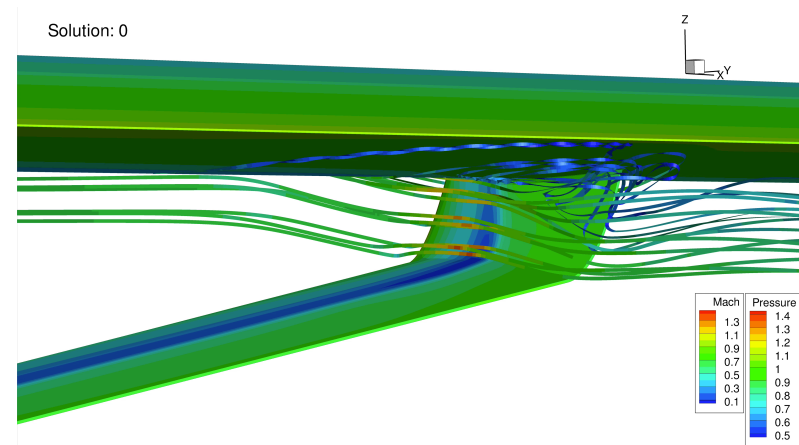


NASA Ames Research Center Contributions to the PADRI workshop

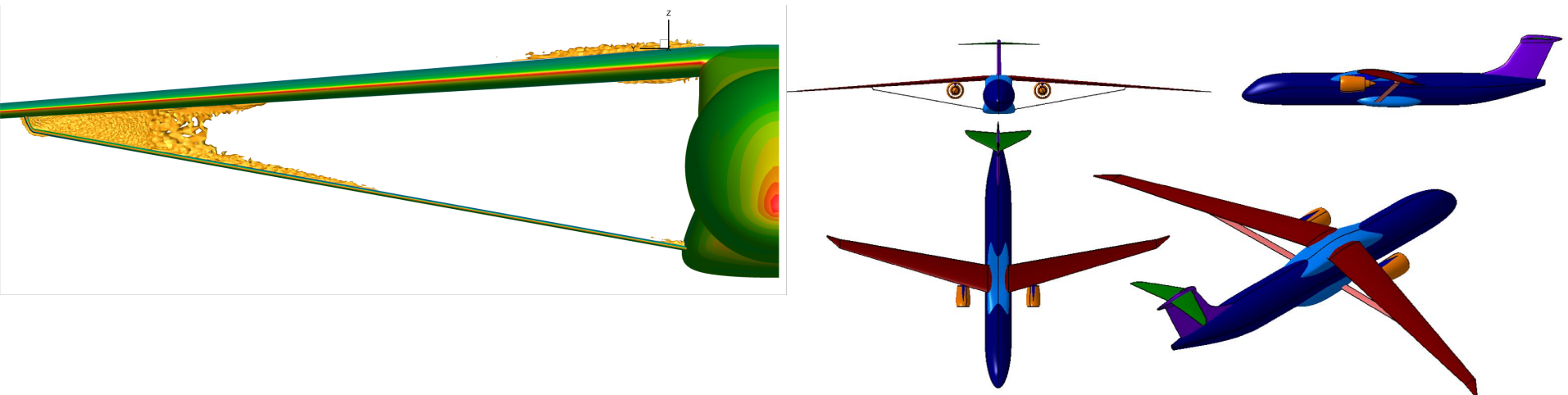
Gaetan Kenway
Jeffery Housman
Cetin Kiris

Computational Aerosciences Branch
NASA Ames Research Center



November 29, 2017

- PADRI: A common platform for validation of aircraft drag reduction technologies
- Generic strut-braced wing configuration
- Slightly swept wing for low cruise Mach number (0.72)
- Simplified geometry without engines, empennage or flap-track fairings
- Significant wave-drag and flow separation at strut-wing intersection
- Focus of this workshop is to redesign the junction

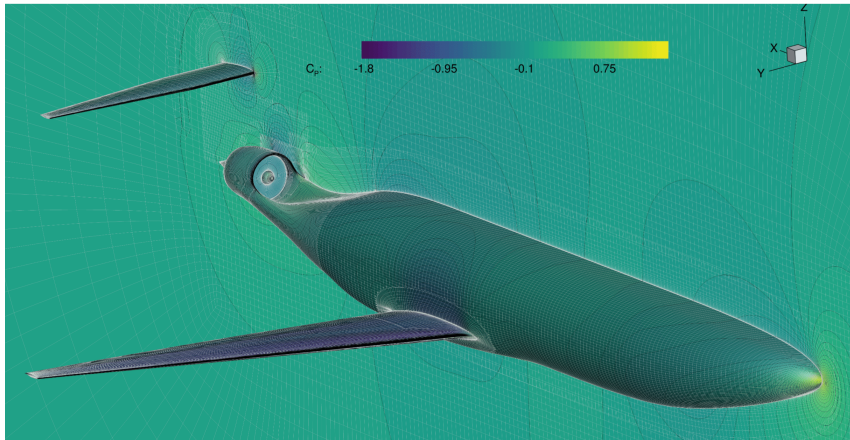




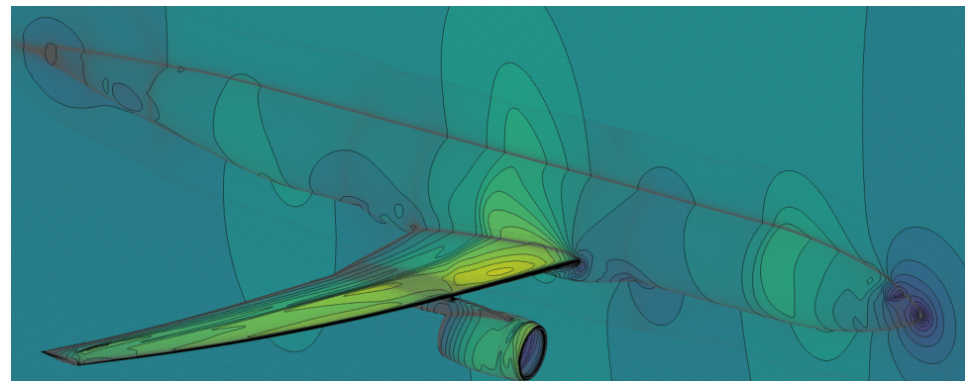
<h2>Python user script</h2> <p>Setup up the problem: objective function, constraints, design variables, optimizer and solver options</p>			
Optimizer interface <i>pyOptSparse</i> Common interface to various optimization software		Aerostructural solver <i>AeroStruct</i> Coupled solution methods and coupled derivative evaluation	
Geometry modeler <i>DVGeometry/GeoMACH</i> Defines and manipulates geometry, evaluates derivatives		Flow solver <i>ADflow</i> Governing and adjoint equations	Structural solver <i>TACS</i> Governing and adjoint equations
SNOPT	Other optimizers		

- Underlying solvers are parallelized and compiled
- All communication done through memory
- Easy-to-use Python scripting interface
- Only using aerodynamic design capacity for PADRI

- Automatic-Differentiation Flow Solver
- Second order finite volume RANS
- Standard SA turbulence model
- Point-matched multiblock and overset grids
- Multiple solvers: Runge Kutta (RK), DDADI, approximate Newton Krylov (ANK) and Newton Krylov (NK) algorithms
- DADI, ANK and NK used for optimization
- Extremely fast convergence for small design changes

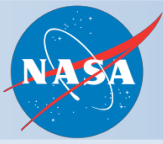


MIT D8 Double Bubble

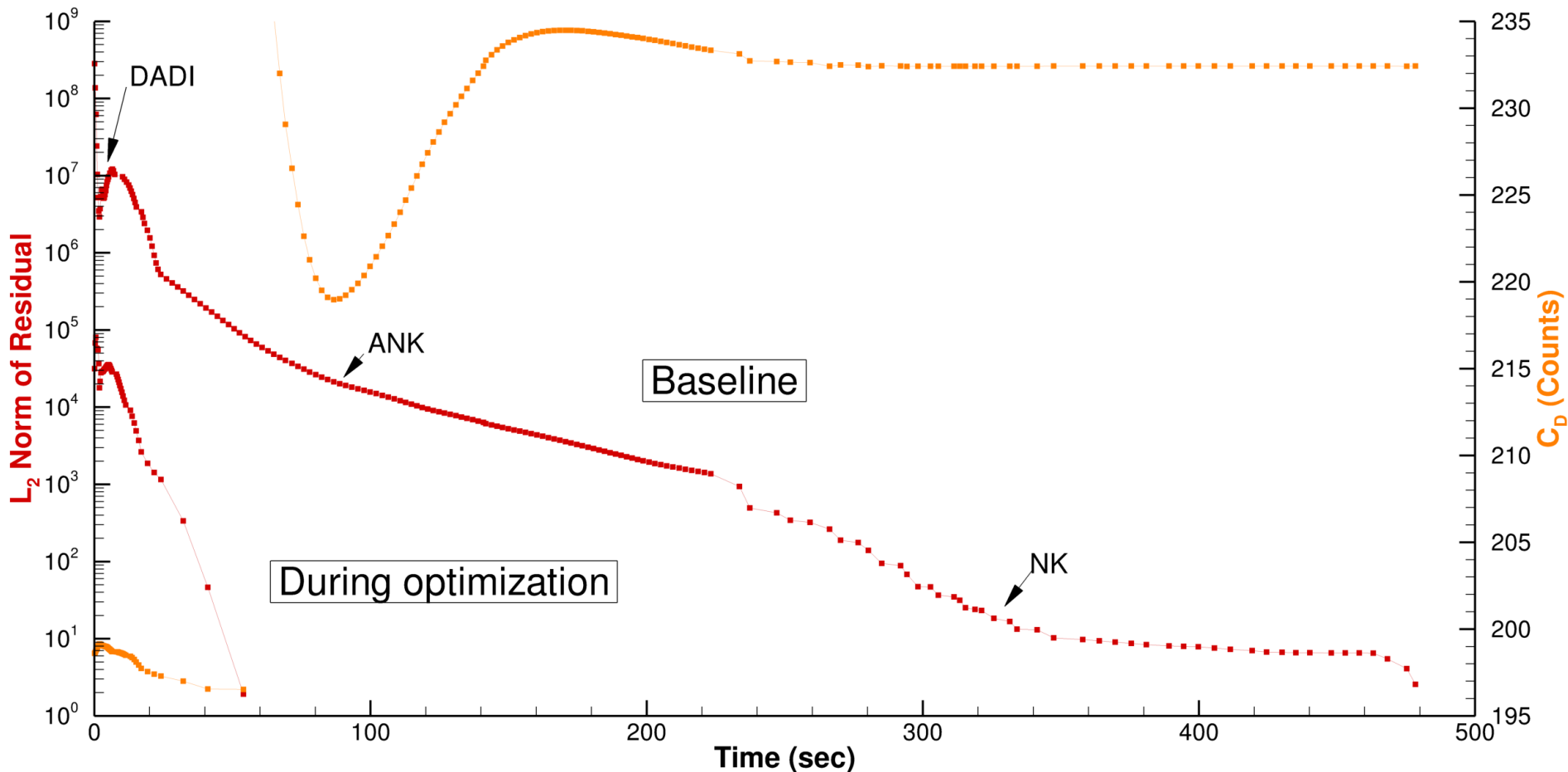


Common Research Model (DPW6)

ADFlow Solver Convergence



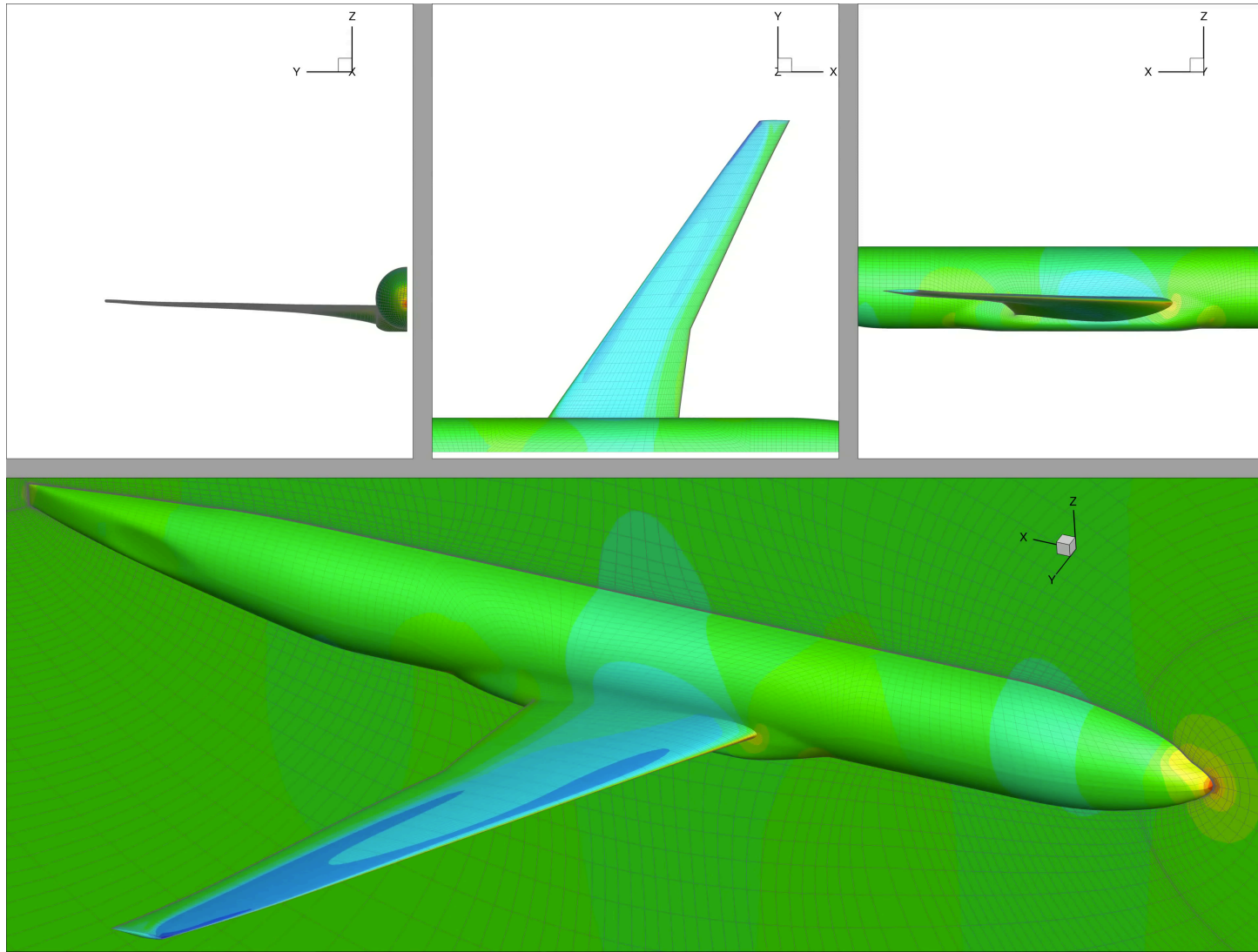
- Combination of three algorithms: Diagonalized Alternating Direction Implicit (DADI), Approximate Newton-Krylov (ANK) and Newton Krylov (NK)
- Newton-Krylov fully couples flow and turbulence variables



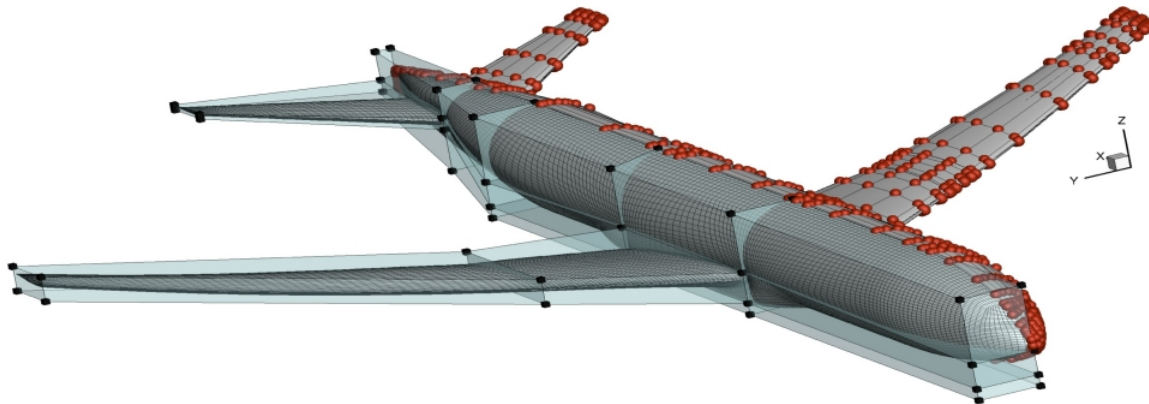
Mesh Deformation



- Inverse-distance weighting method
- Parallel, fast and highly robust for large deformations



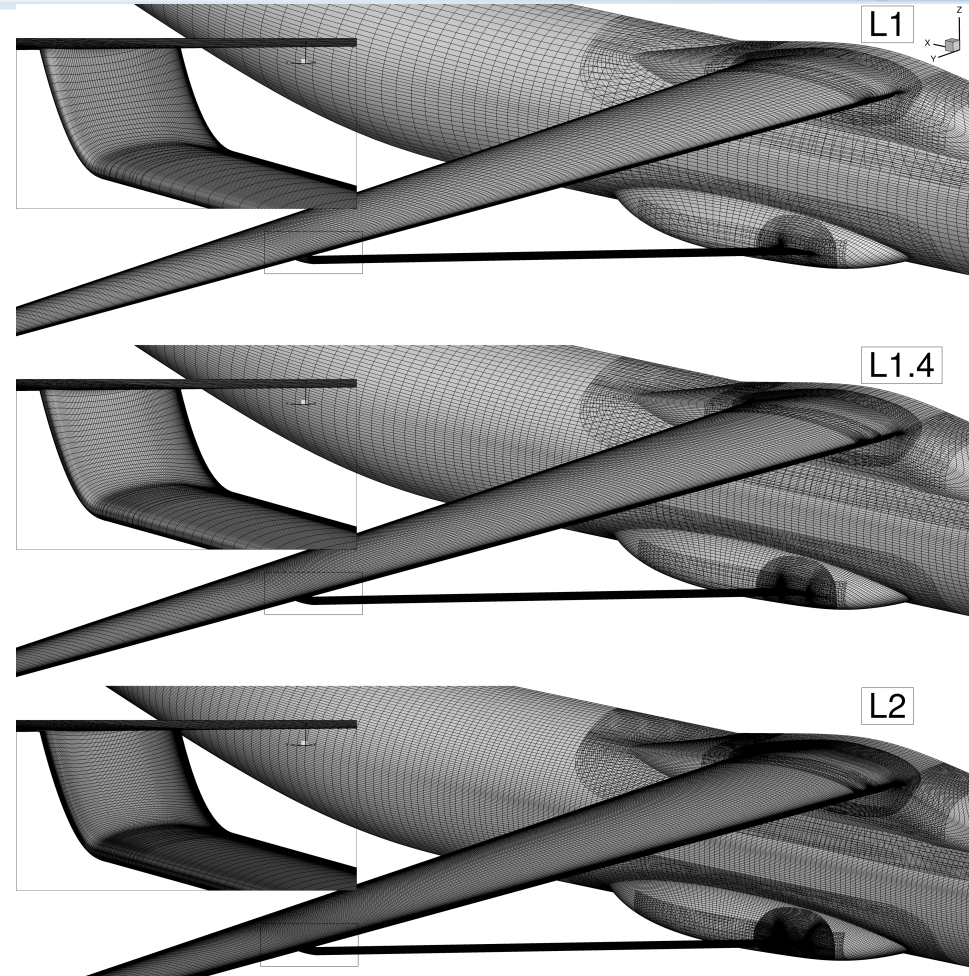
- Free-form deformation (FFD) volume approach
- Parametrize the change in geometry
- Embed discrete geometry into trivariate B-spline volumes
- Point-inversion algorithm to find u-v-w coordinates
- Control point motion smoothly controls the underlying geometry
- Sub-FFD approach for localized control



Overset Meshes

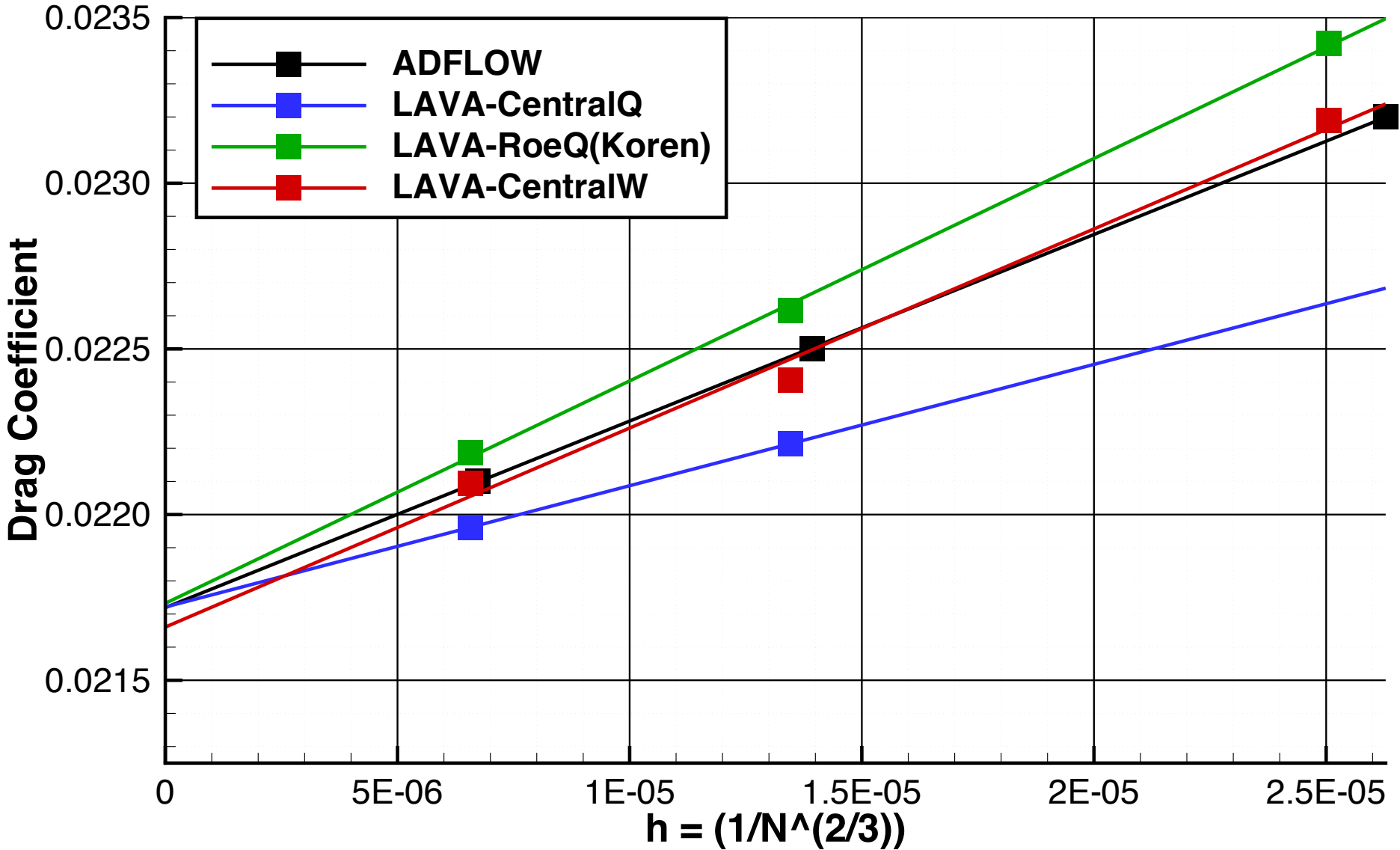
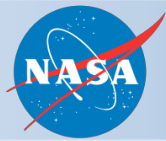


