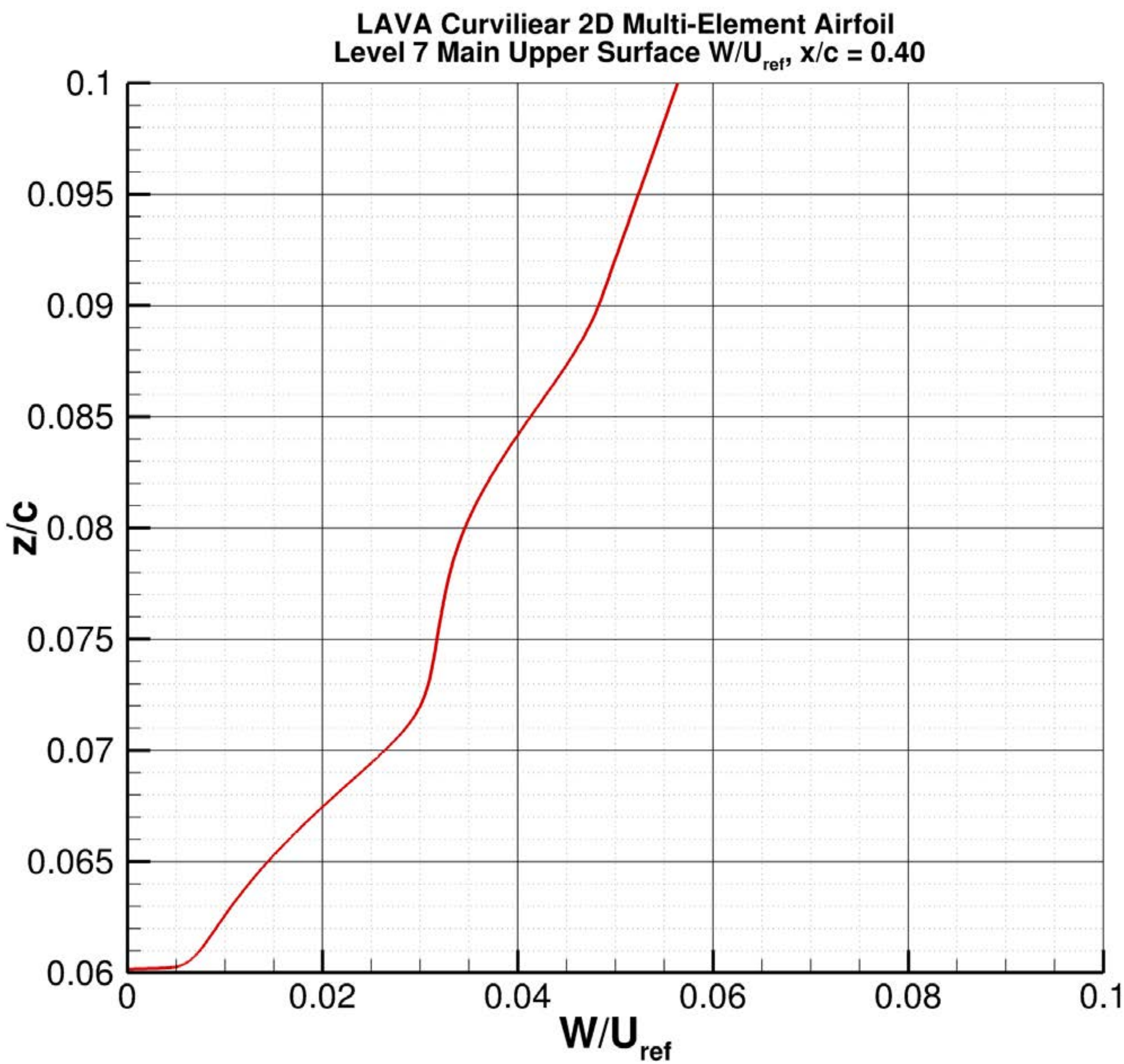
LAVA Curvilinear Results: *U* 1D Slices



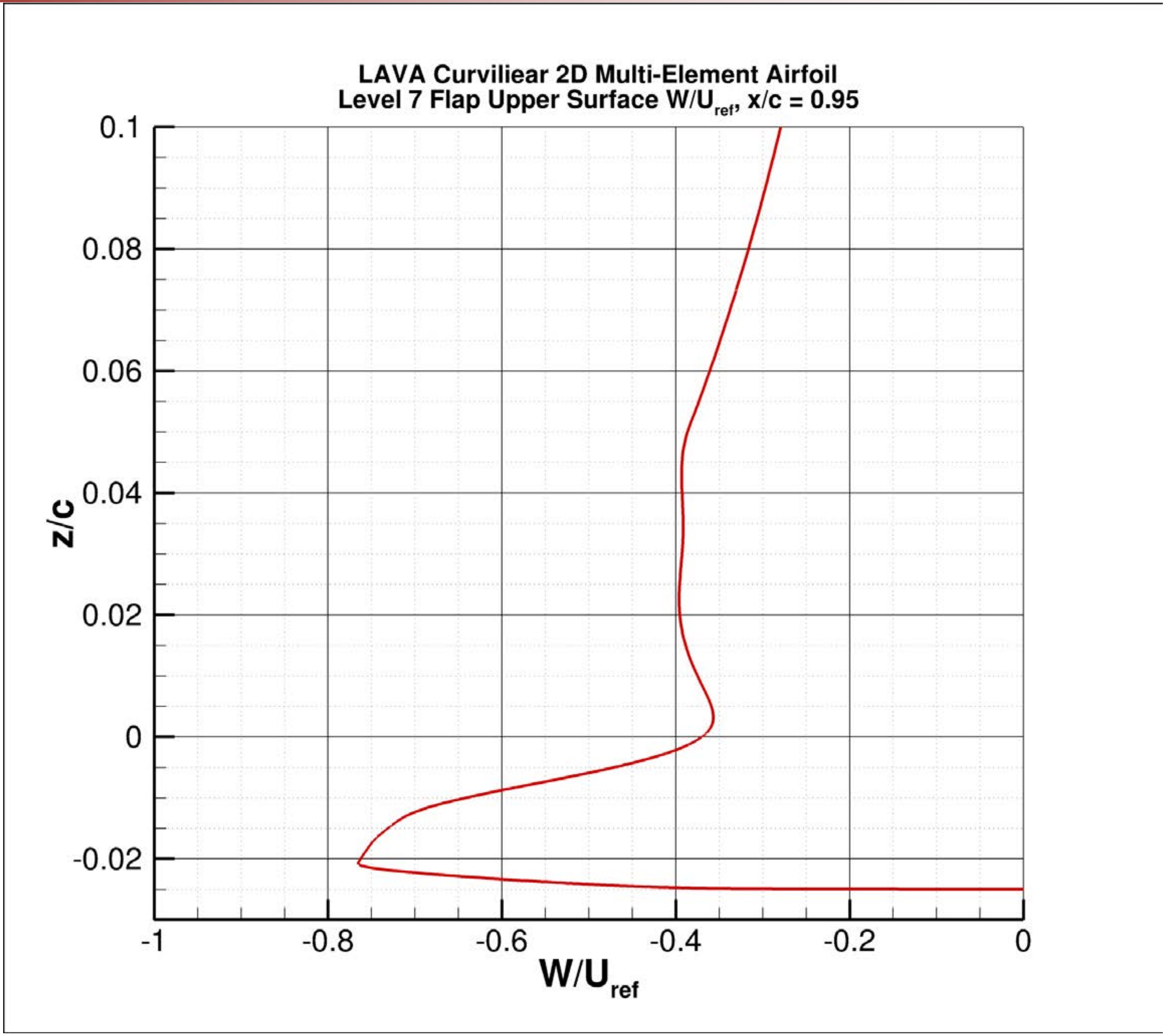
LAVA Curvilinear Results: *W* 1D Slices



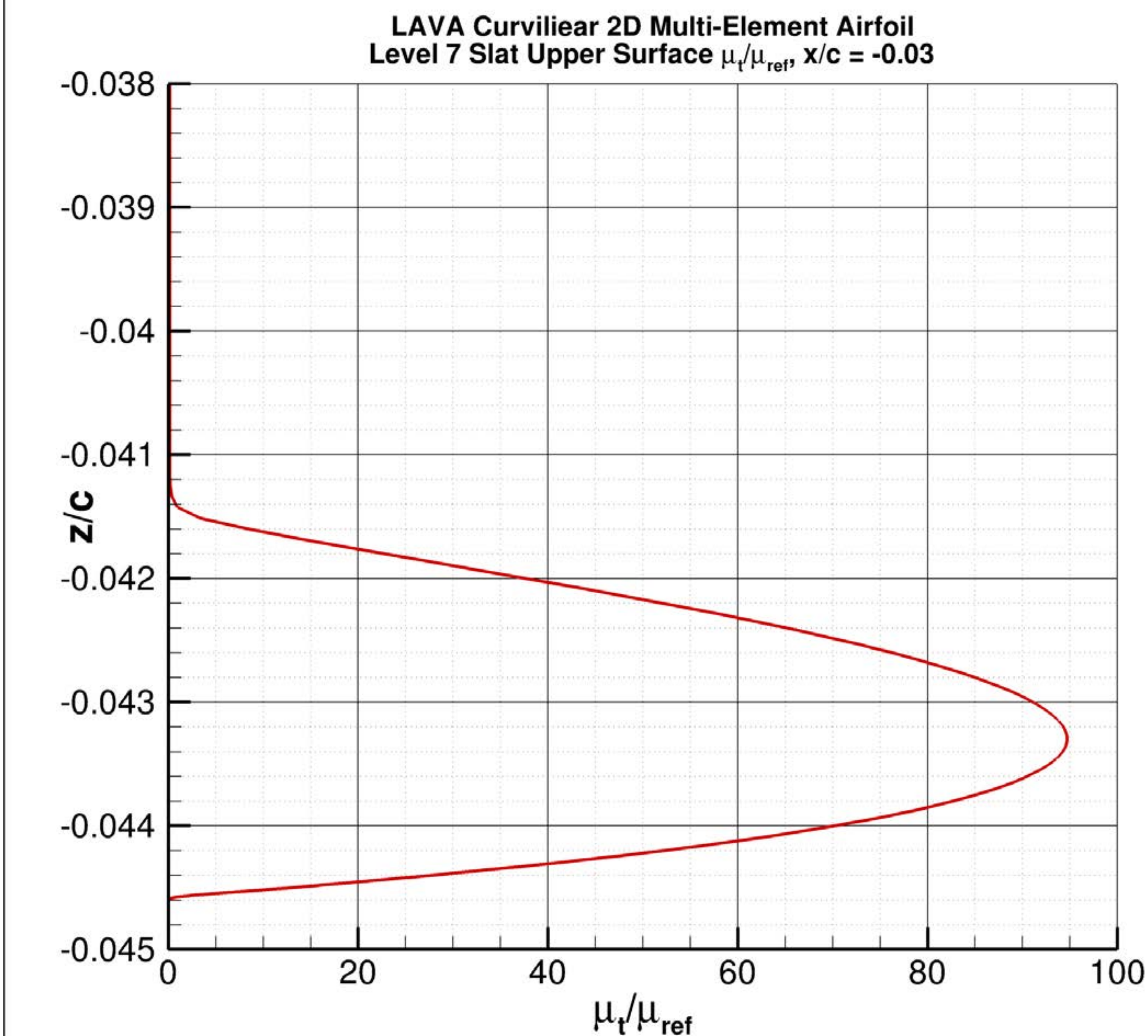
LAVA Curvilinear Results: *W* 1D Slices