- Surface patches generated with Pointwise
- Chimera Grid Tools (CGT) for volumetric extrusion
- Hyperbolic mesh extrusion
- Consistent refinement between levels

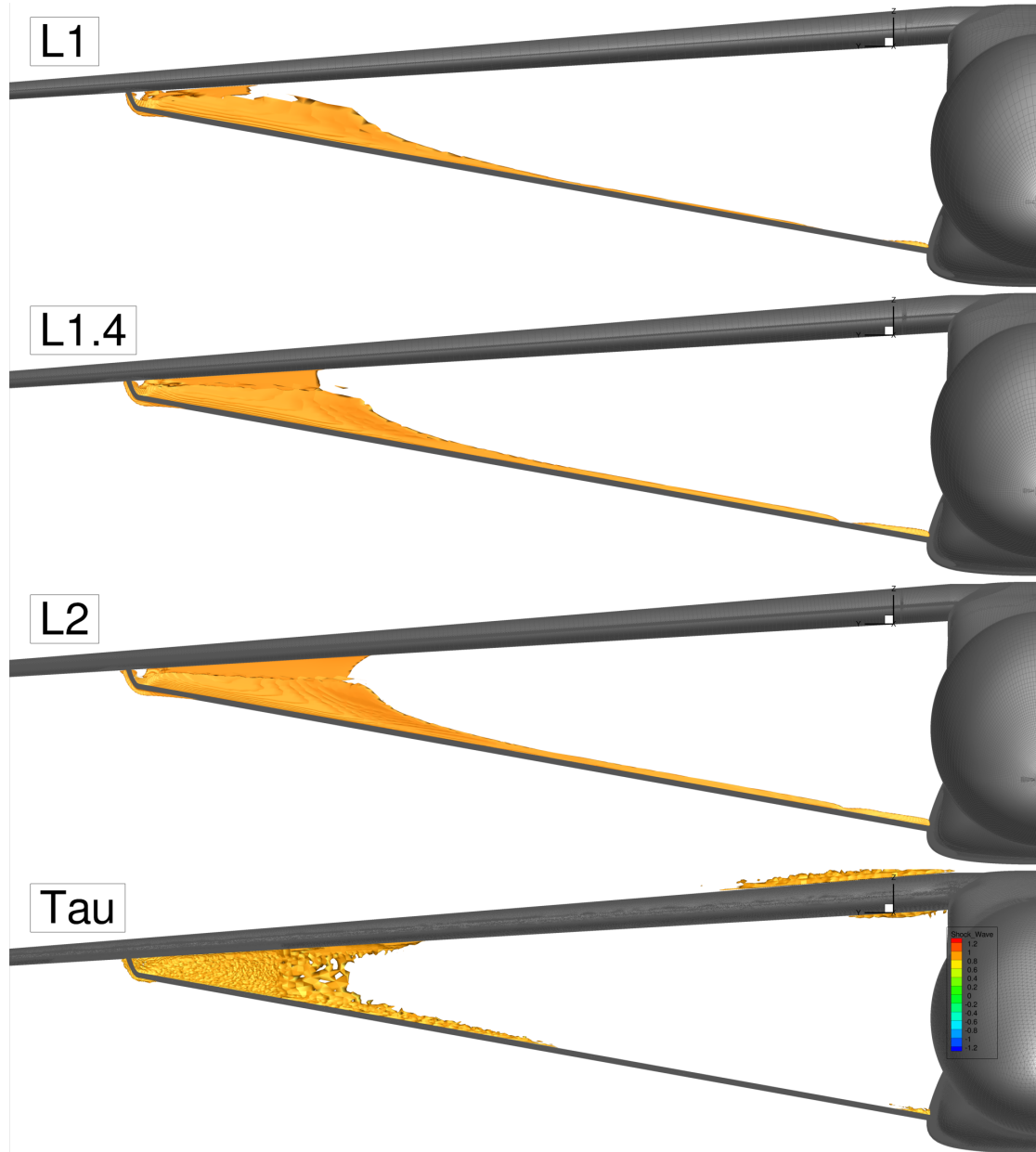
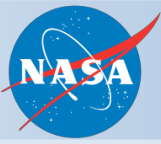


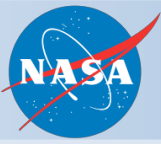
Mesh	# Wing Chordwise	# Wing Spanwise	# Truss Chordwise	# Truss Spanwise	Total Cells	Drag (counts)
L1	64	202	96	110	7.4 M	232.42
L1.4	88	282	134	154	19.2 M	224.61
L2	126	404	192	220	57.3 M	220.87

Baseline Configuration Grid Convergence



Baseline Solutions (Shock Sensor)





- Single point drag minimization ($CL=0.417$)
- Design Variables: FFD Shape position + angle of attack
- Flight condition: $M=0.72$, altitude=30,000 ft, $\alpha=1.0$

- **Case 1**

- Nominal design problem

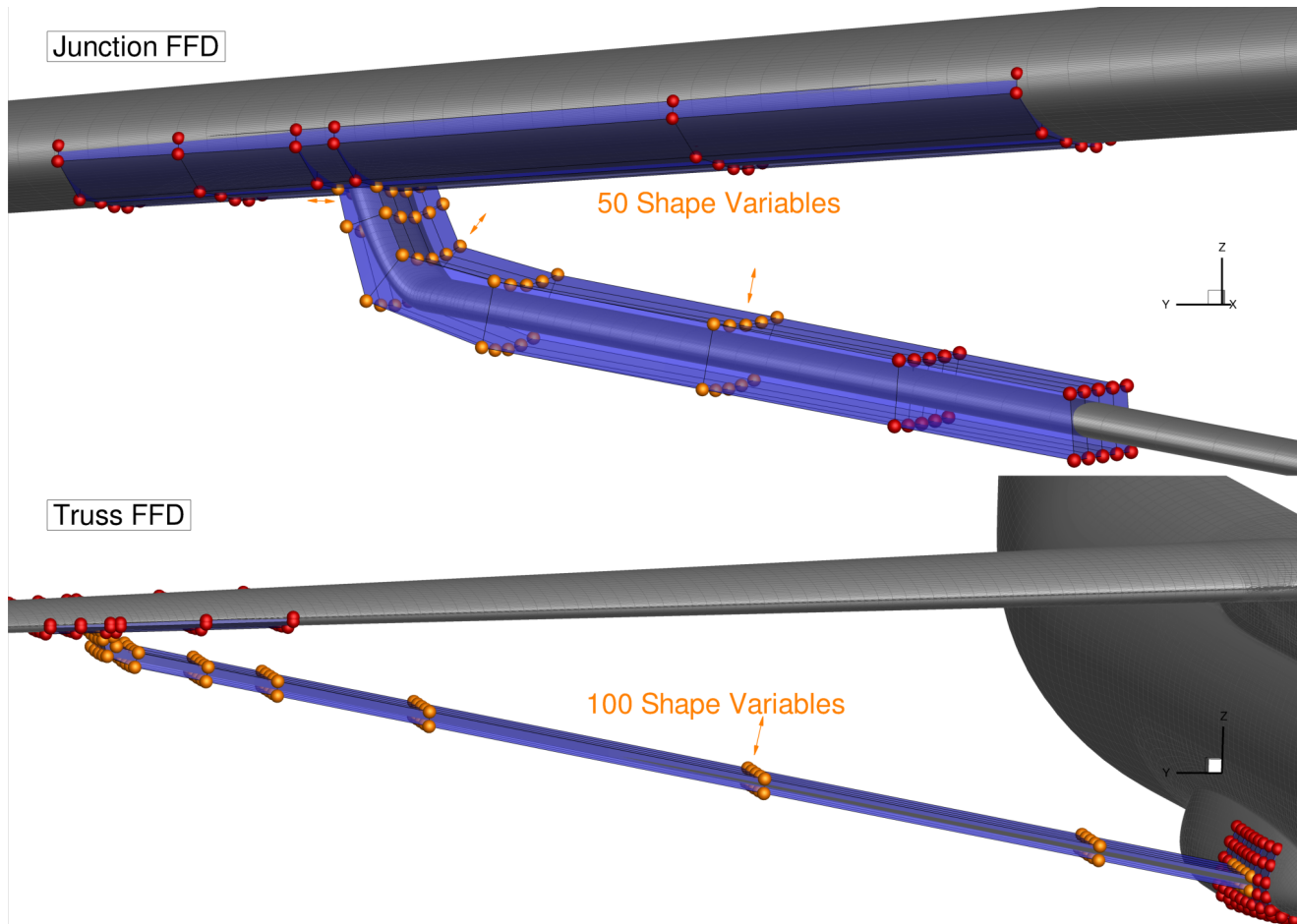
- **Case 2**

- Nominal design problem + fixed trailing edge

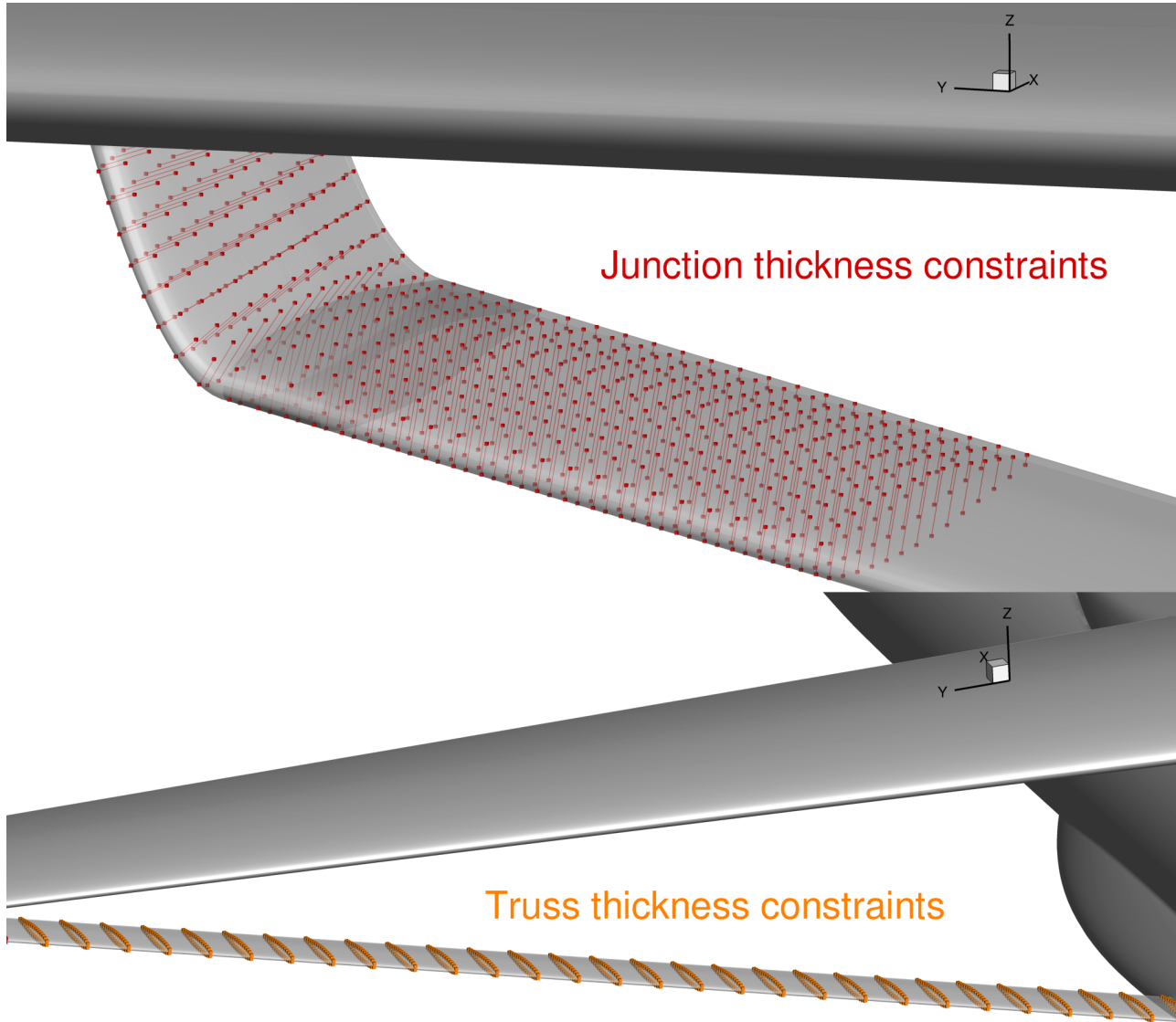
- **Case 3**

- Full truss redesign

- Only truss is modified
- Follows workshop guidelines for design region (Case 1 and 2)
- Orange control point spheres are modified



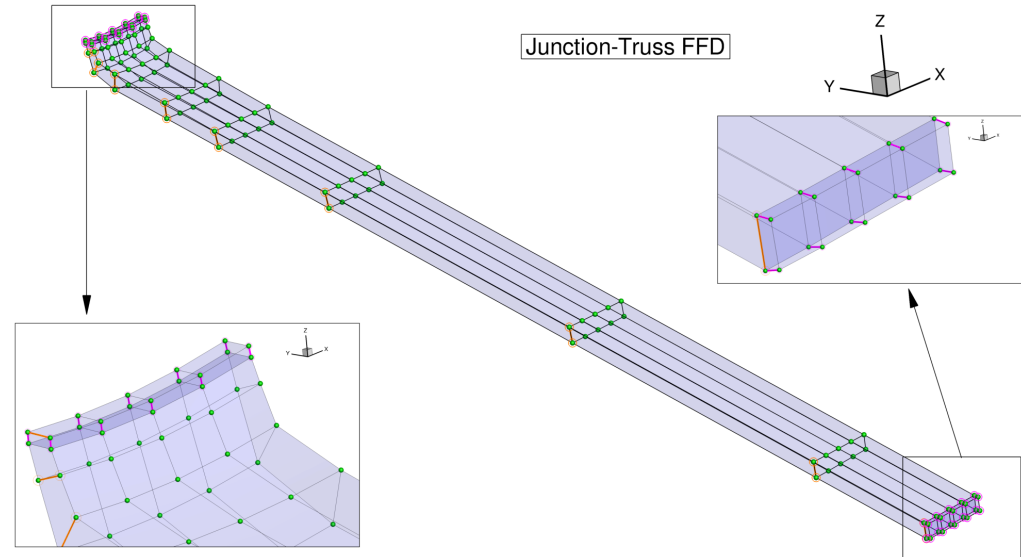
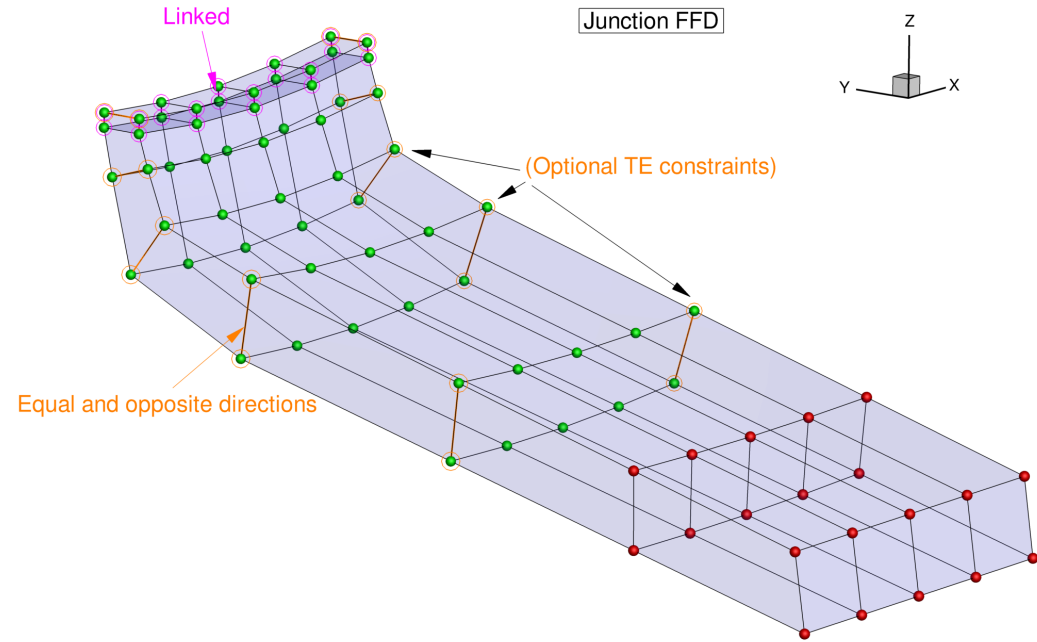
- Explicit “toothpick” thickness constraints



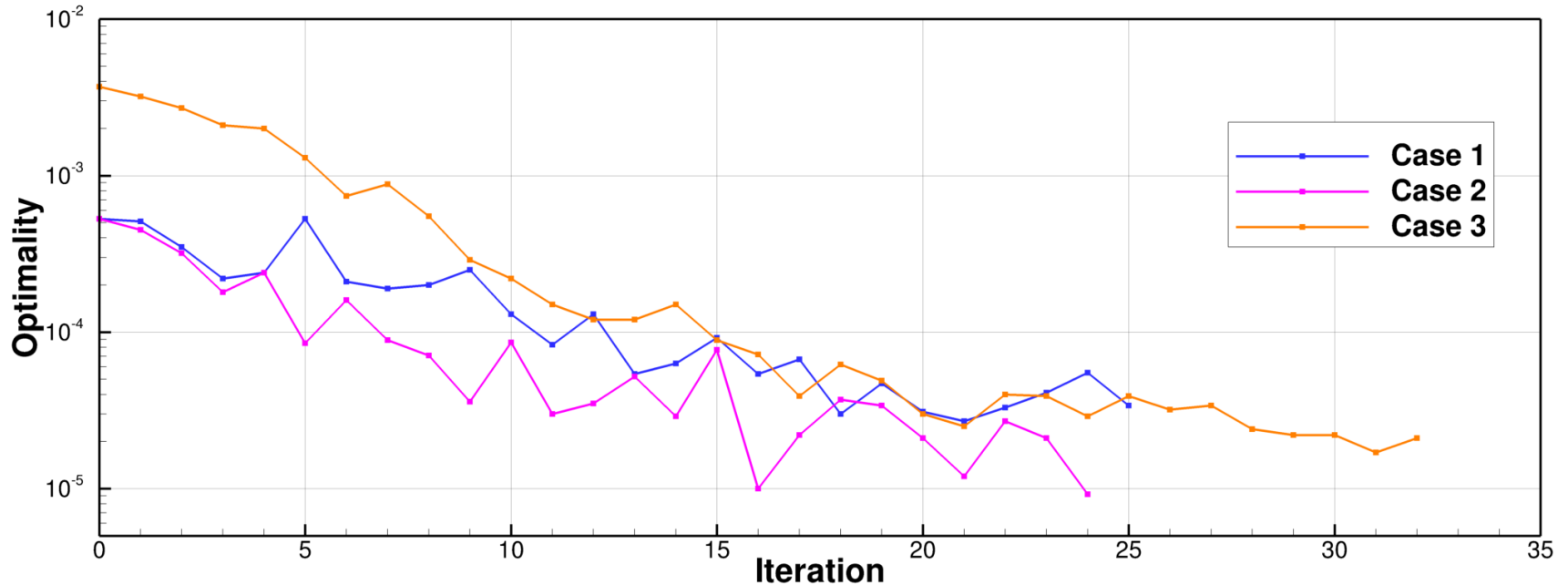
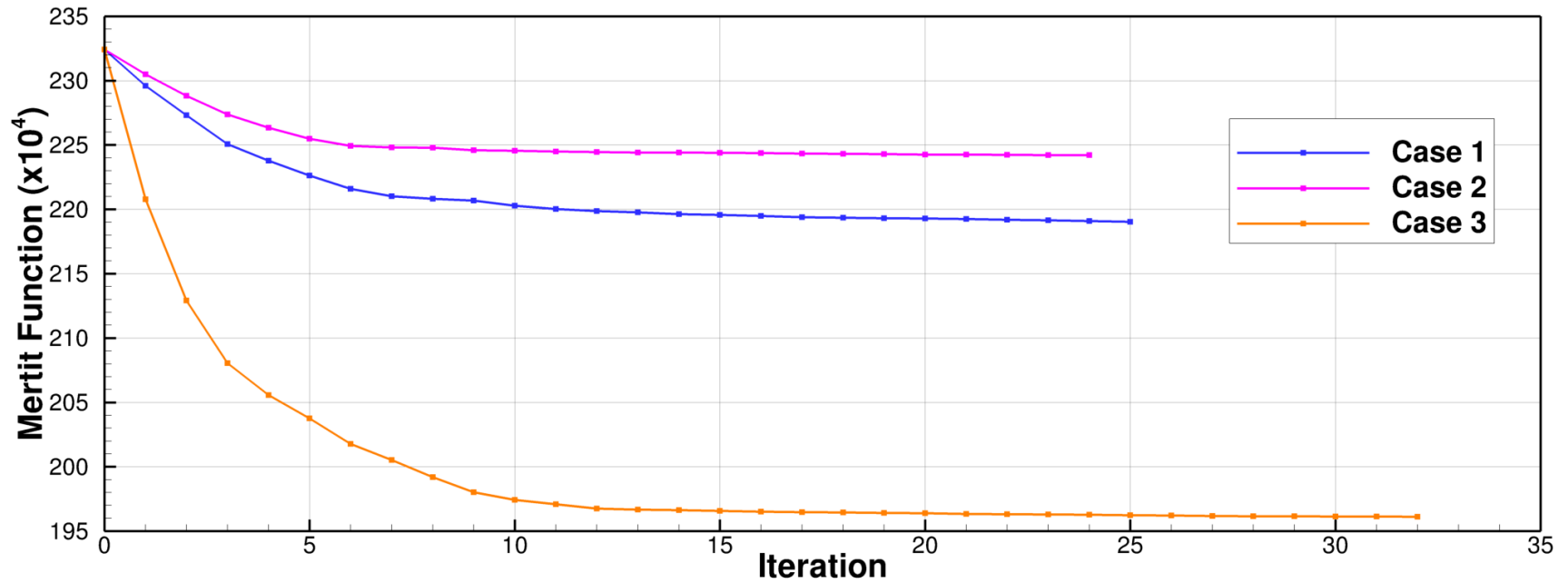
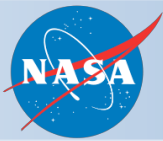
Optimization Constraints