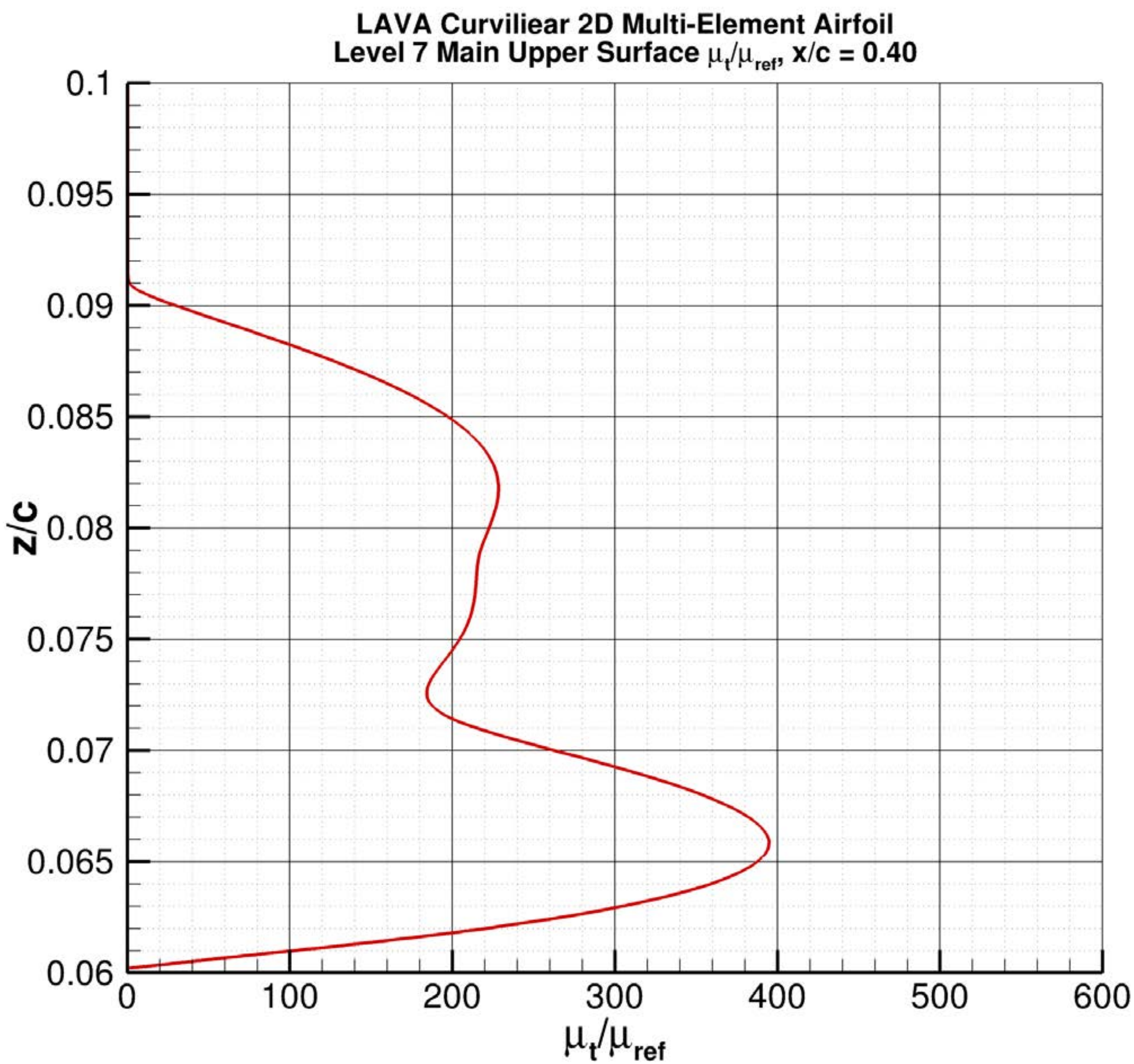
LAVA Curvilinear Results: *W* 1D Slices



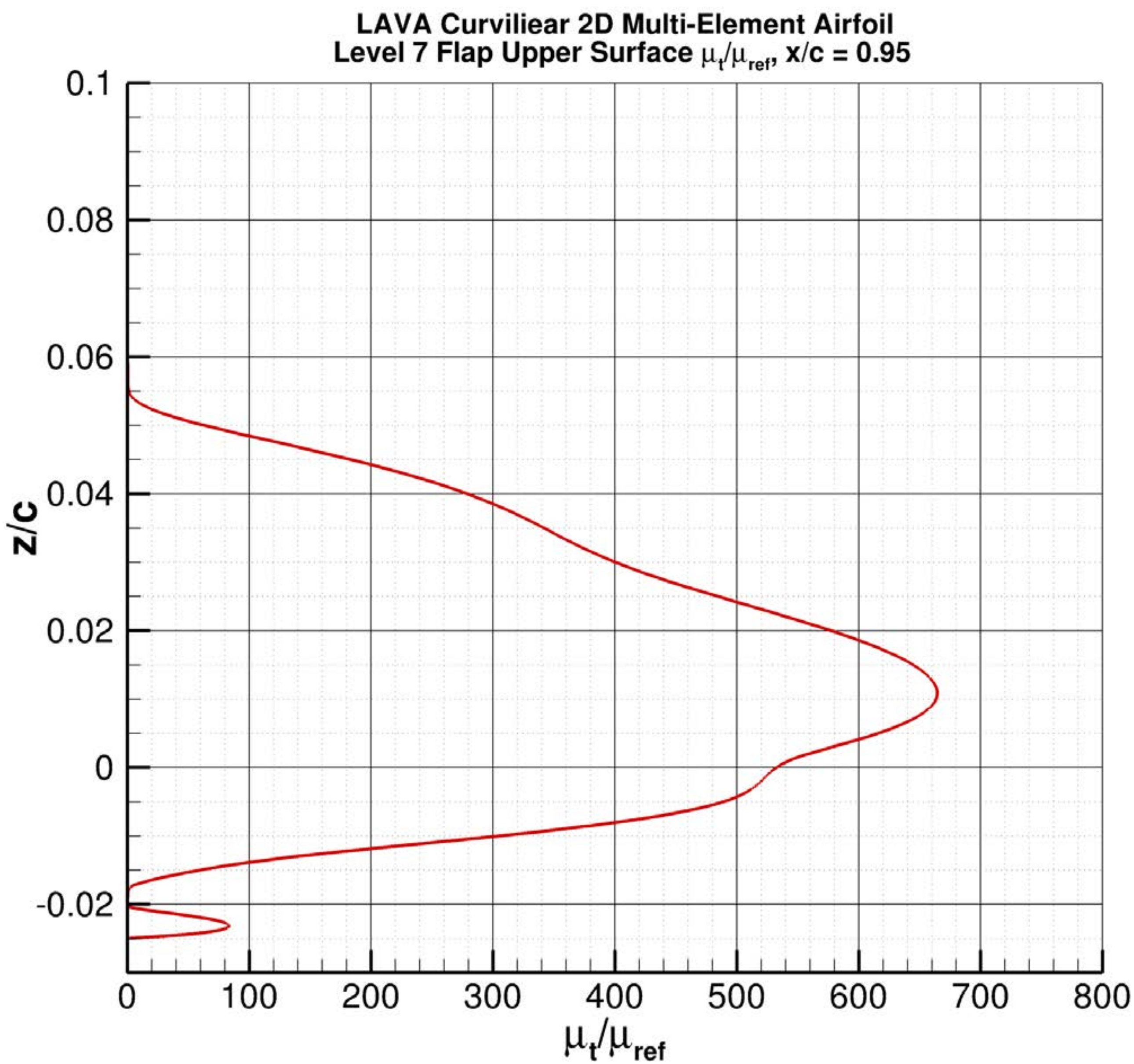
LAVA Curvilinear Results: μ 1D Slices



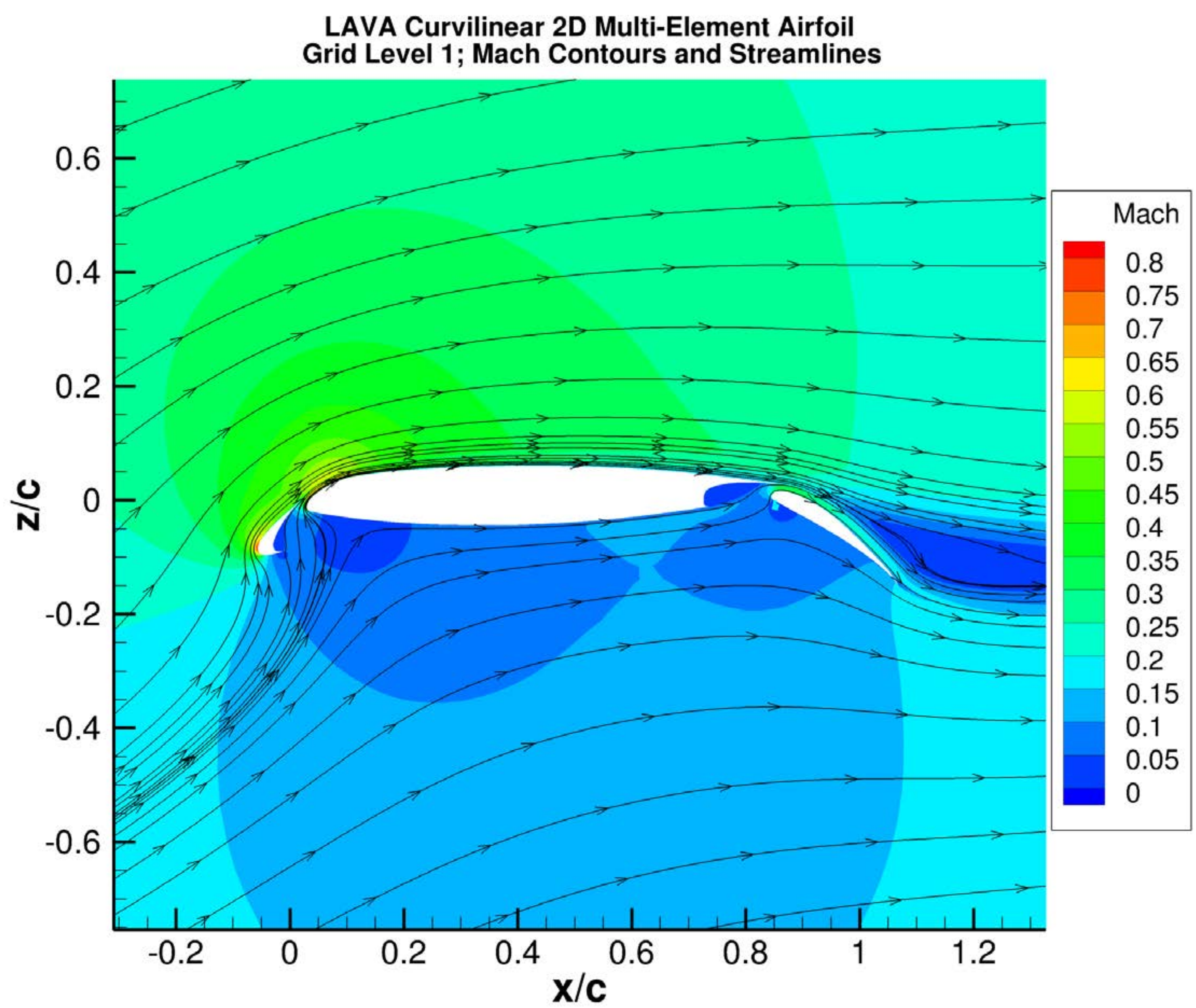
LAVA Curvilinear Results: μ 1D Slices



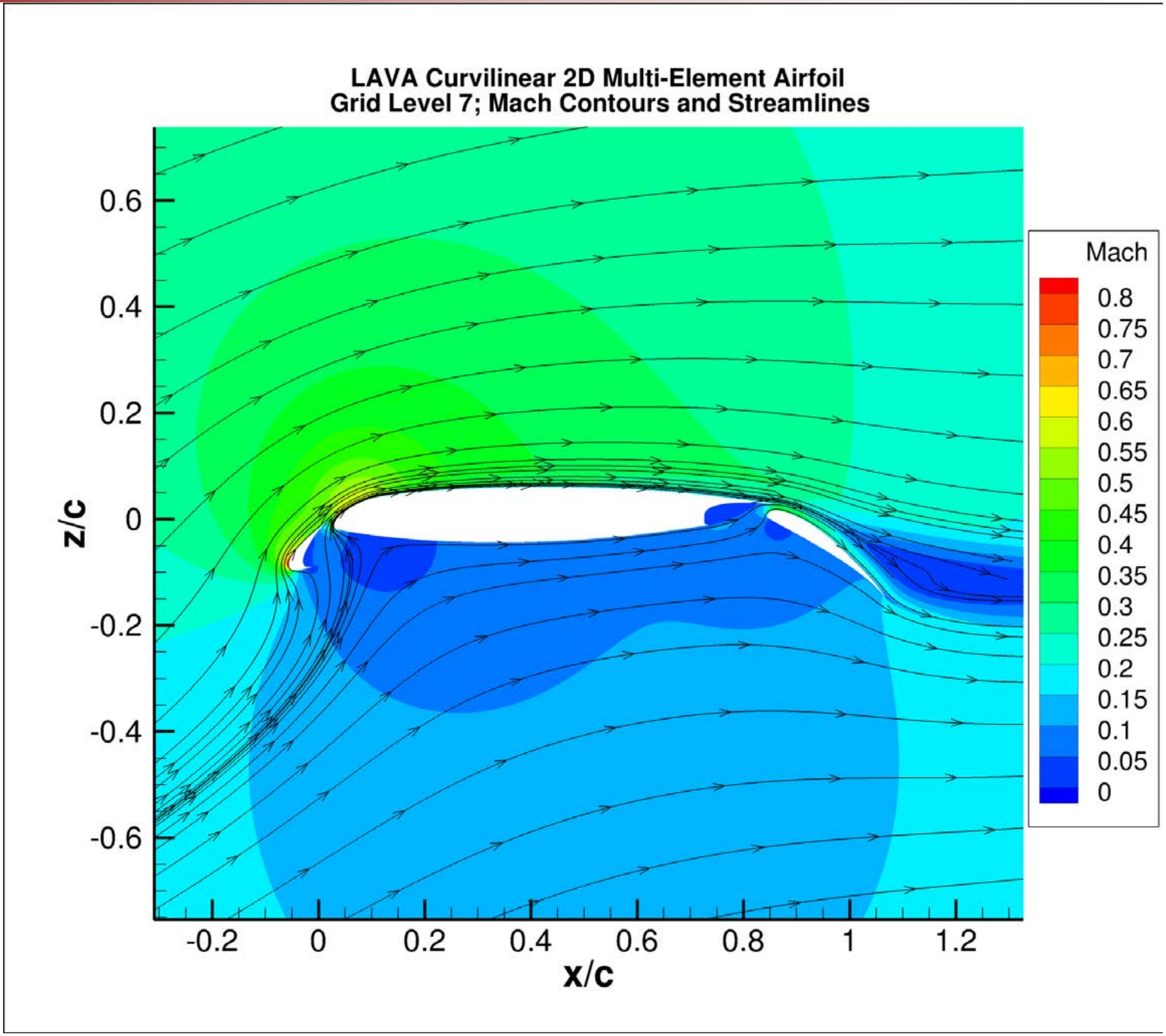
LAVA Curvilinear Results: μ 1D Slices



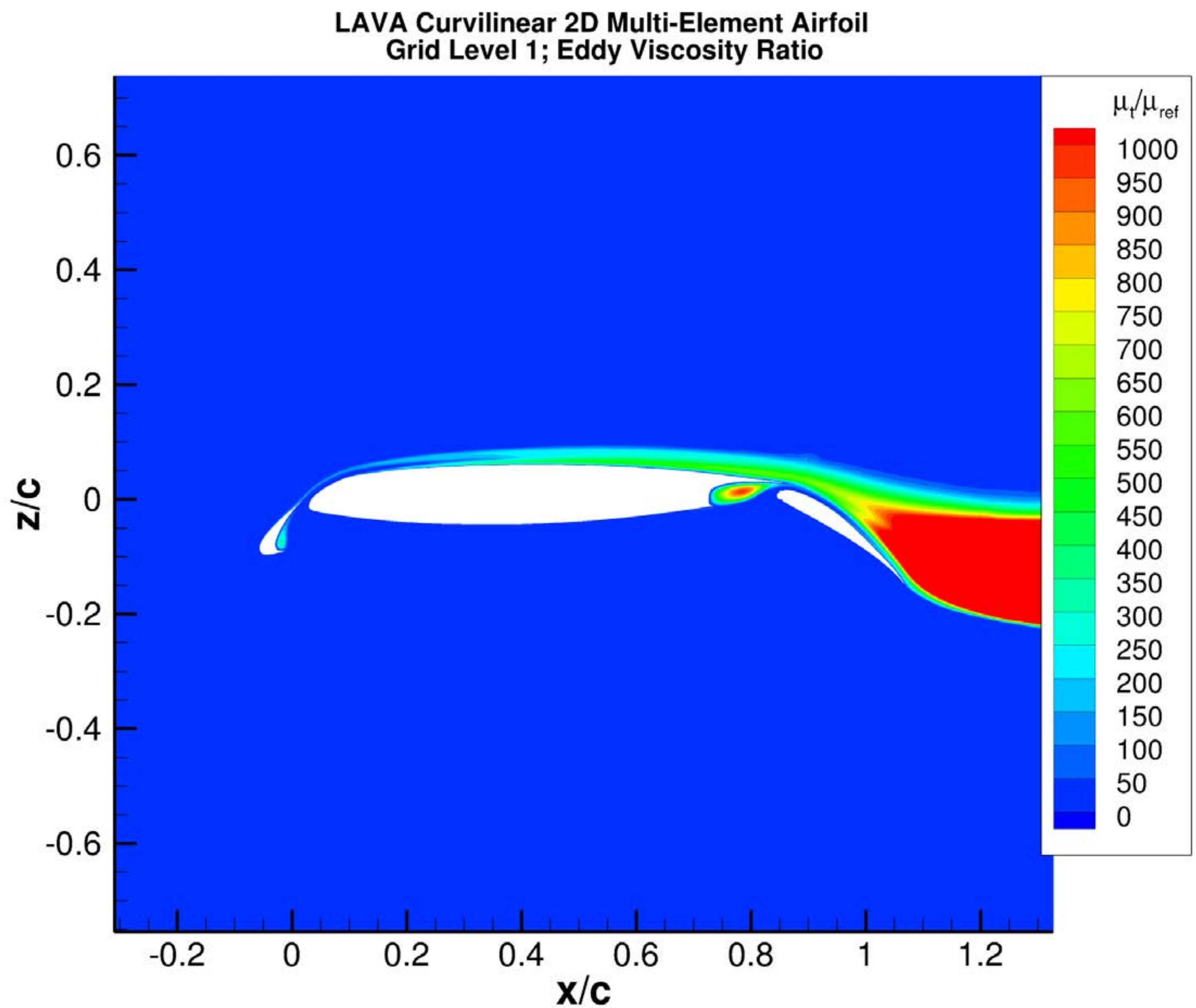
LAVA Curvilinear Results: Mach Contour



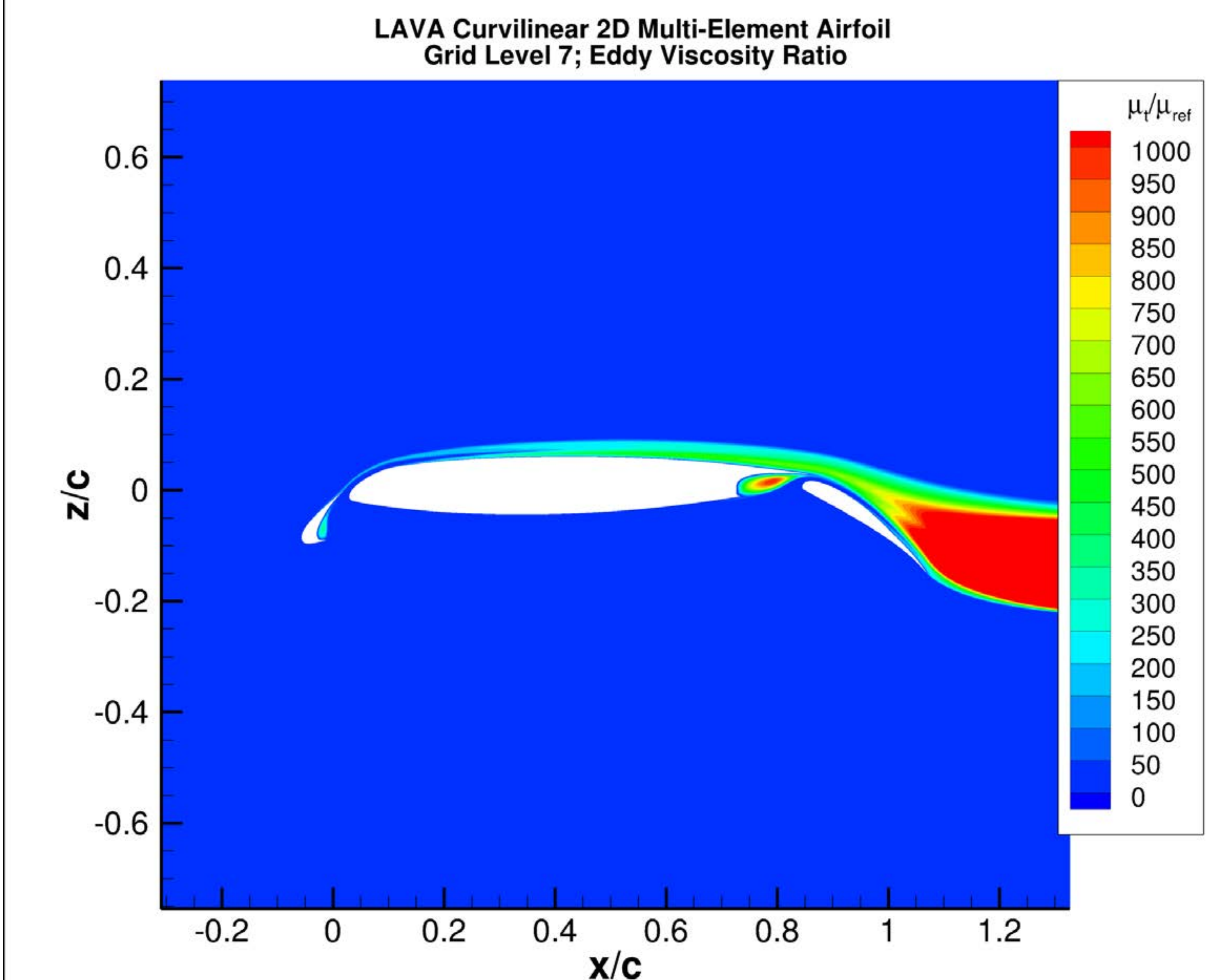
LAVA Curvilinear Results: Mach Contour



LAVA Curvilinear Results: Eddy Viscosity Ratio



LAVA Curvilinear Results: Eddy Viscosity Ratio



LAVA Curvilinear Results: Conclusions

Conclusions

- As expected from HLPW4 problem statement, no separation (except in coves) is evident in structured results
- Structured: More cells → more lift, less drag → higher *L/D*
  - Finer grids: higher peak C_p on each element
- Grid convergence intercept values for C_L and C_D match well with FUN3D results and LAVA Unstructured results
- C_p and C_f profiles match within 0.5% between FUN3D, LAVA Unstructured, and LAVA Curvilinear results for the Level 7 mesh
- Structured grids converge to grid-converged loads quicker and with fewer total grid cells than for unstructured codes (regardless of wake refinement grids)

Recommended Best Practices

- Avoid high aspect ratio cells in slat/main element coves by stopping growth of volume mesh and then dividing it into several pieces before the high aspect ratio cells appear
- Ensure points belonging to non-body-fitted grids are blanked sufficiently far away from the surface; otherwise, ripples can appear in pressure profiles