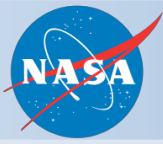
- Linear constraints enforce fixed leading and (optionally) trailing edge
- These constraints are enforced exactly by the optimizer



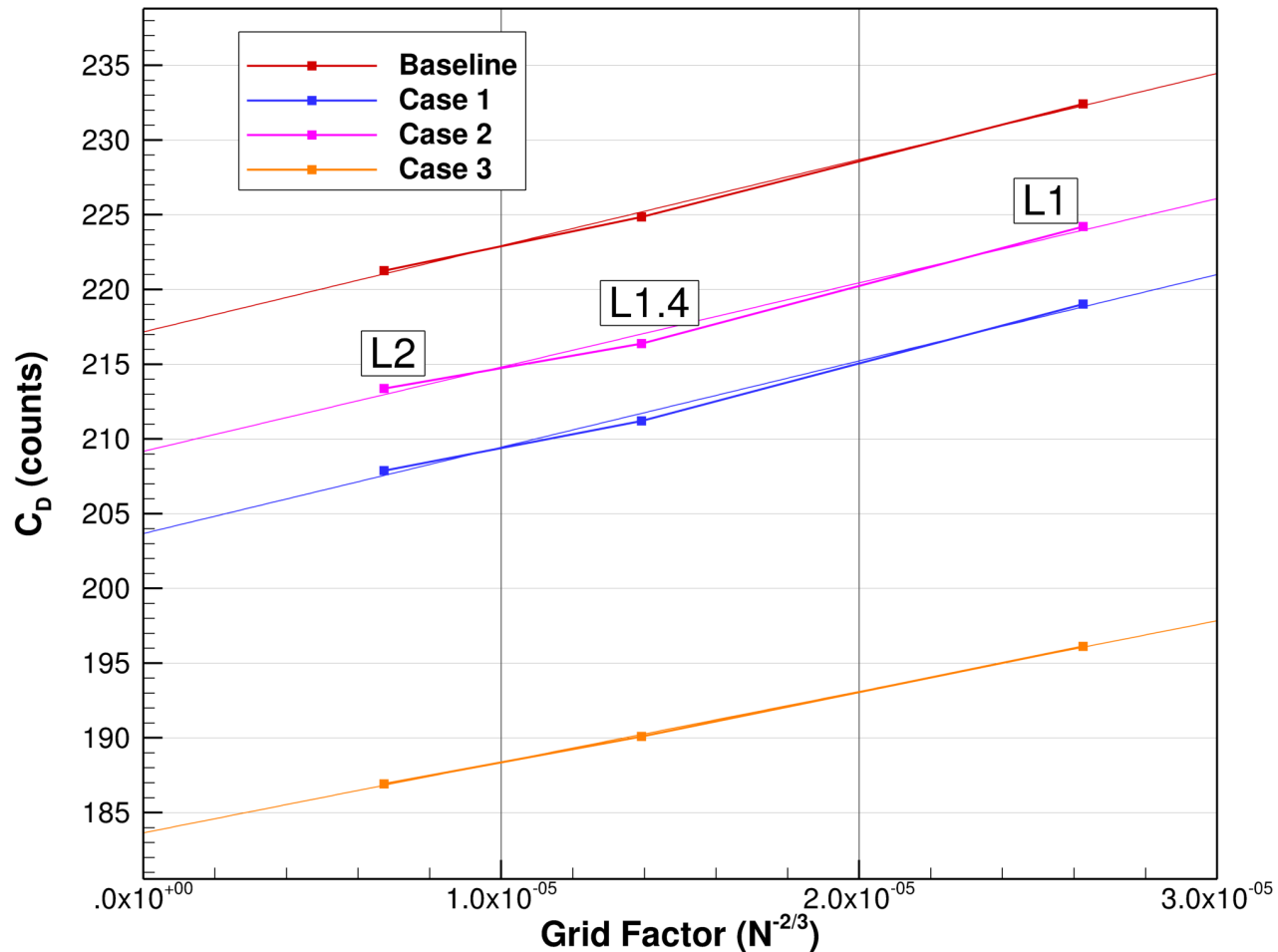
Optimization Convergence History



Grid Convergence Study



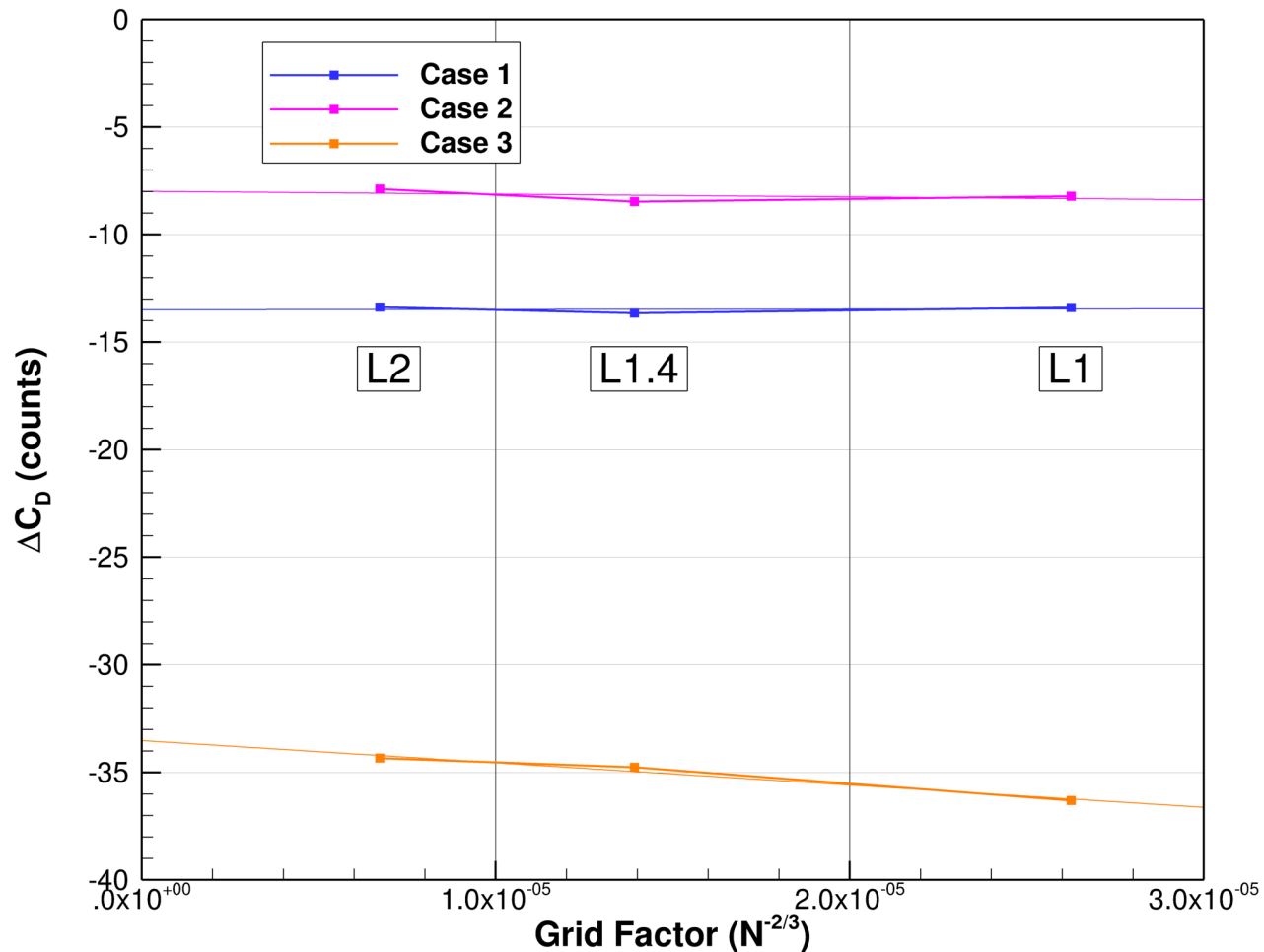
- Optimized L1 shape analyzed using finer meshes



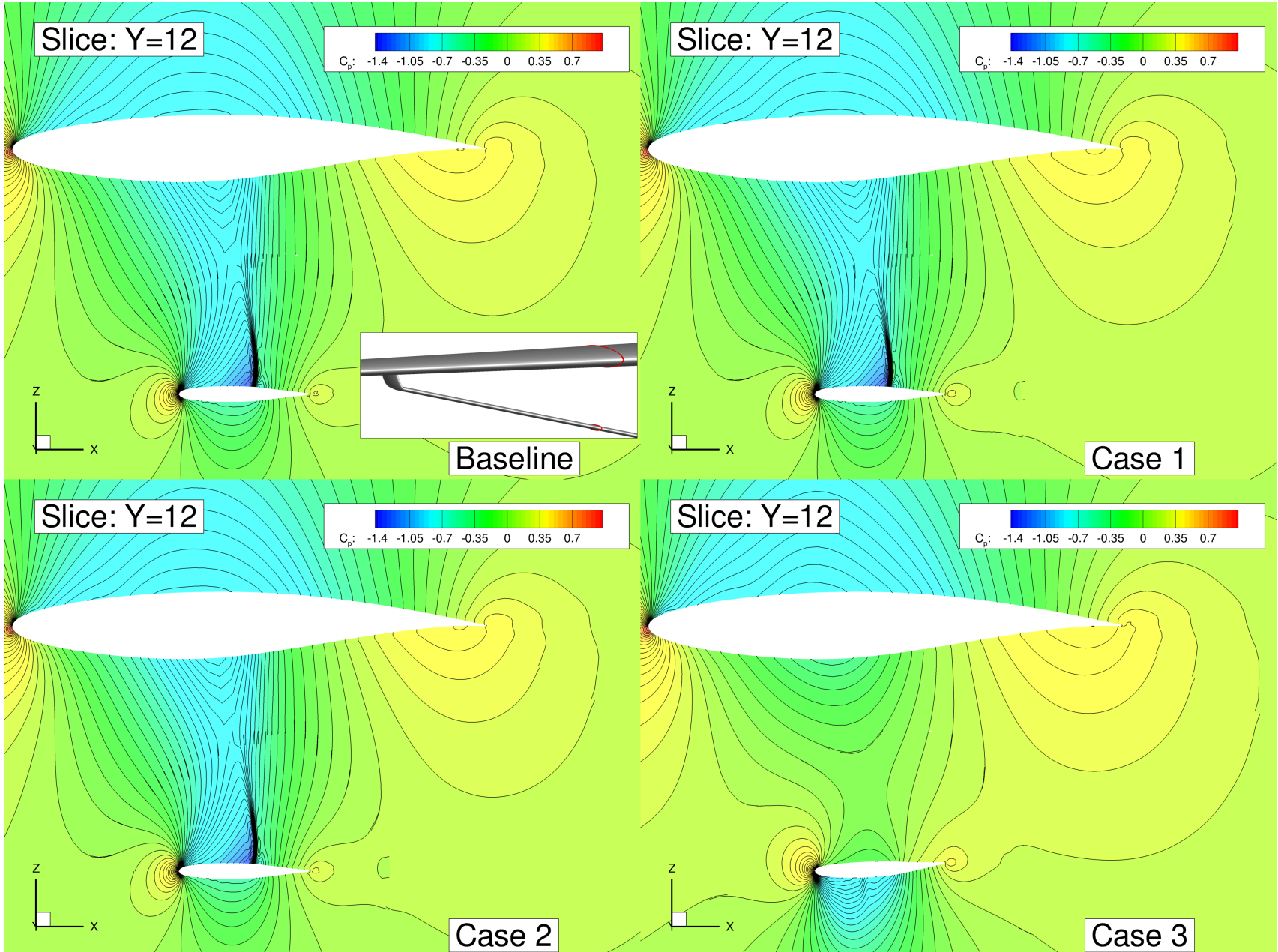
Grid Convergence Study



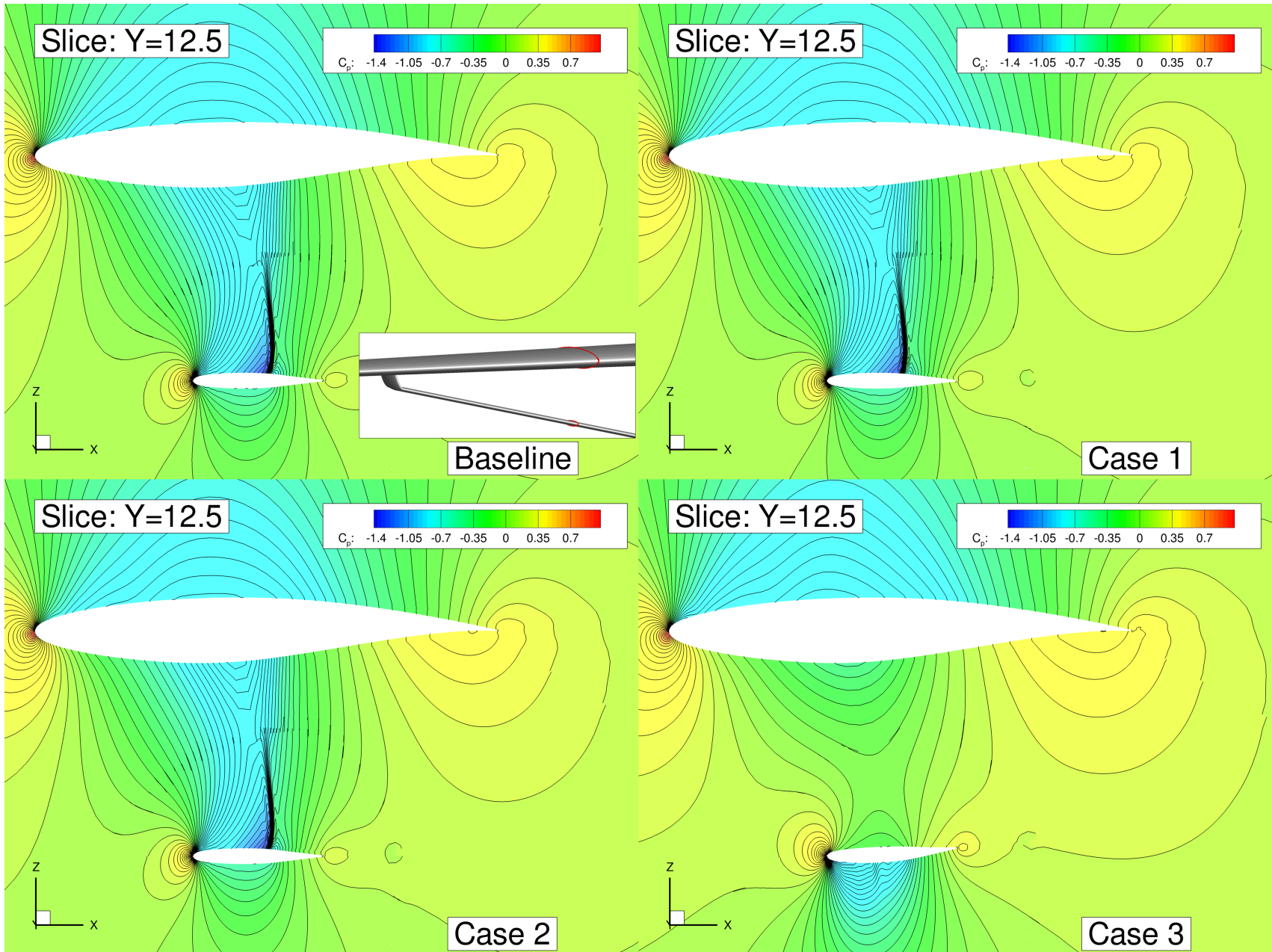
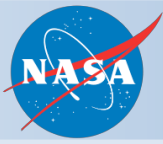
- Nearly constant drag deltas
- L1 mesh capturing the critical flow features



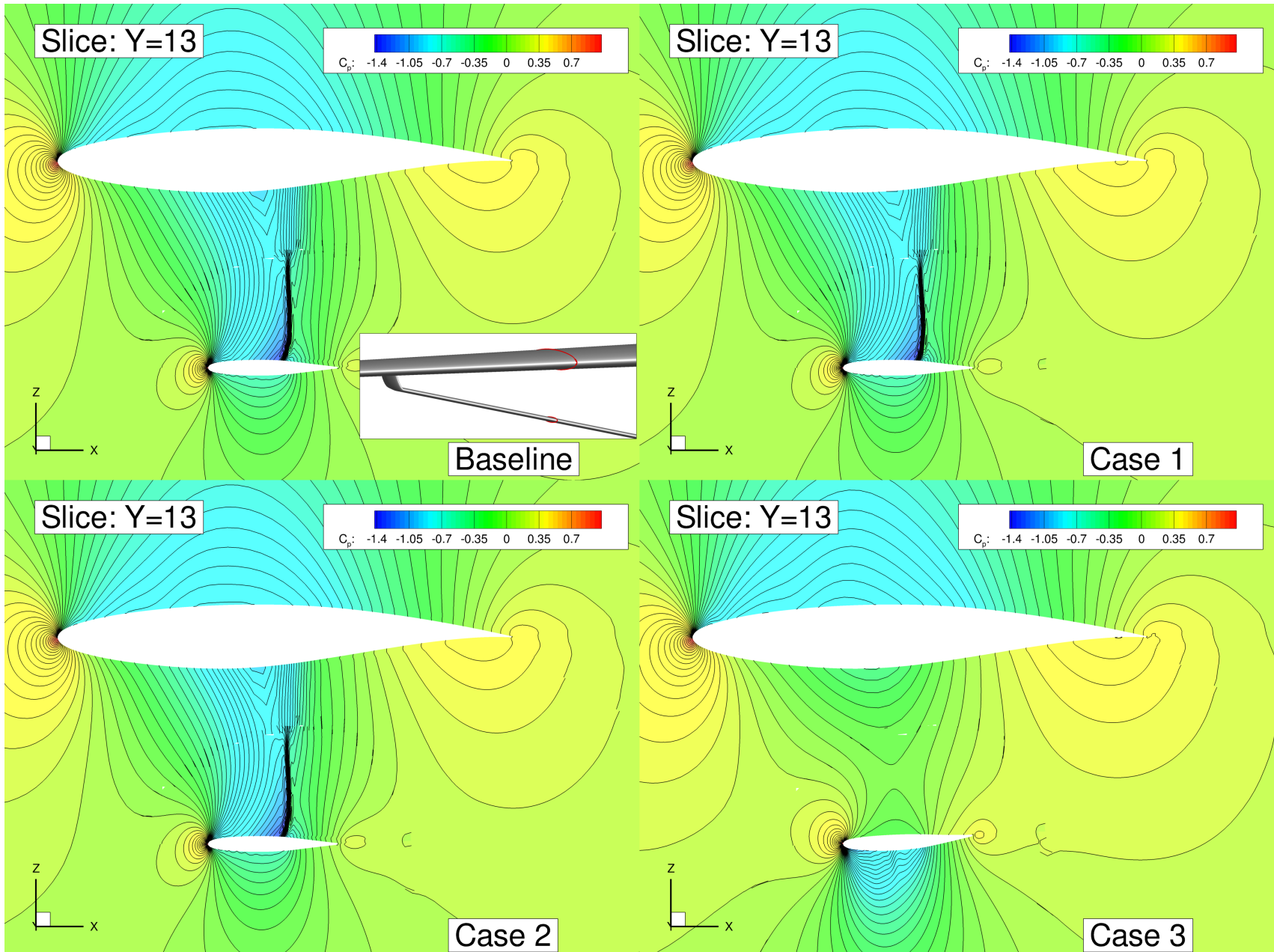
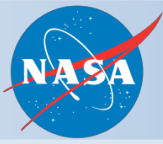
2D Slices of Junction Region



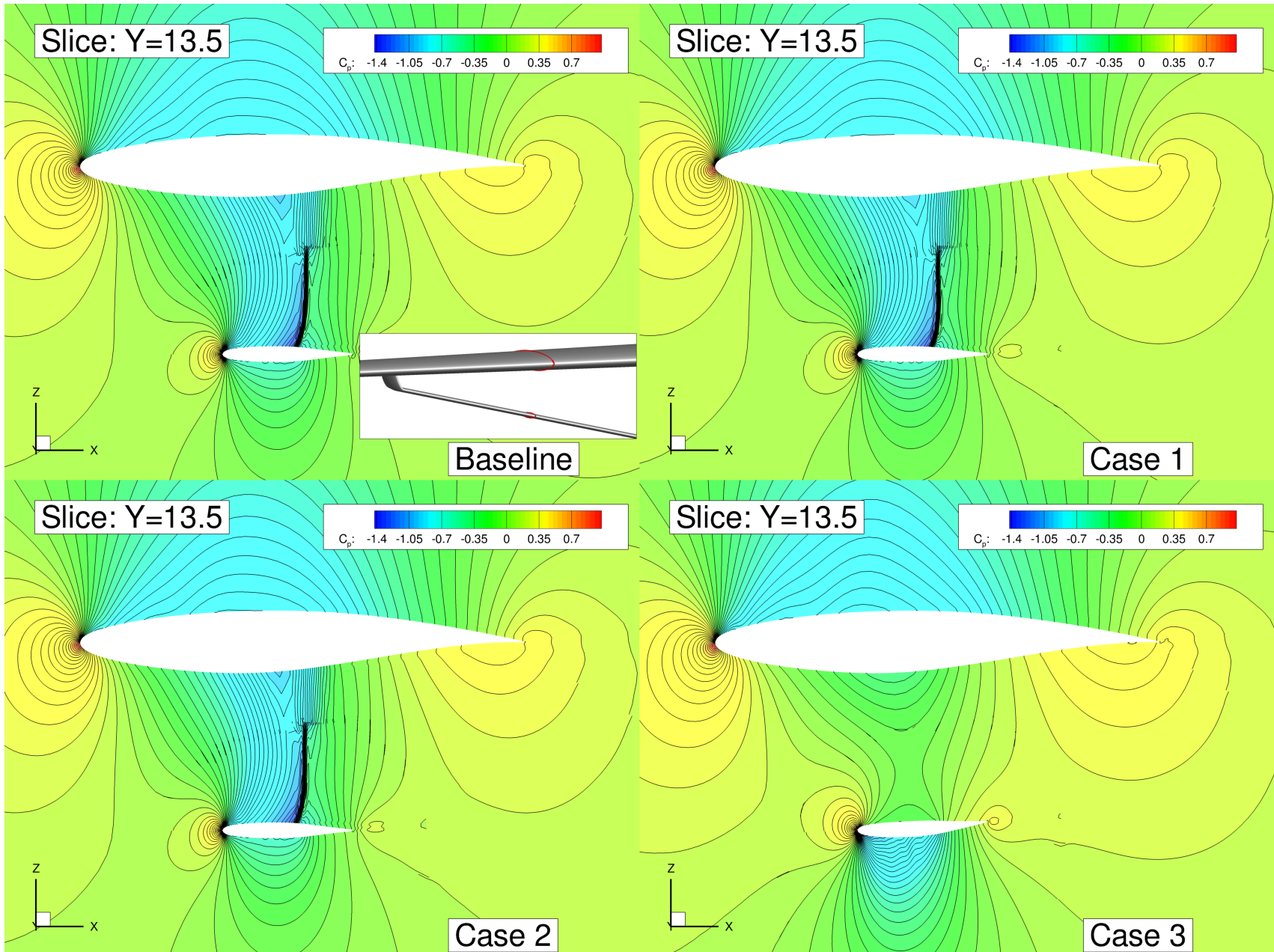
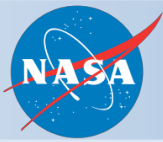
2D Slices of Junction Region



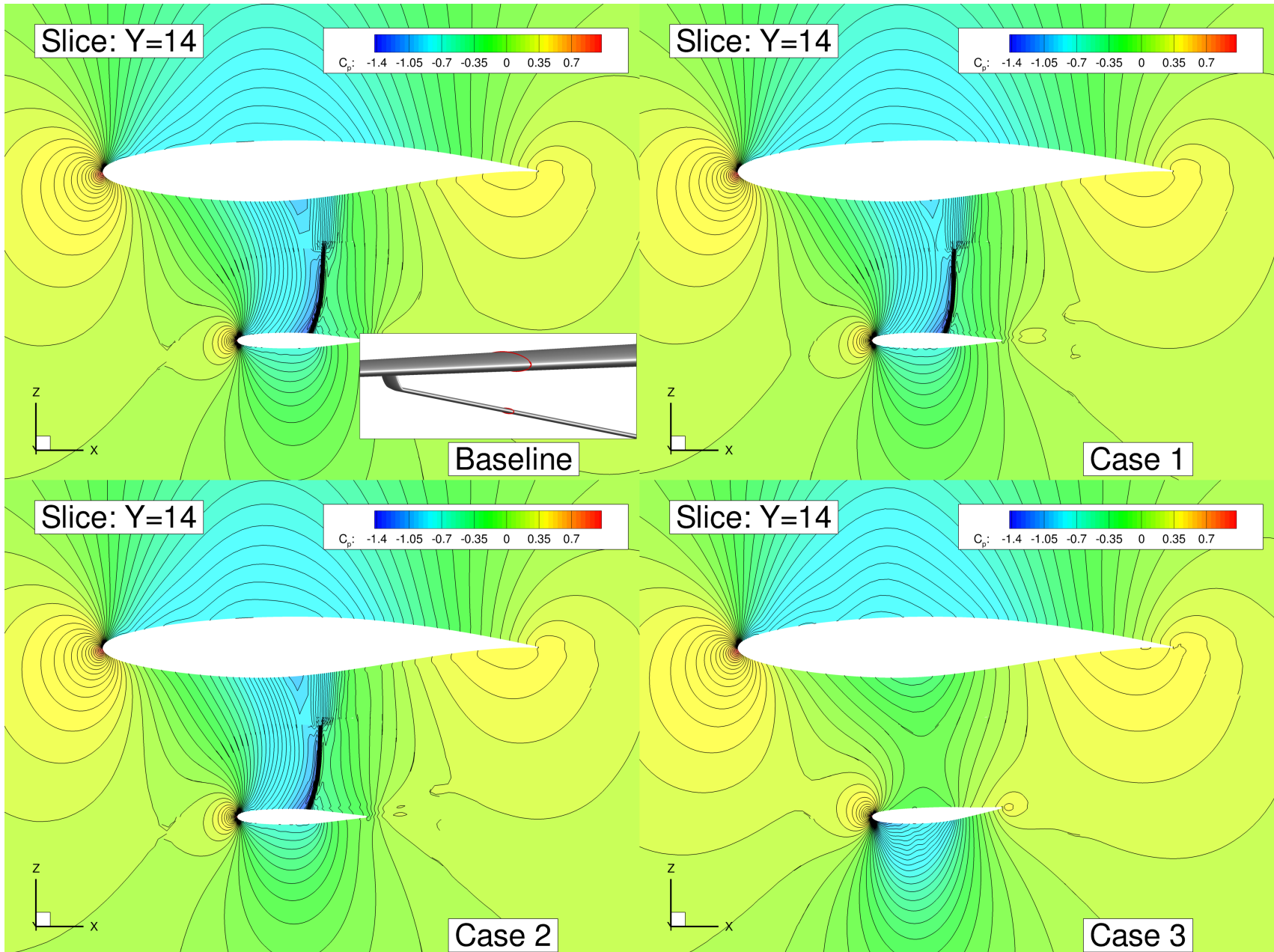
2D Slices of Junction Region



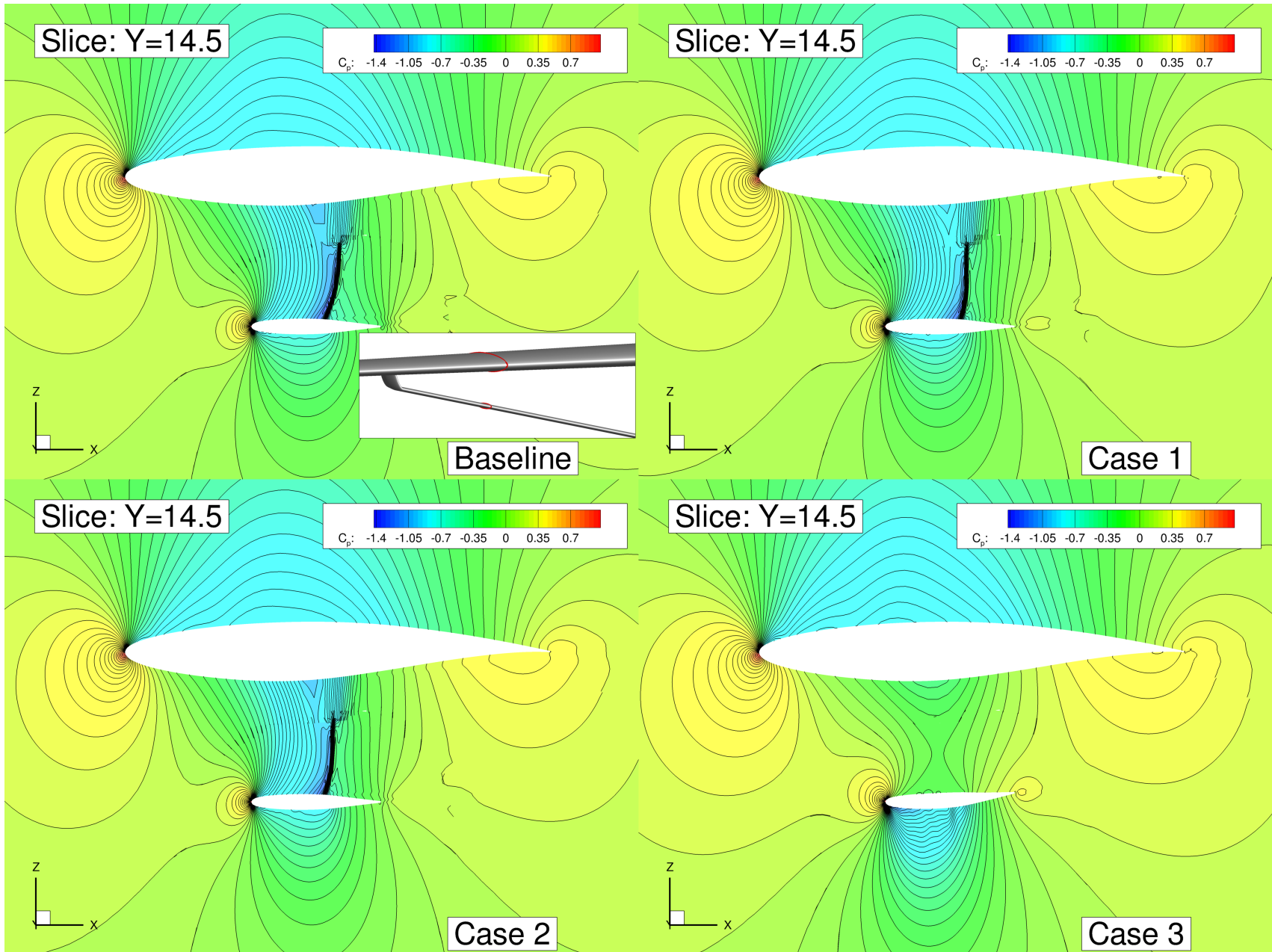
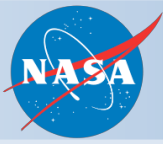
2D Slices of Junction Region



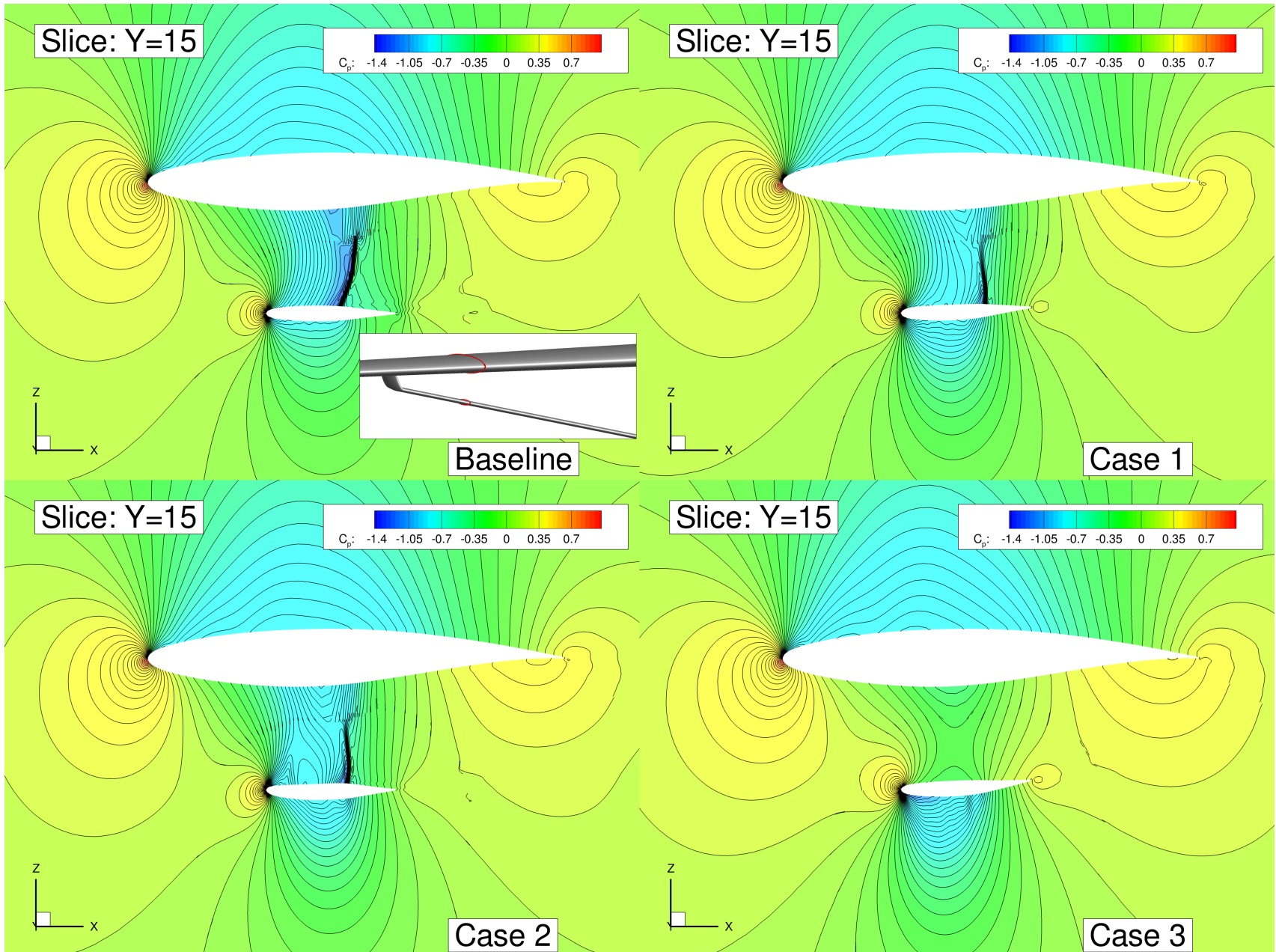
2D Slices of Junction Region



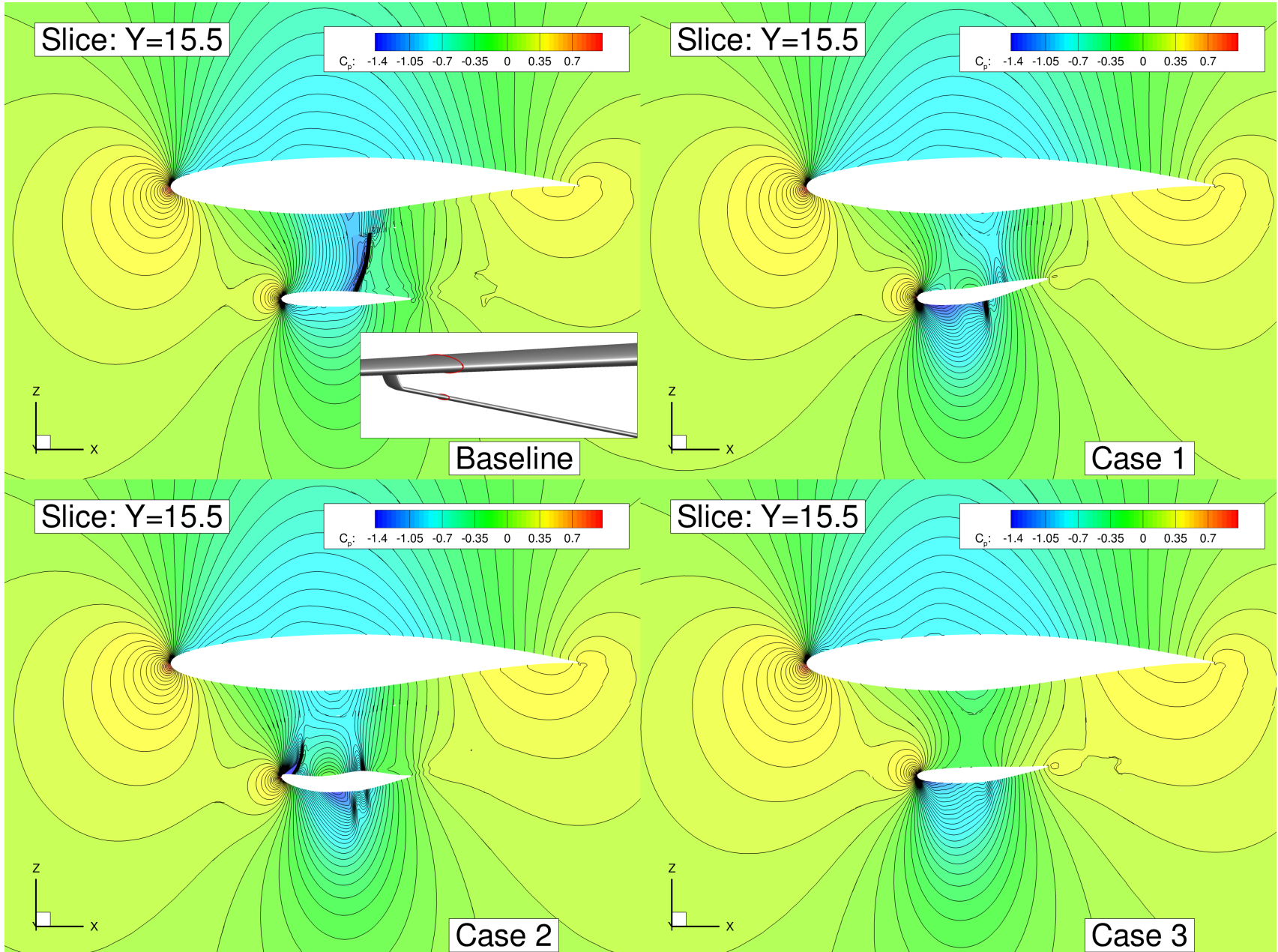
2D Slices of Junction Region



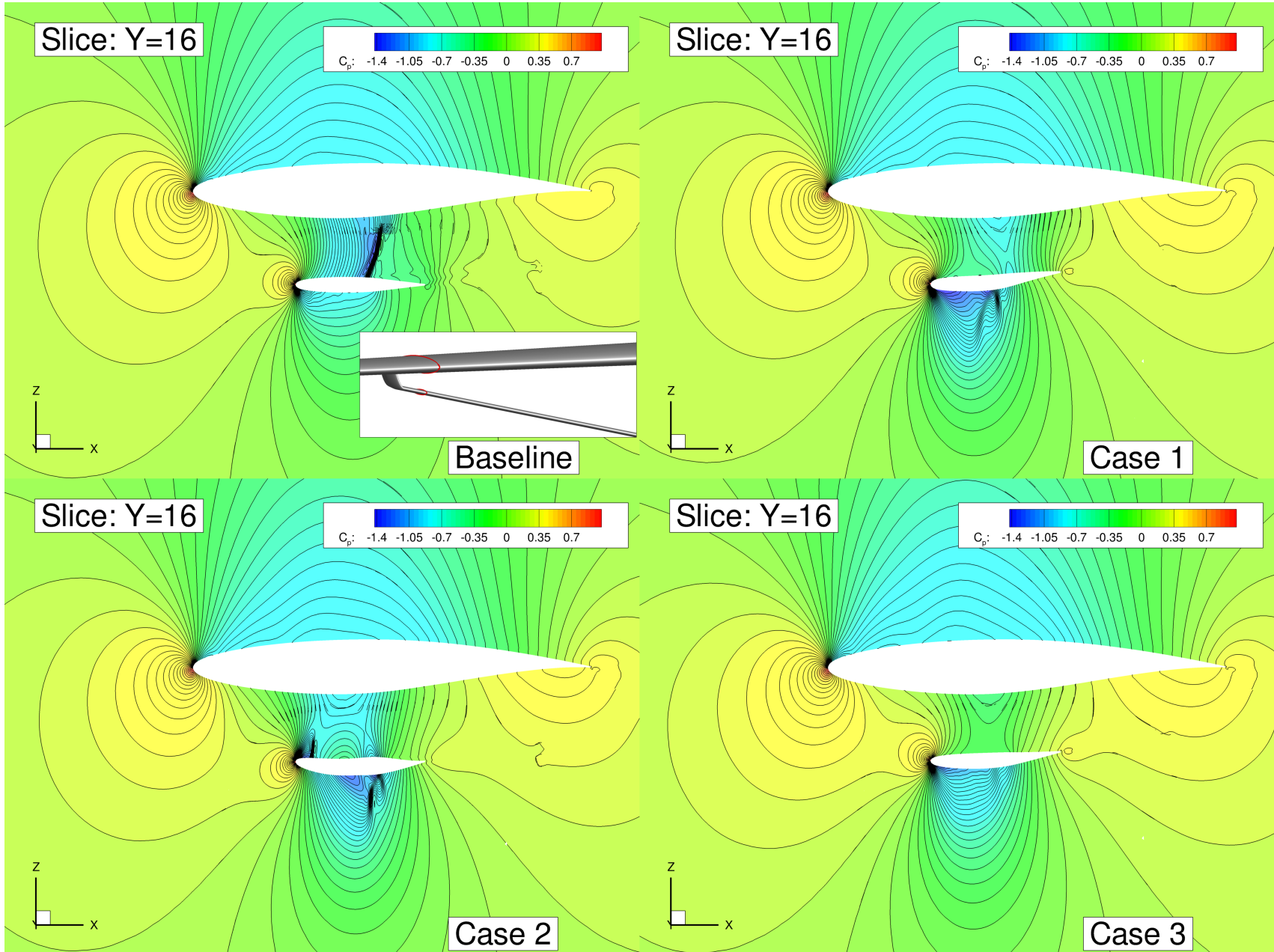
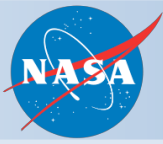
2D Slices of Junction Region



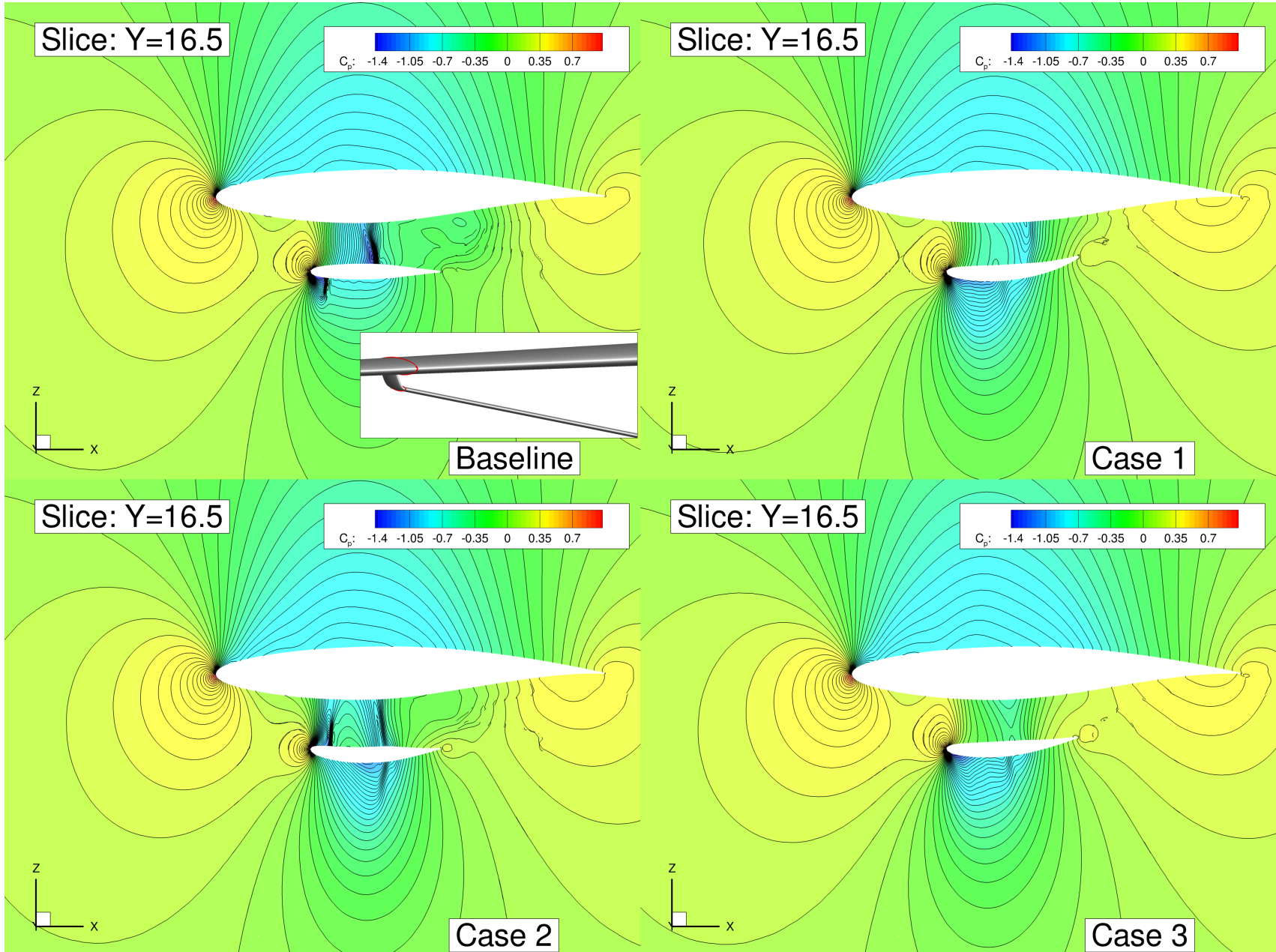
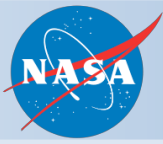
2D Slices of Junction Region



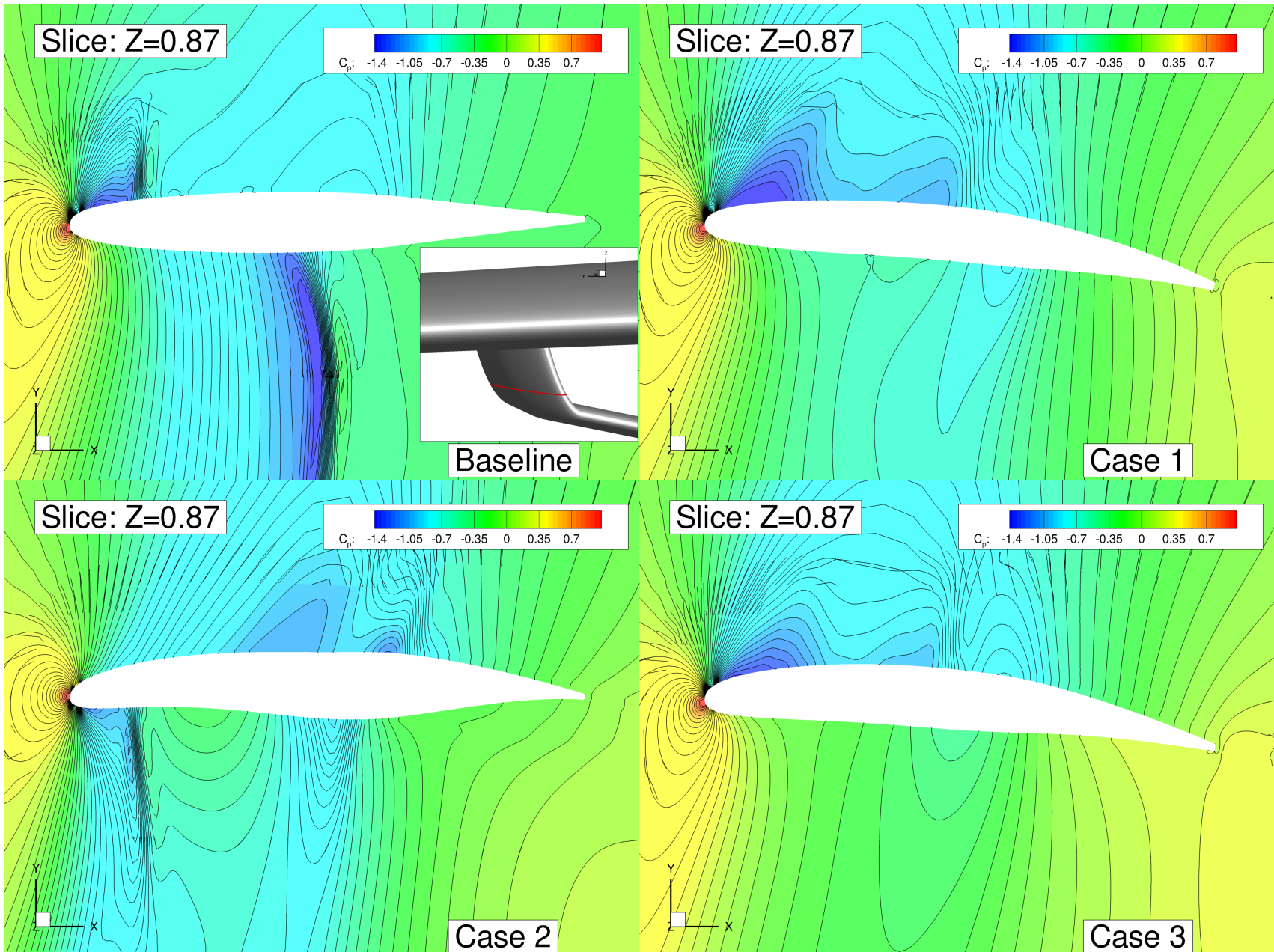
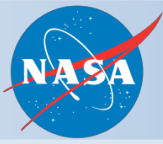
2D Slices of Junction Region



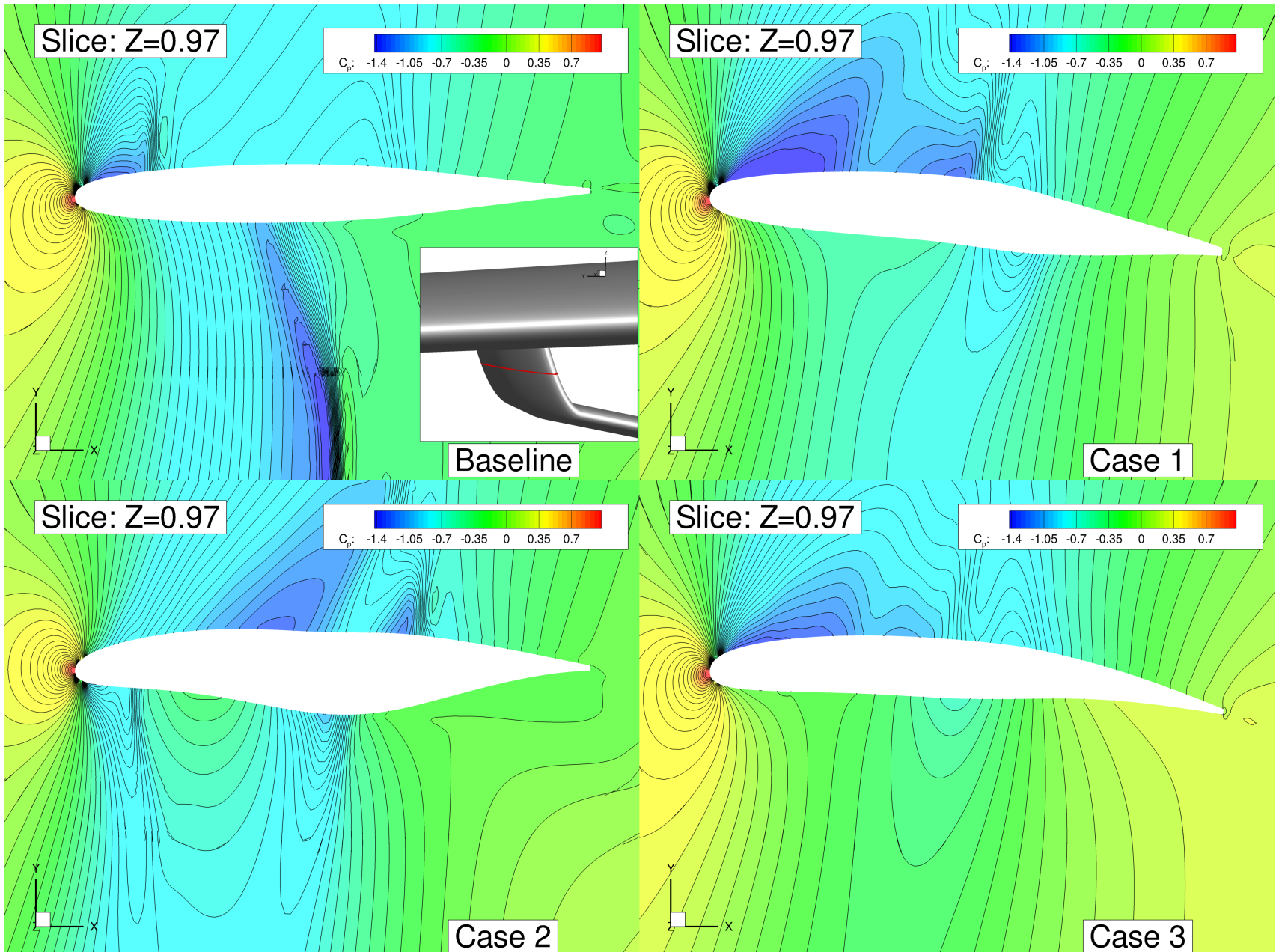
2D Slices of Junction Region



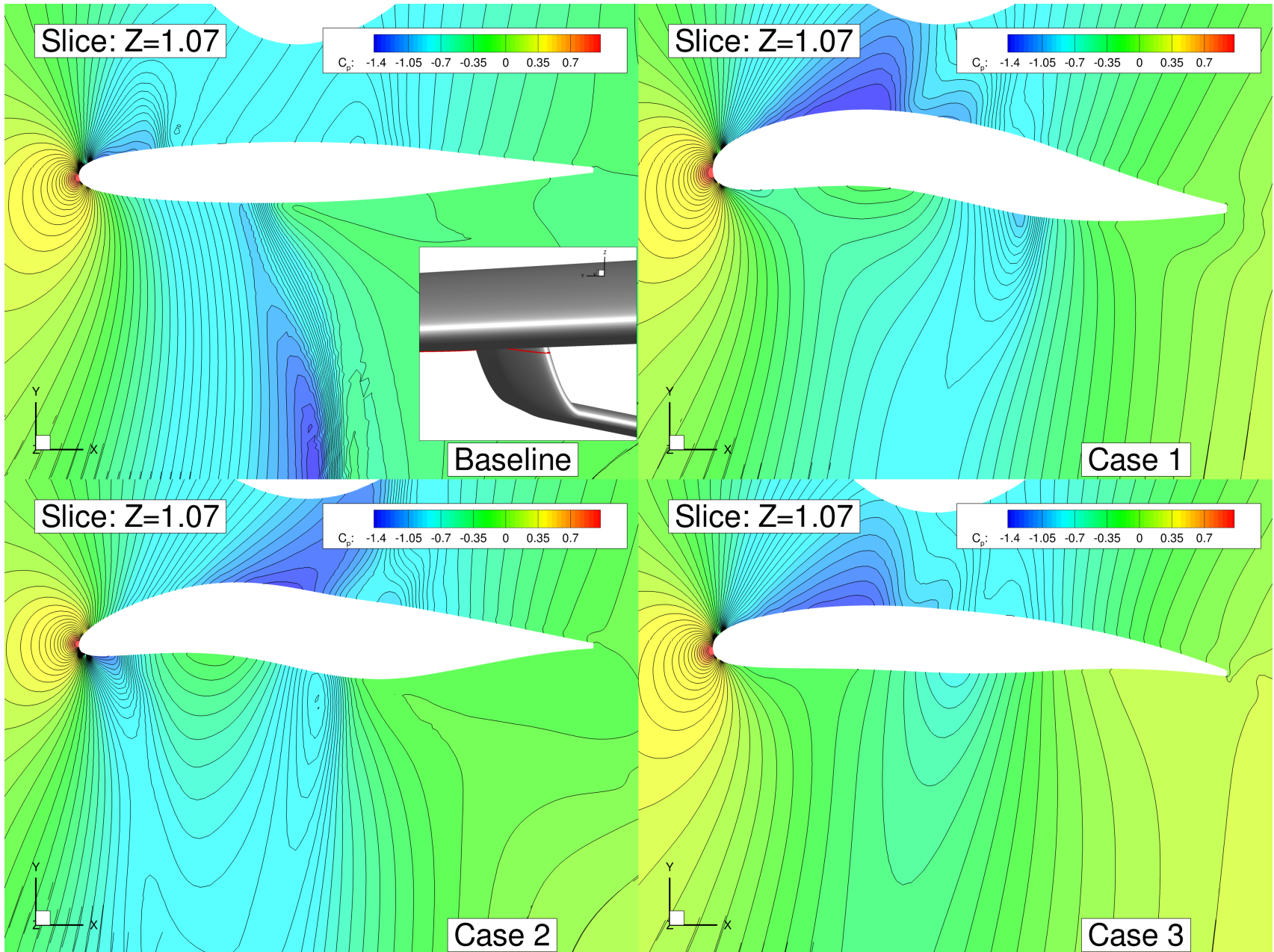
2D Slices of Junction Region



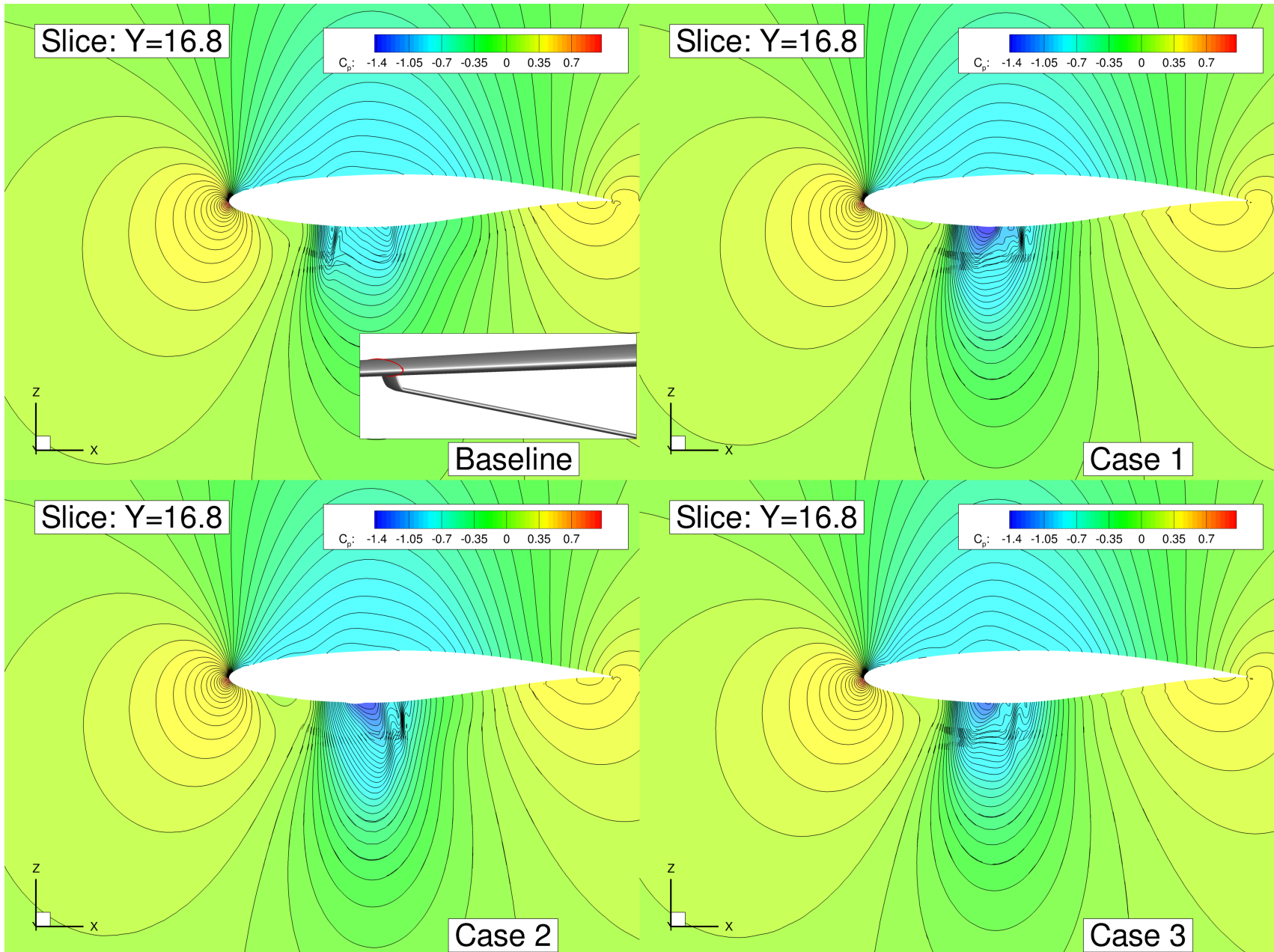
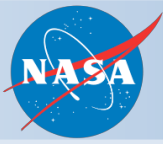
2D Slices of Junction Region



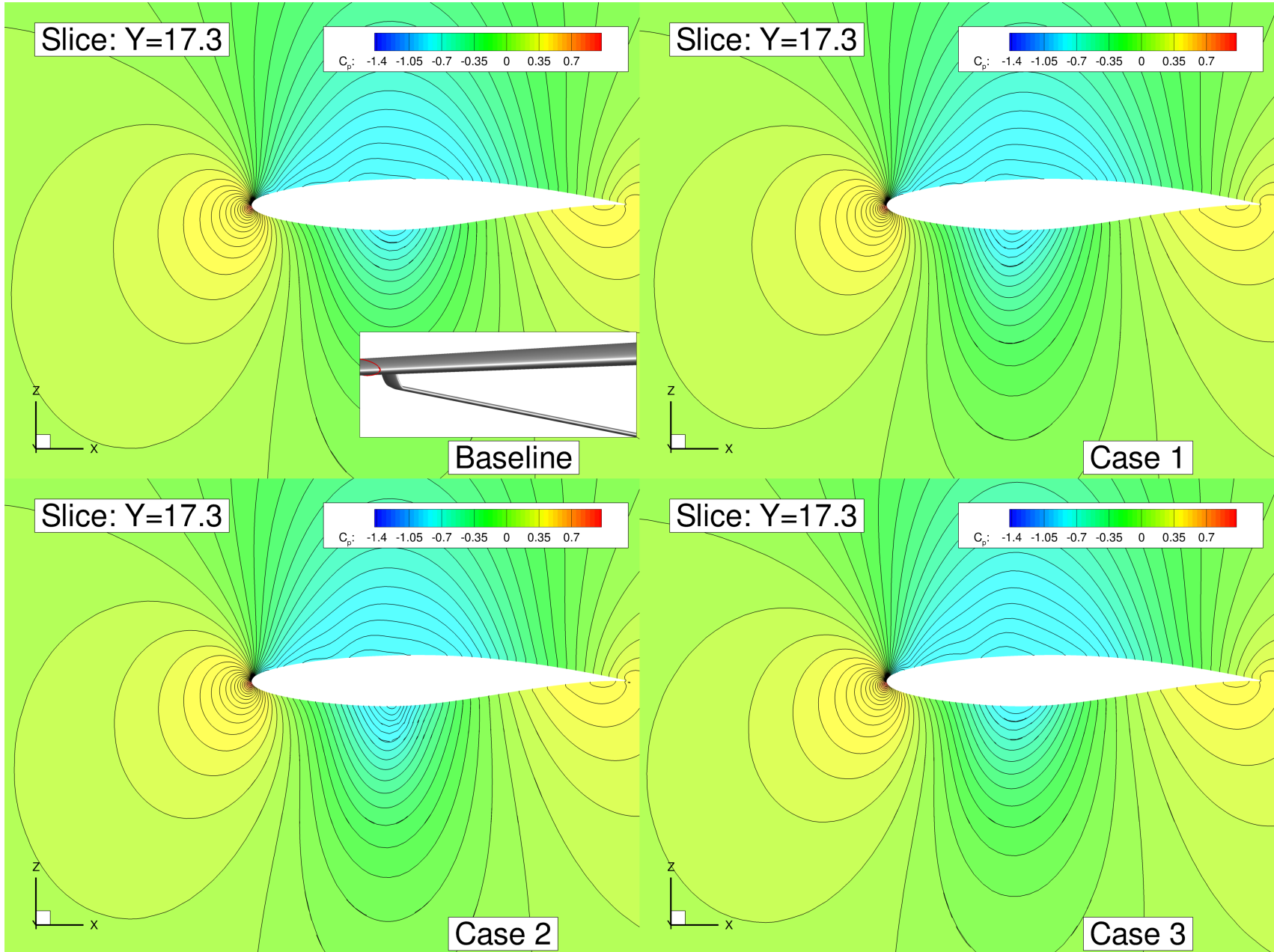
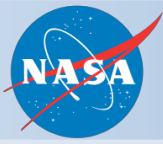
2D Slices of Junction Region



2D Slices of Junction Region



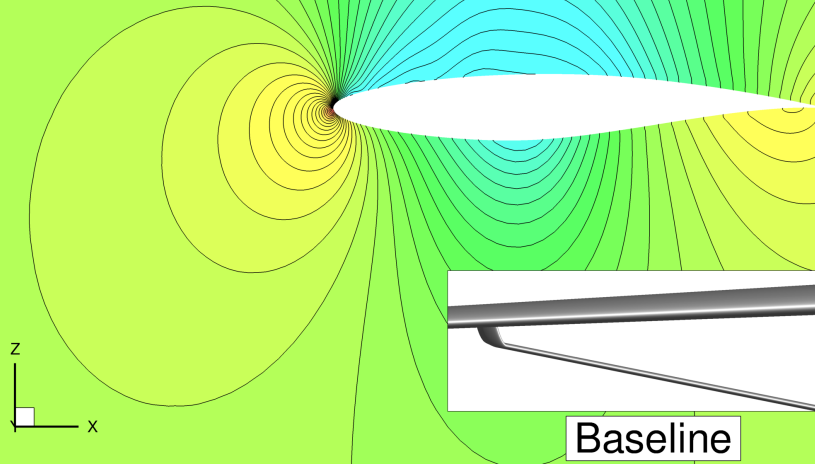
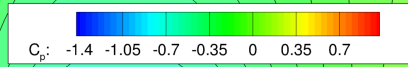
2D Slices of Junction Region



2D Slices of Junction Region

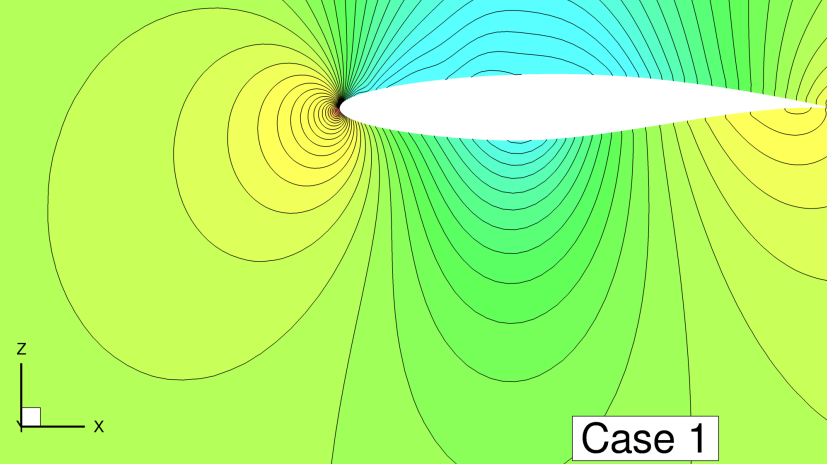
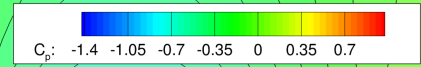


Slice: Y=17.8



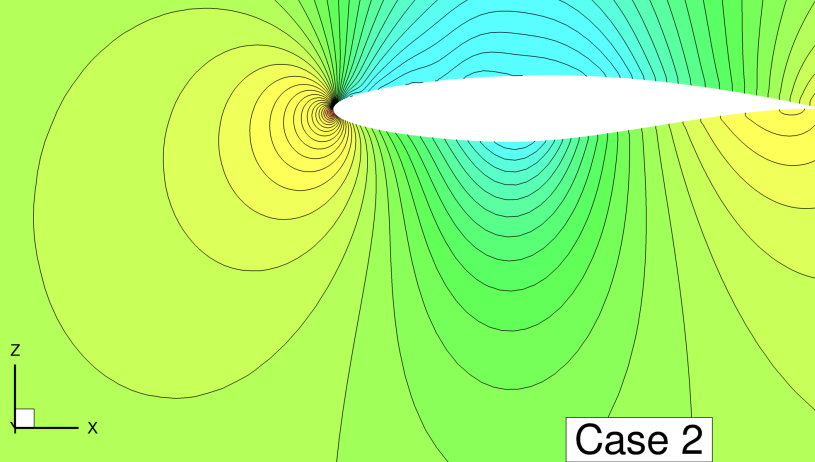
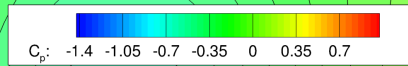
Baseline

Slice: Y=17.8



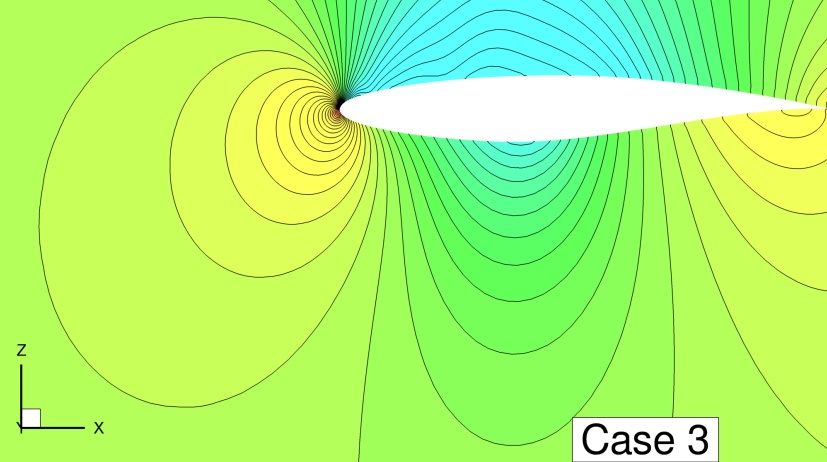
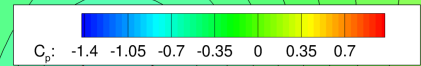
Case 1

Slice: Y=17.8



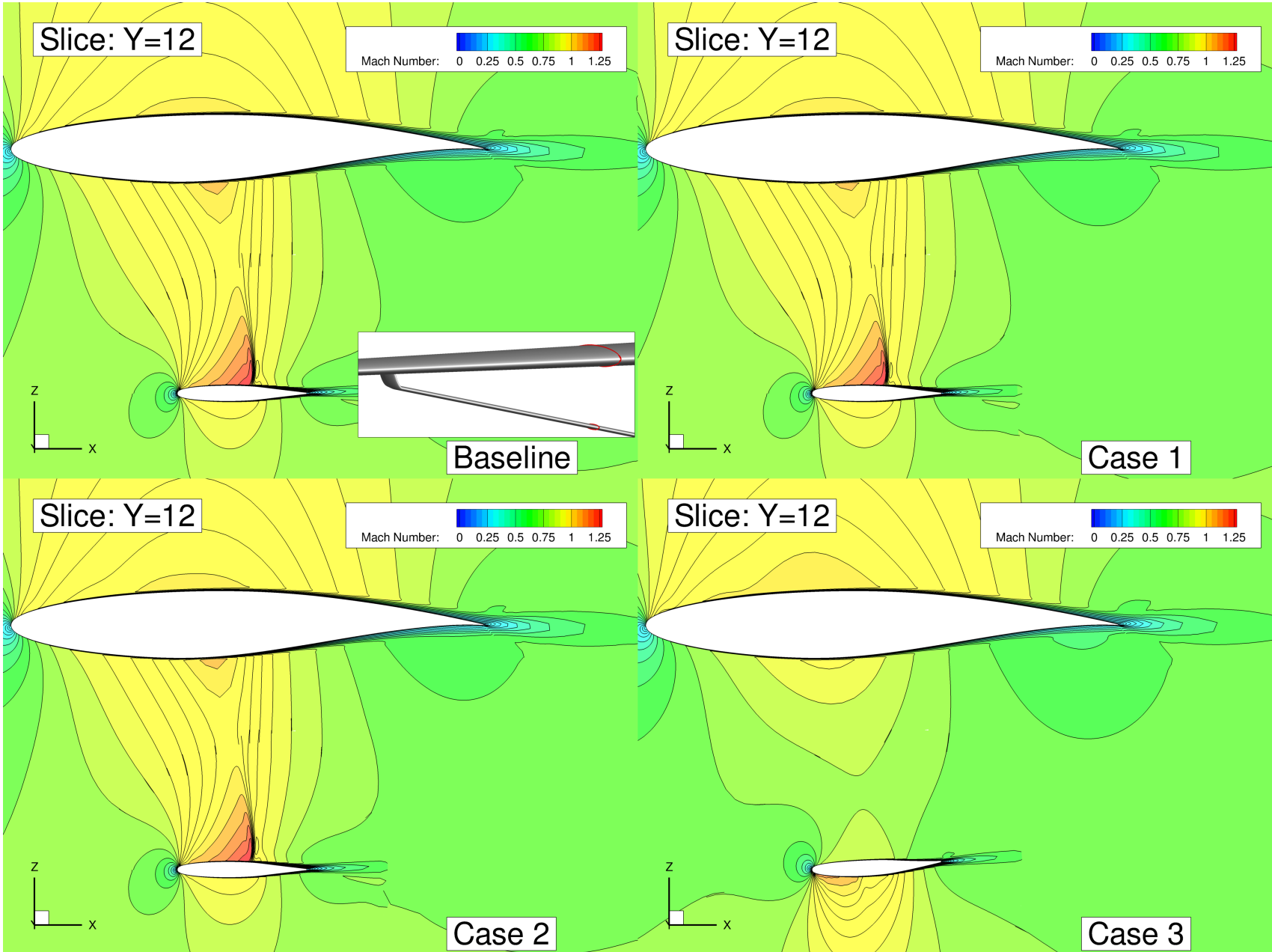
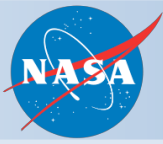
Case 2

Slice: Y=17.8

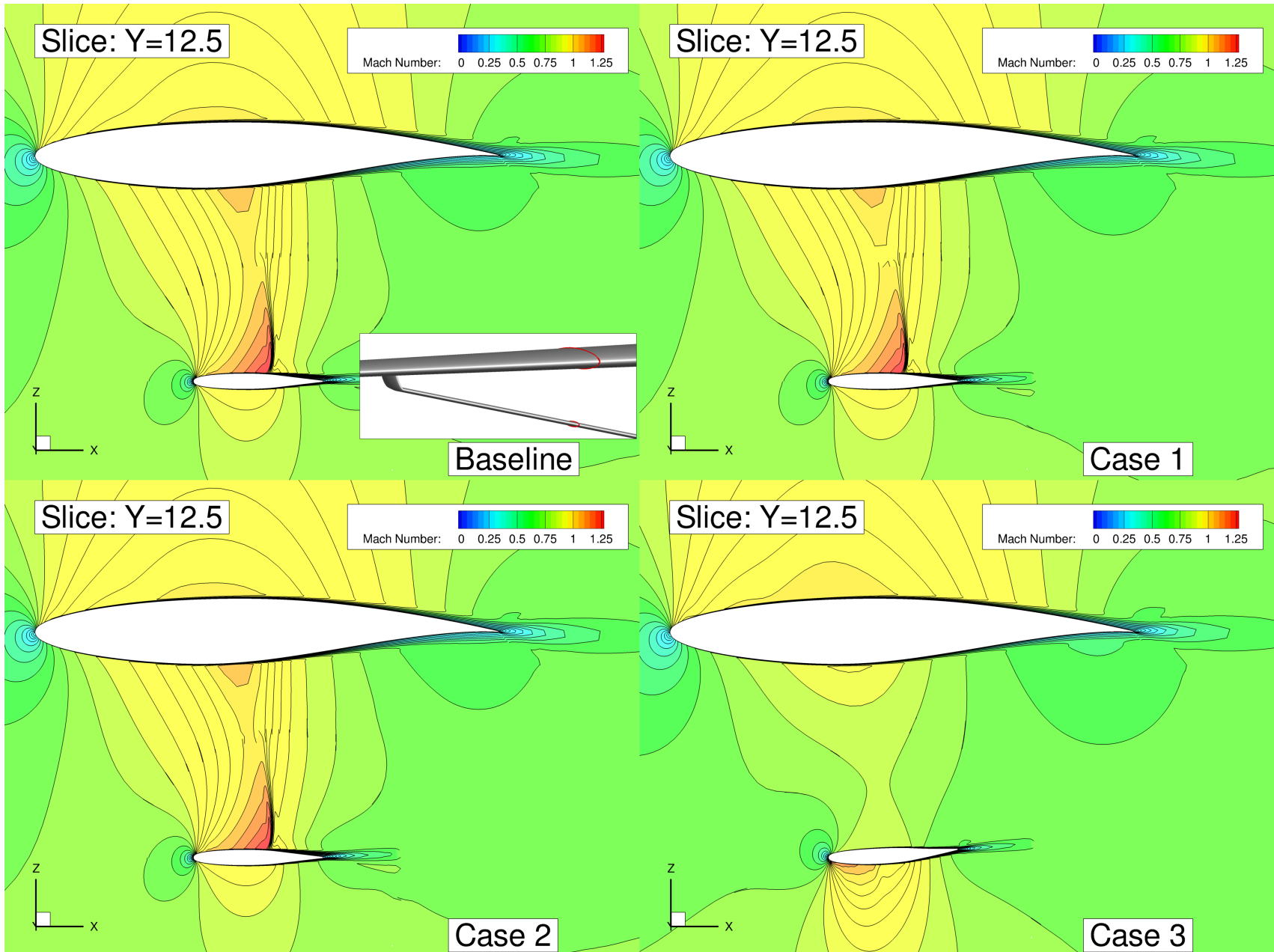
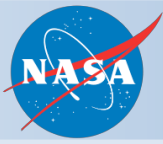


Case 3

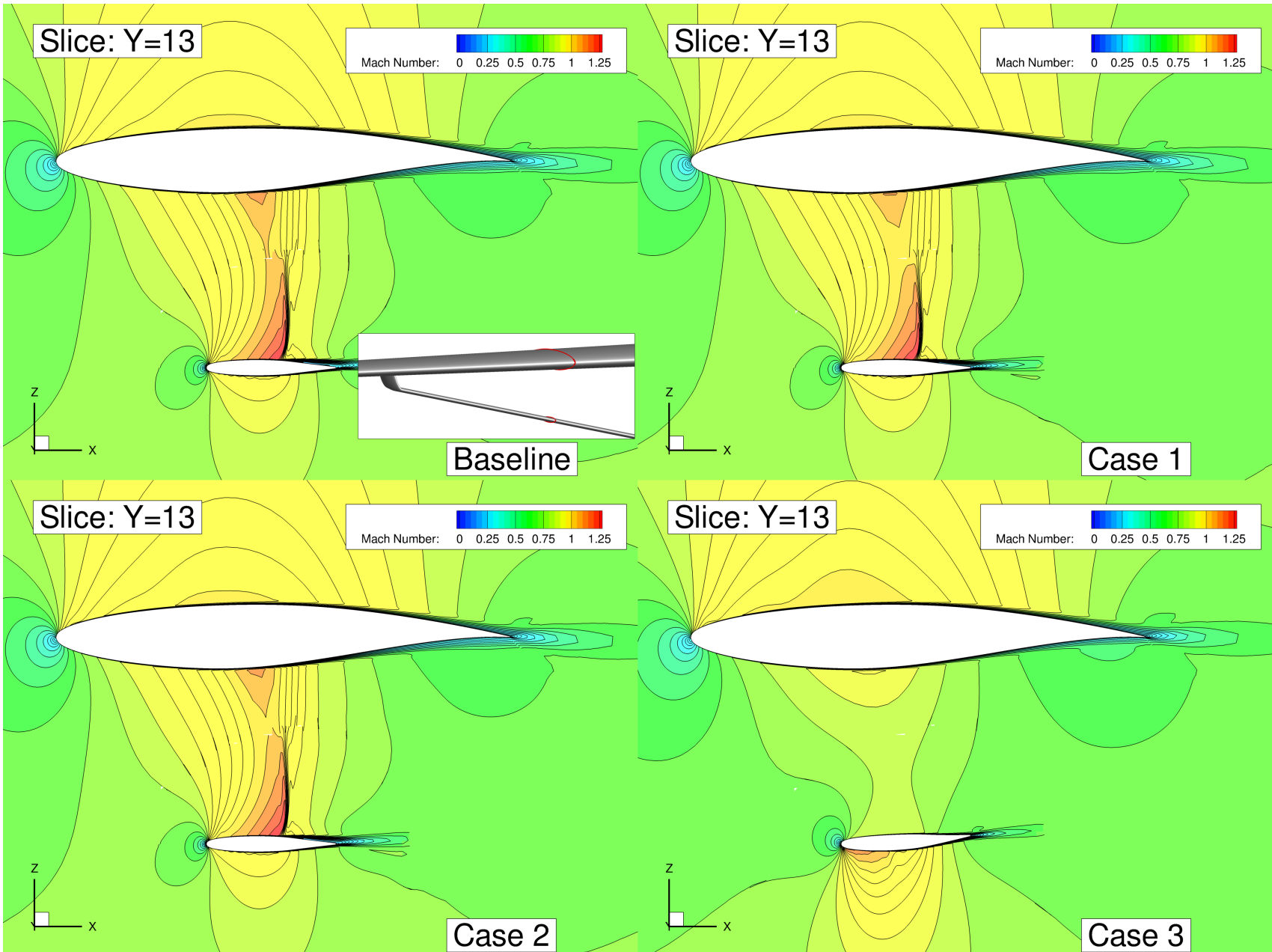
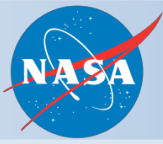
2D Slices of Junction Region



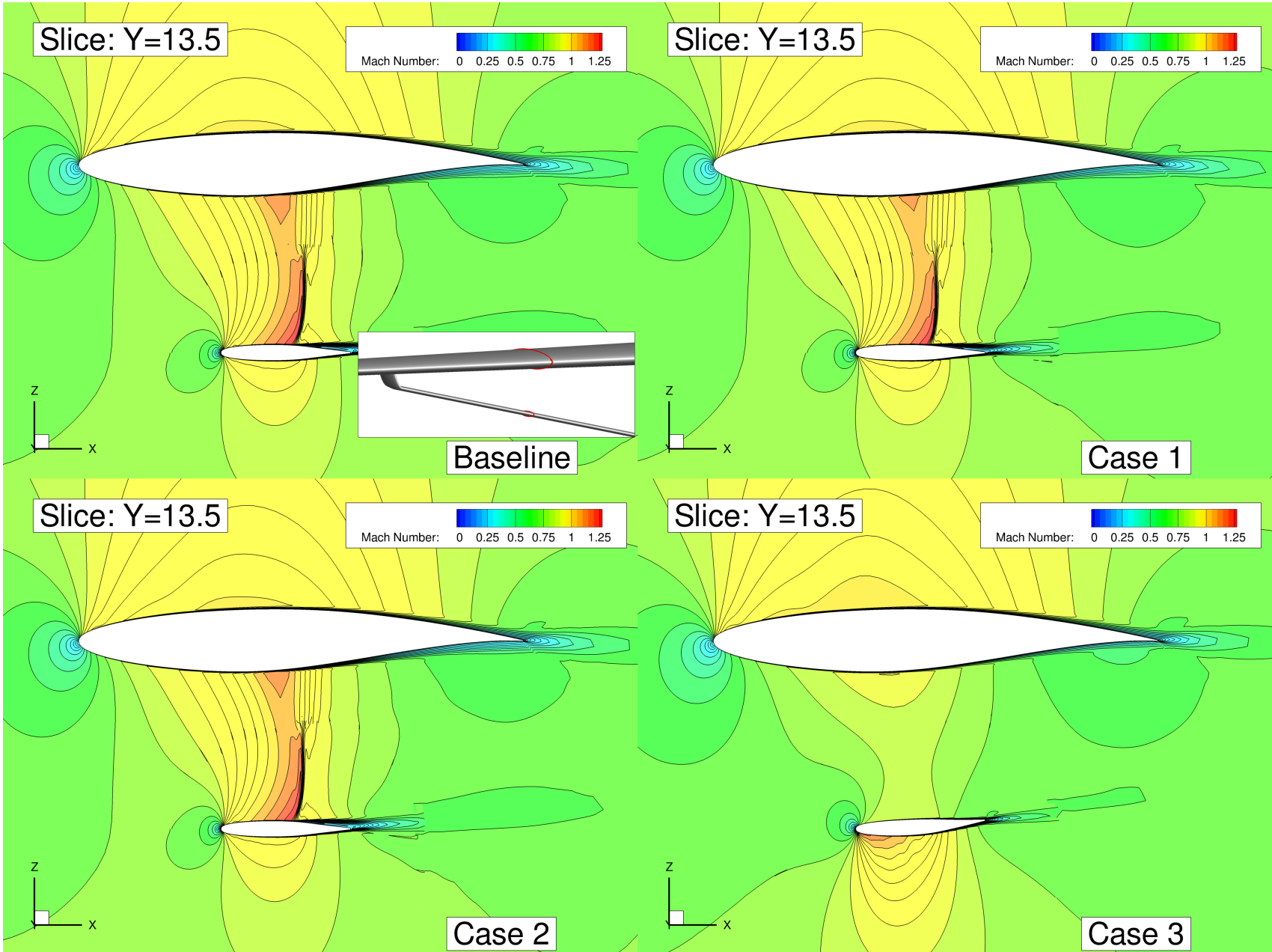
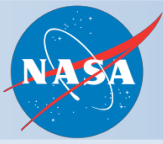
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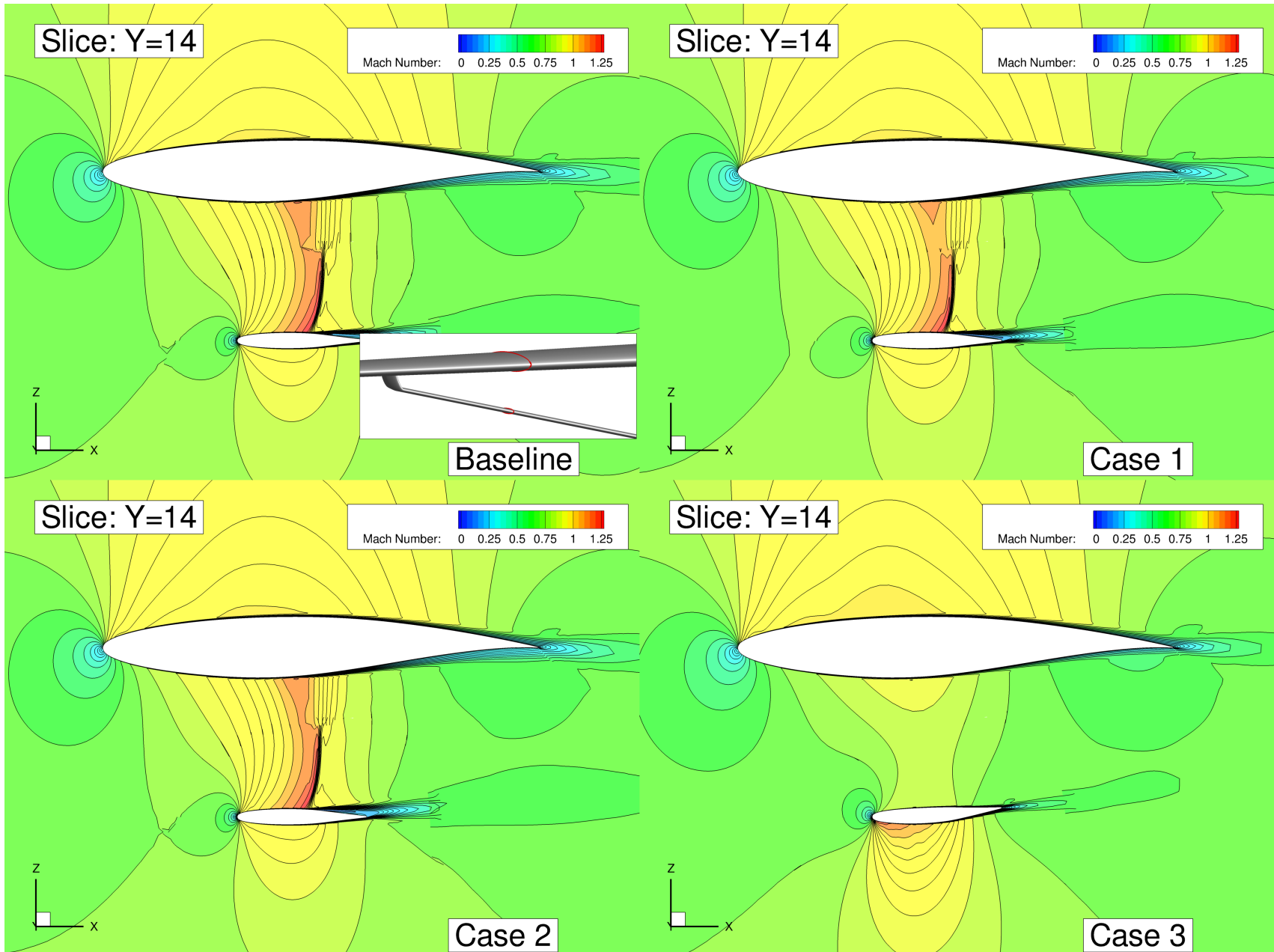
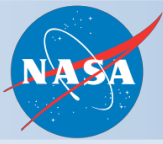
2D Slices of Junction Region



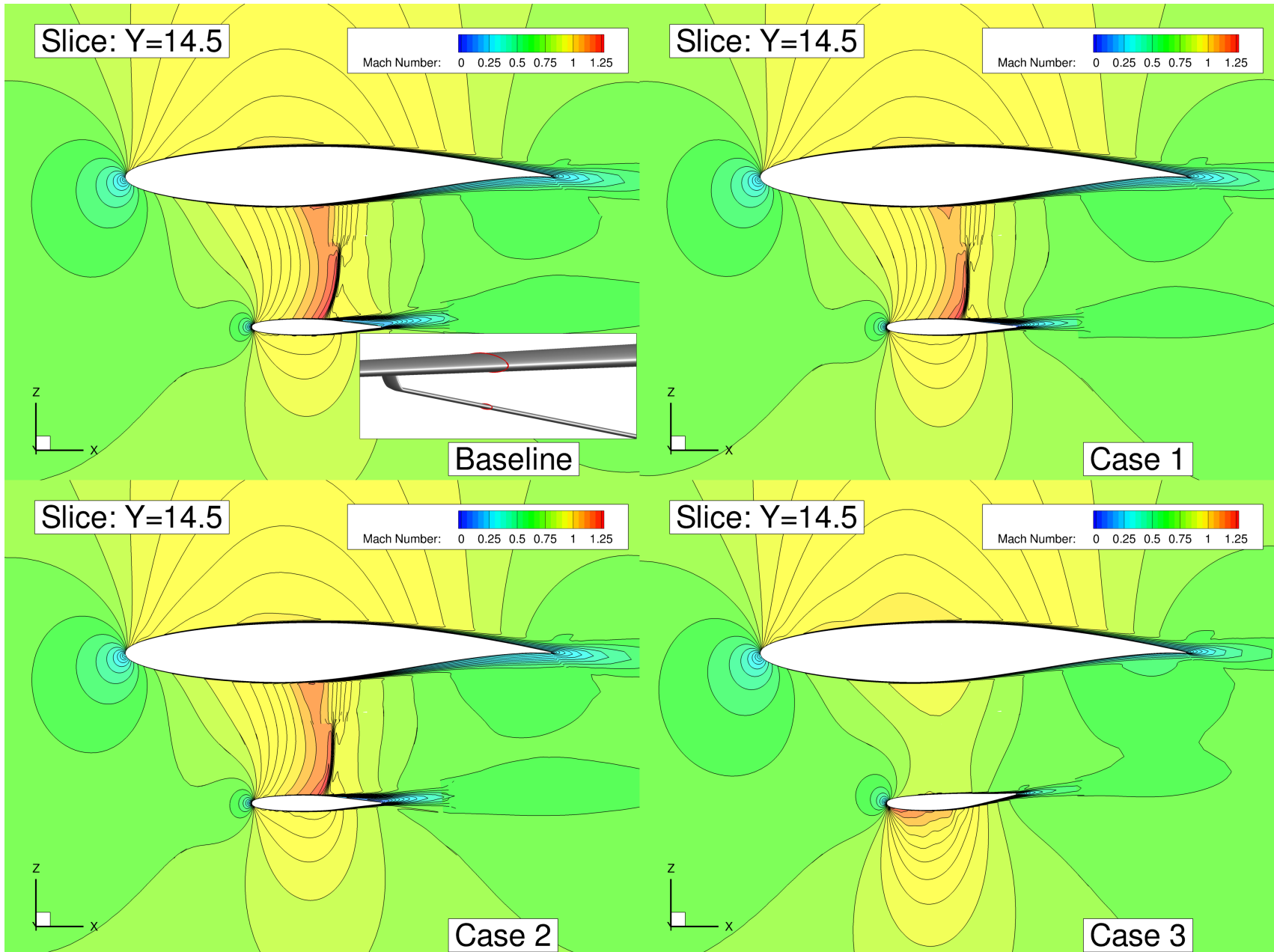
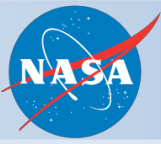
2D Slices of Junction Region



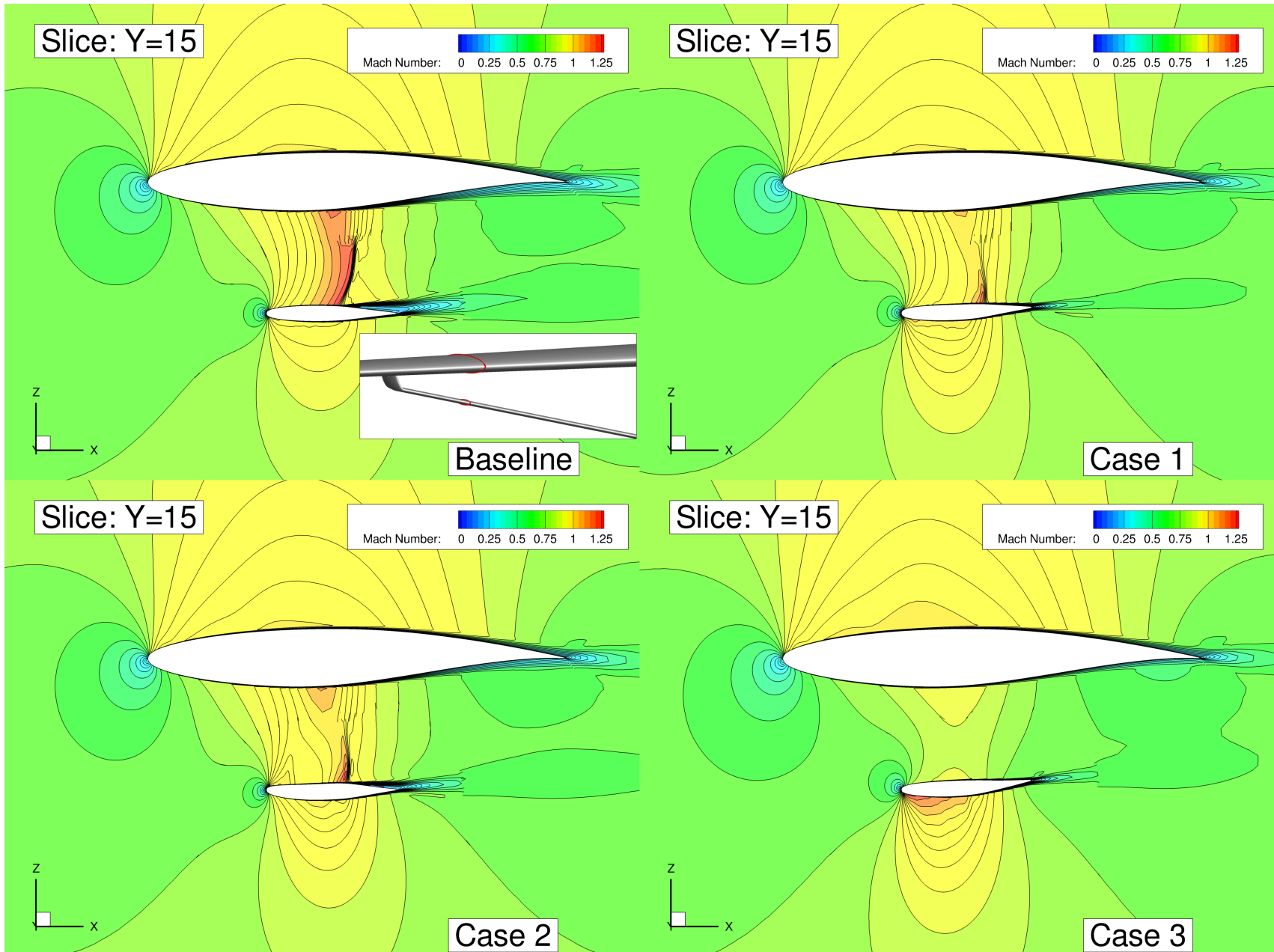
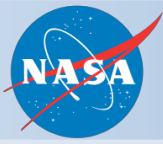
2D Slices of Junction Region



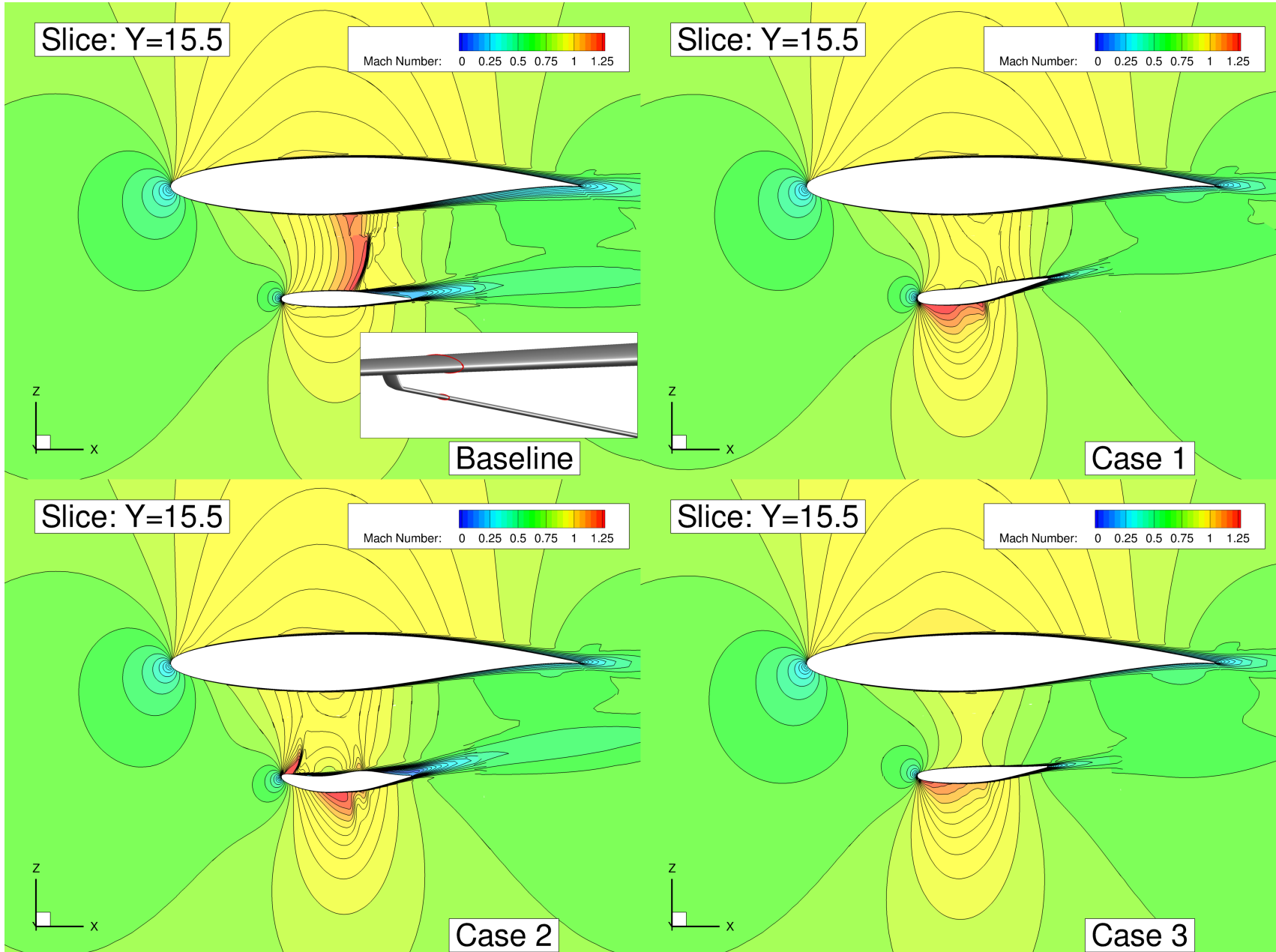
2D Slices of Junction Region



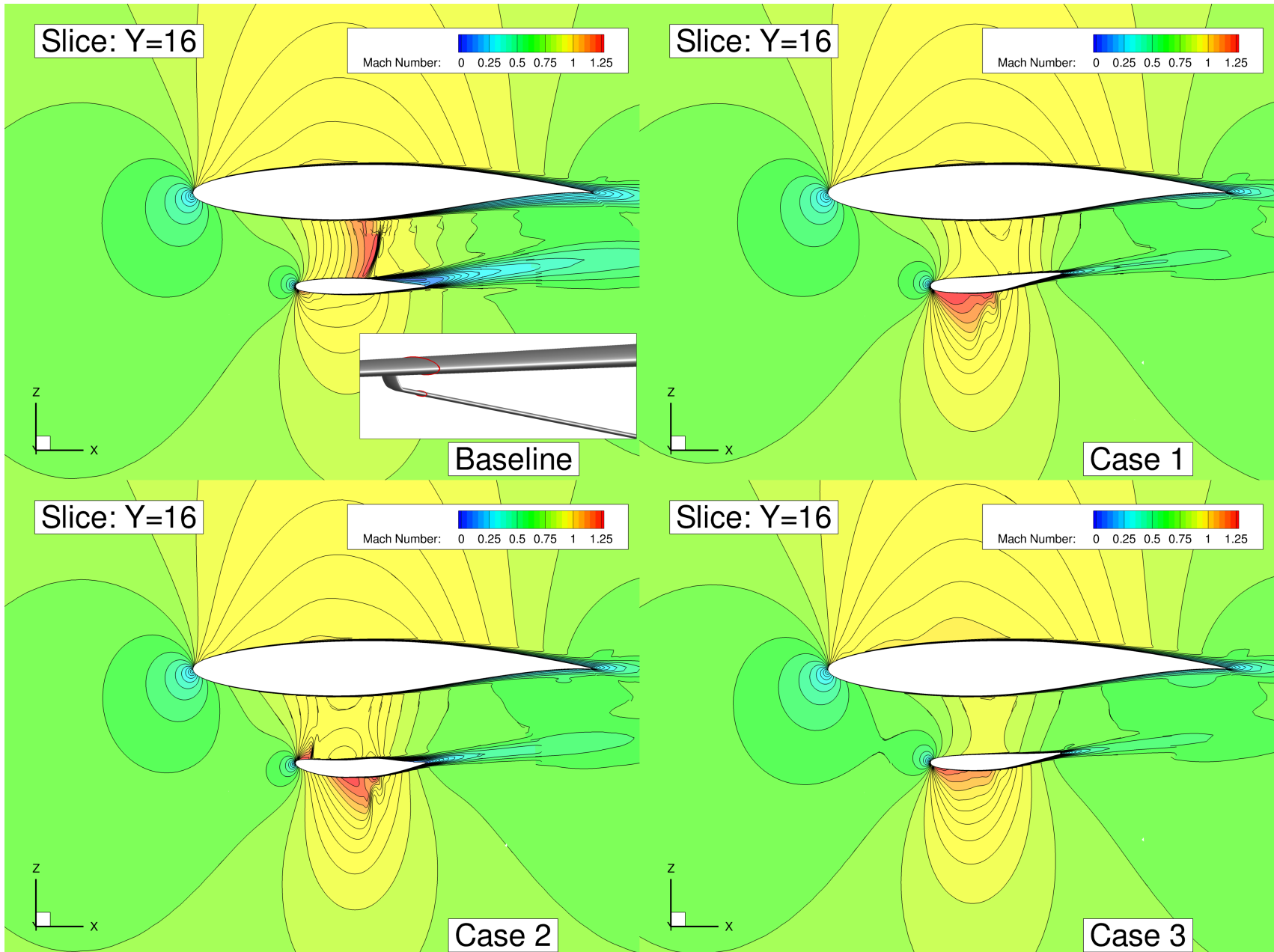
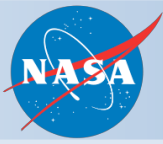
2D Slices of Junction Region



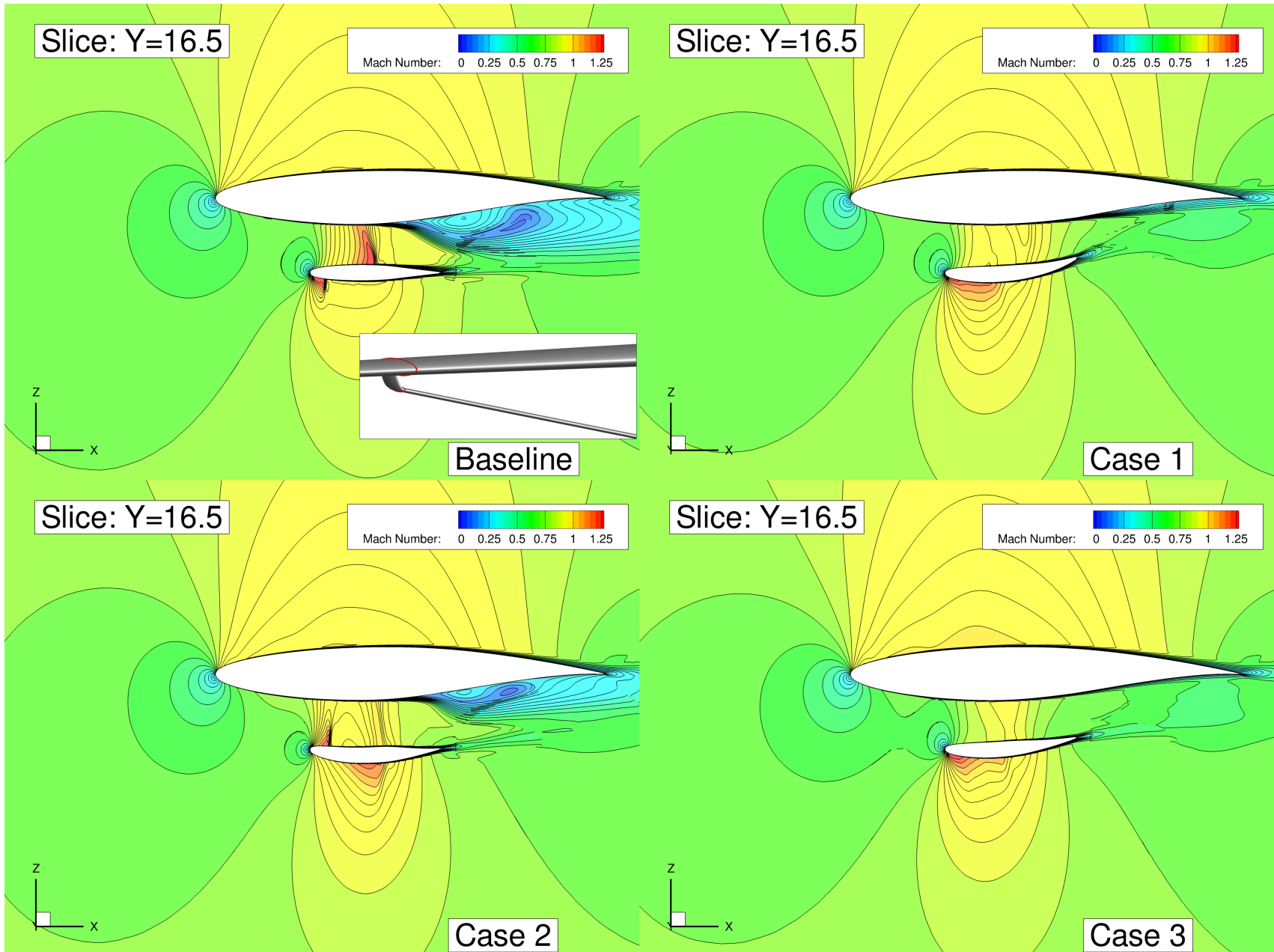
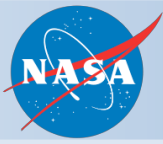
2D Slices of Junction Region



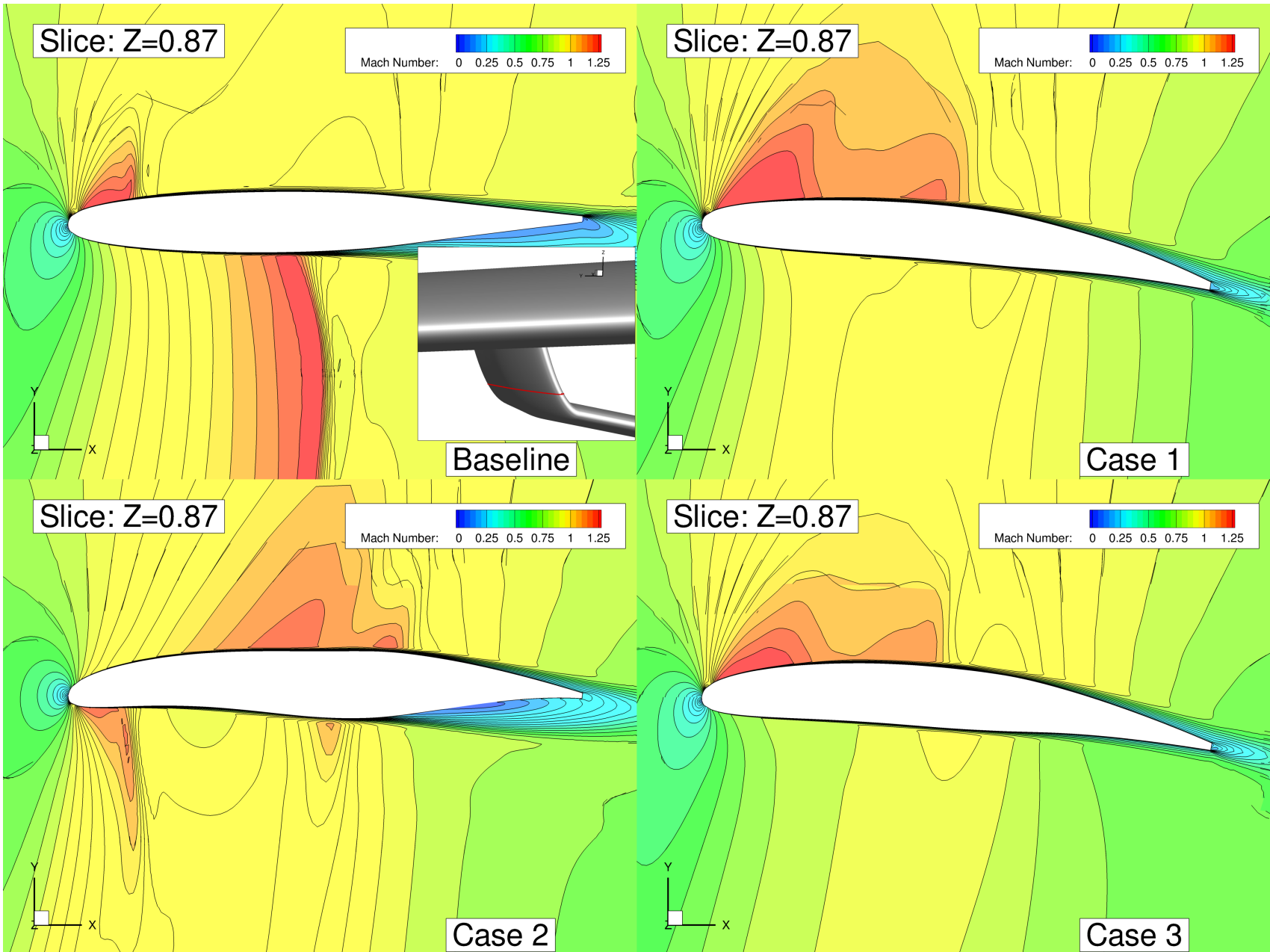
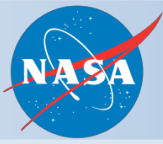
2D Slices of Junction Region



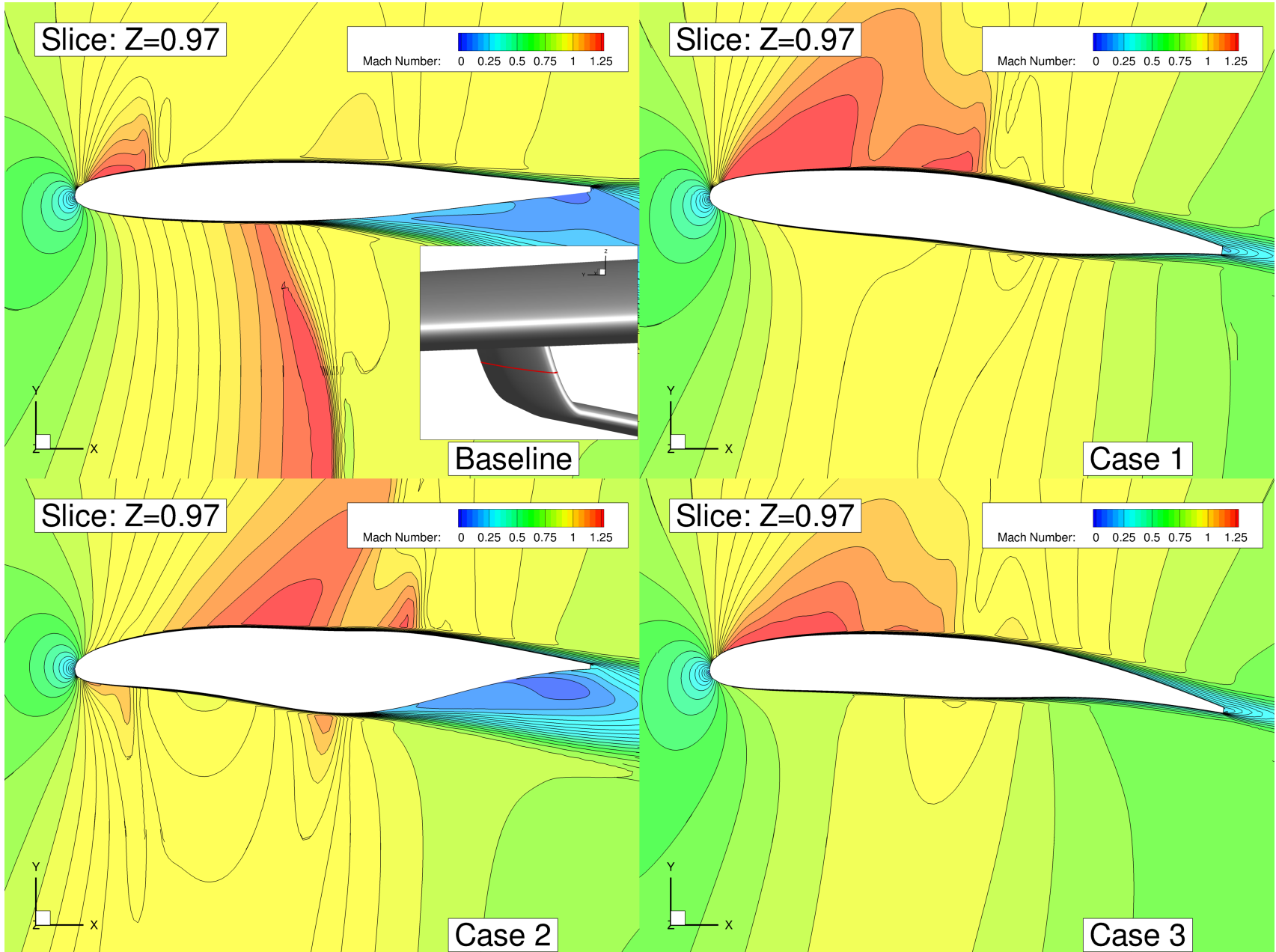
2D Slices of Junction Region



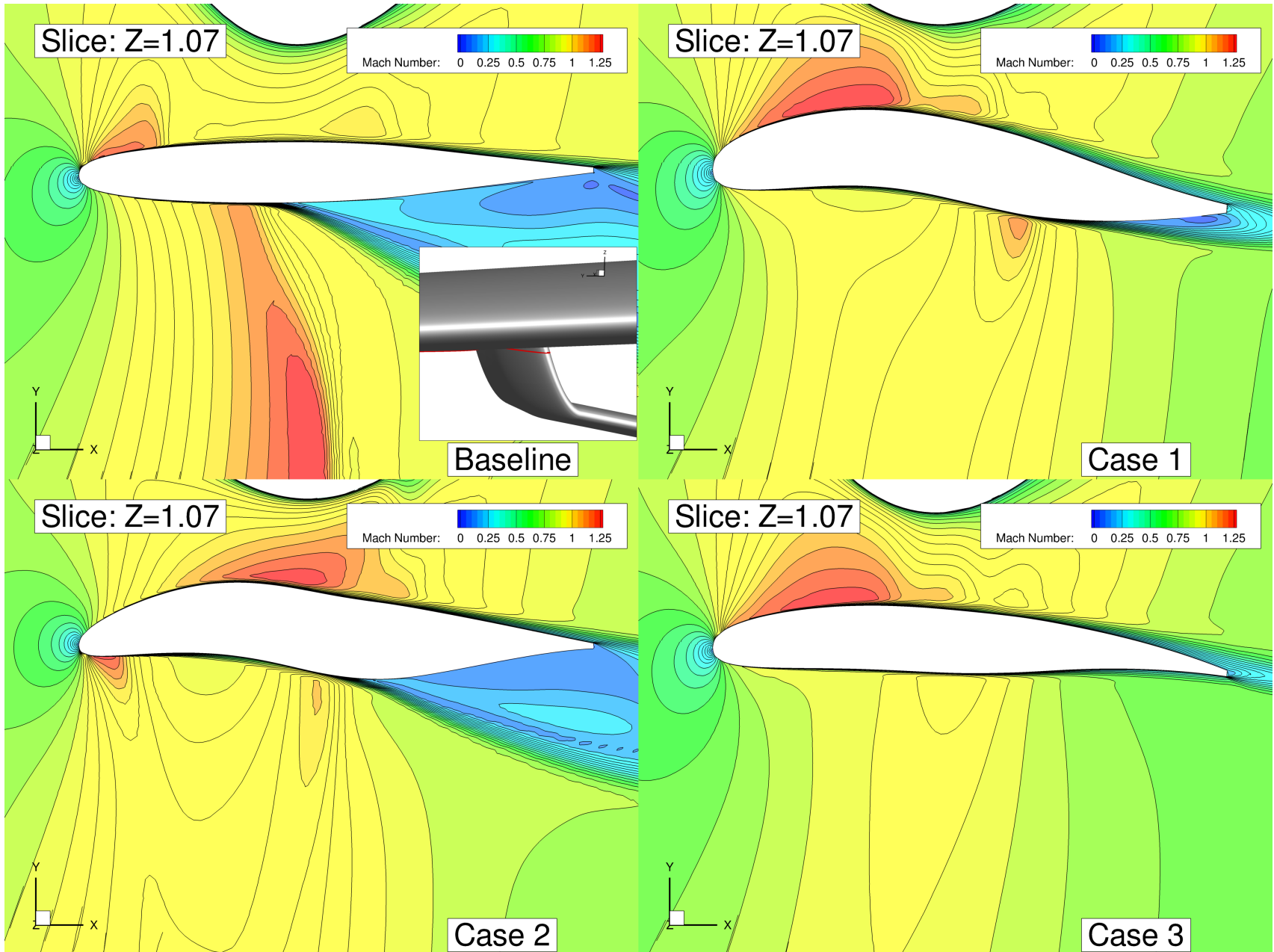
2D Slices of Junction Region



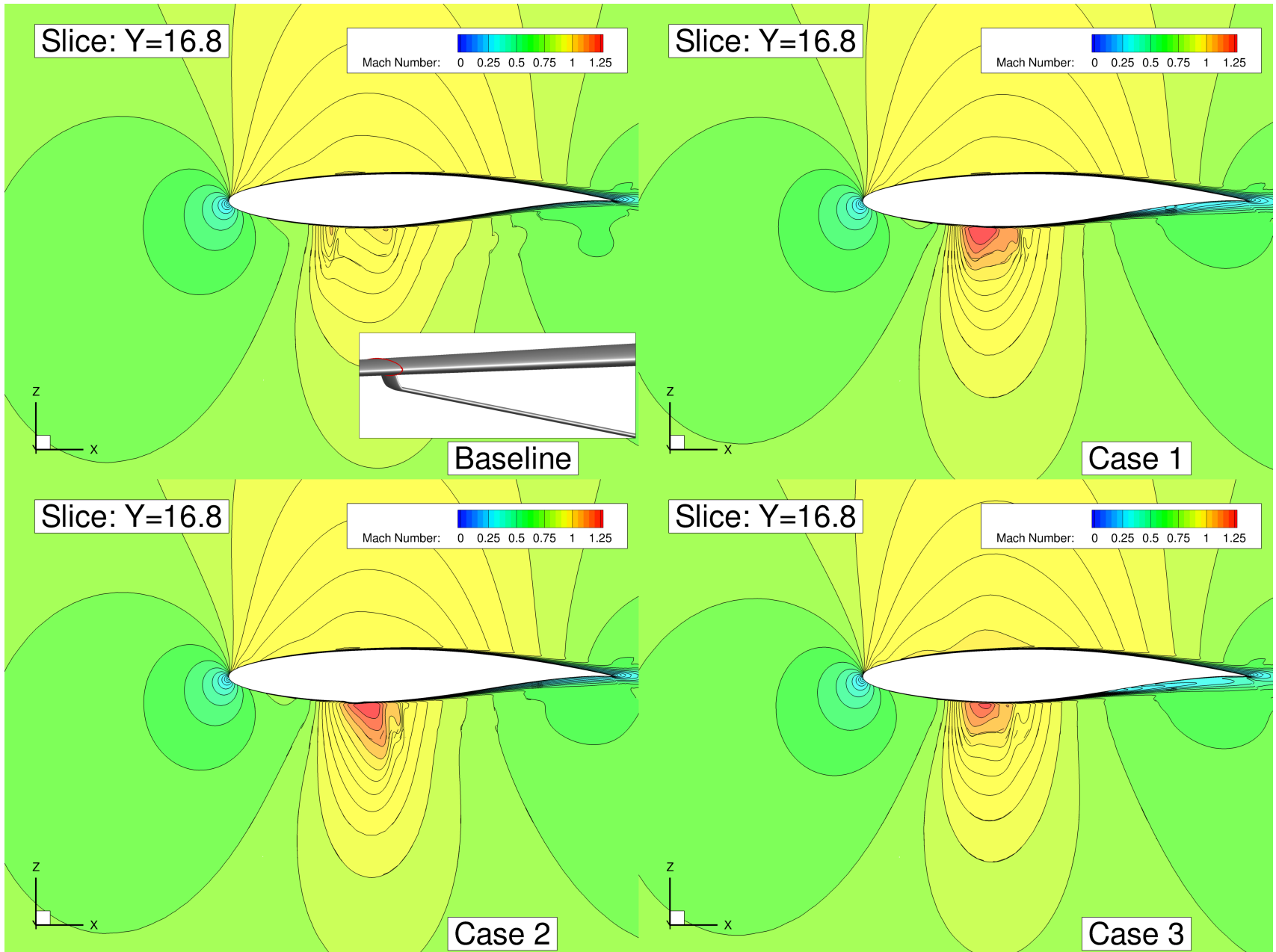
2D Slices of Junction Region



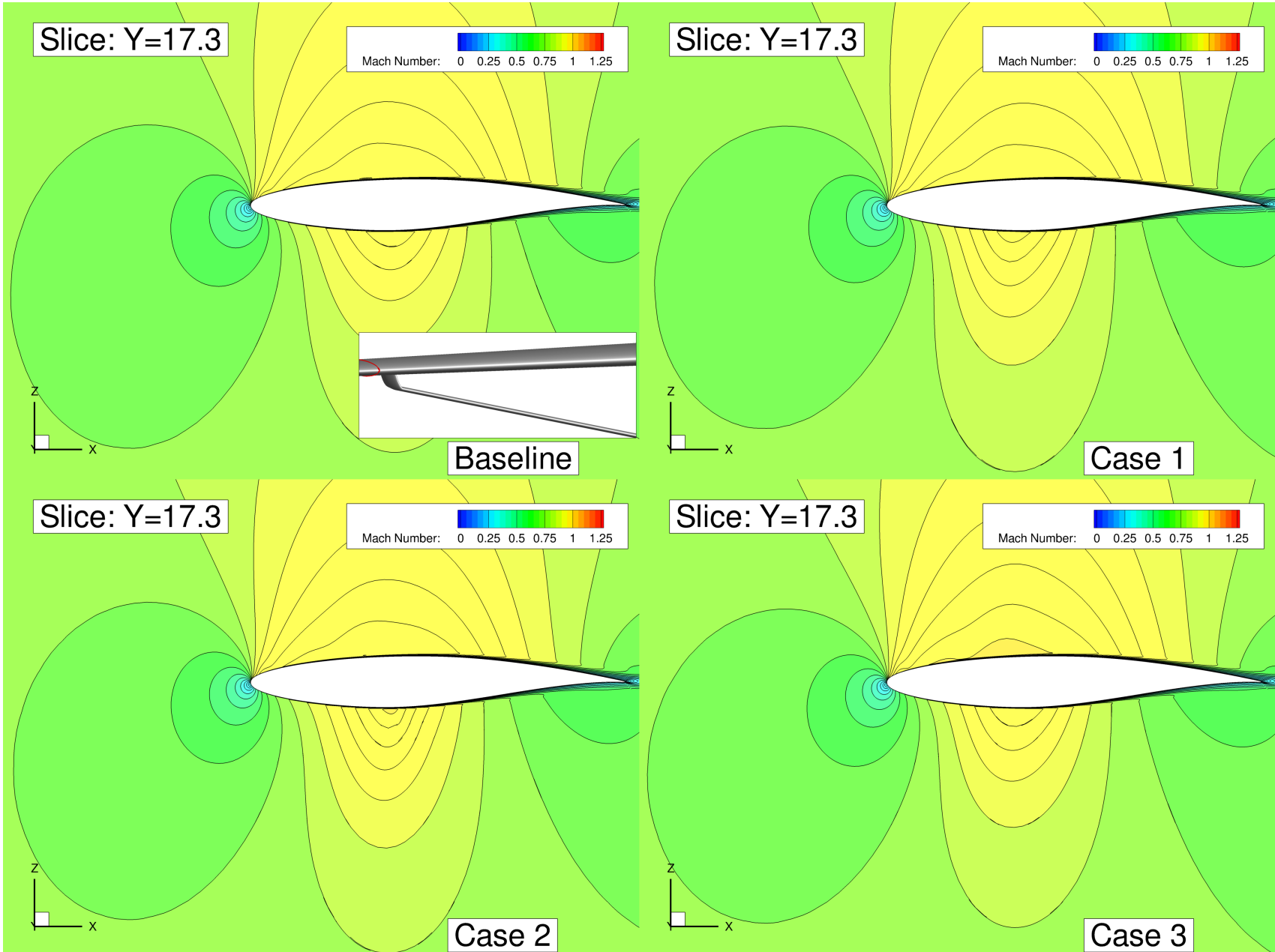
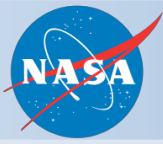
2D Slices of Junction Region



2D Slices of Junction Region



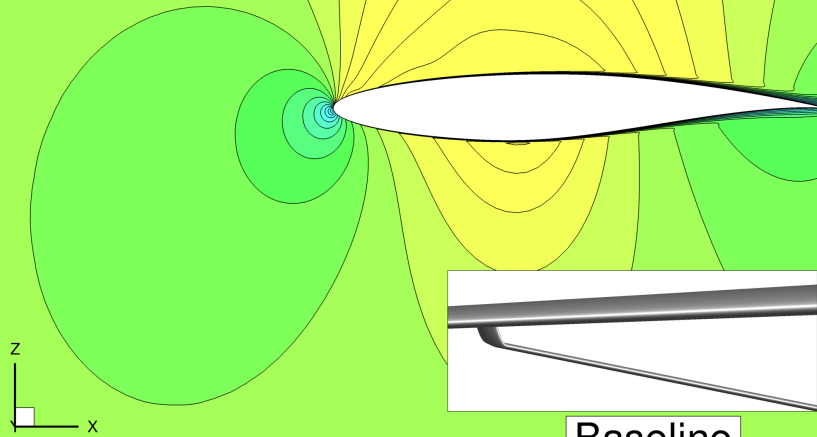
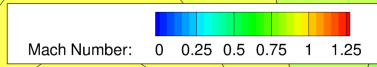
2D Slices of Junction Region



2D Slices of Junction Region

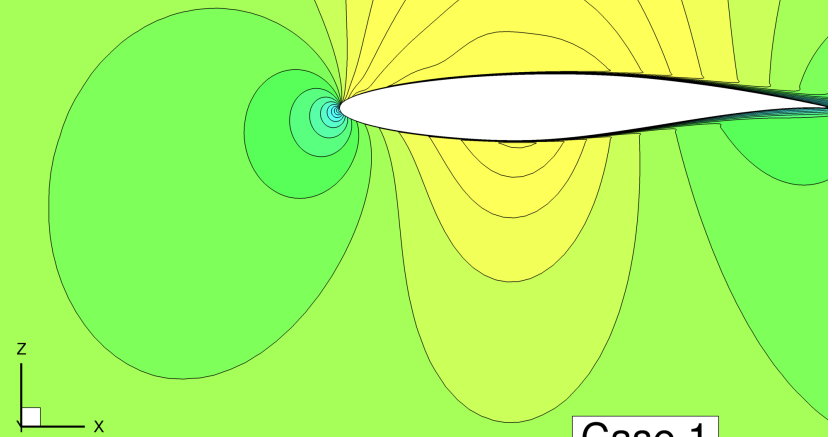
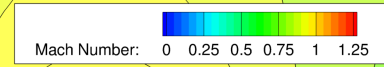


Slice: $Y=17.8$



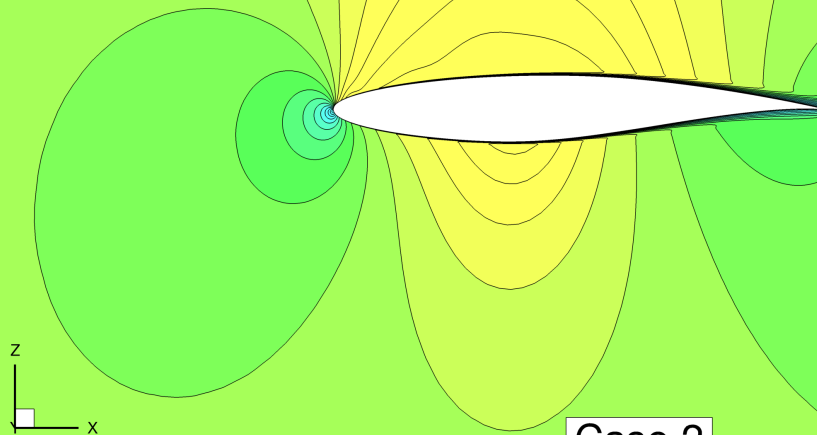
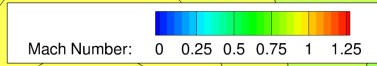
Baseline

Slice: $Y=17.8$



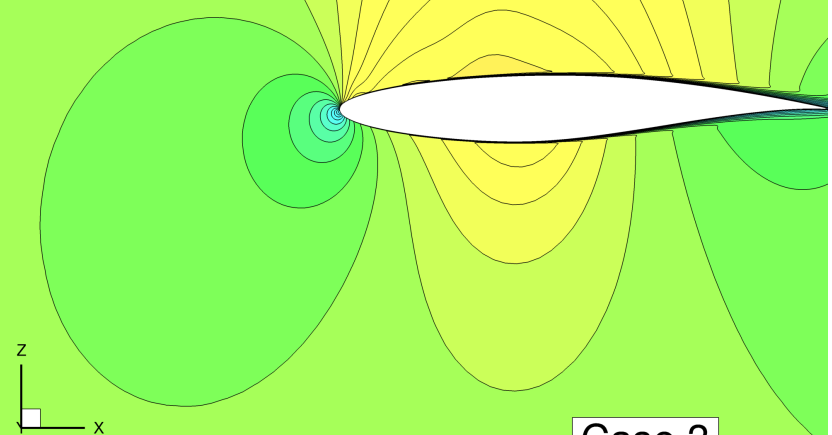
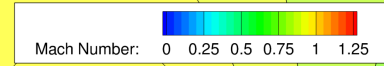
Case 1

Slice: $Y=17.8$



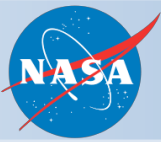
Case 2

Slice: $Y=17.8$

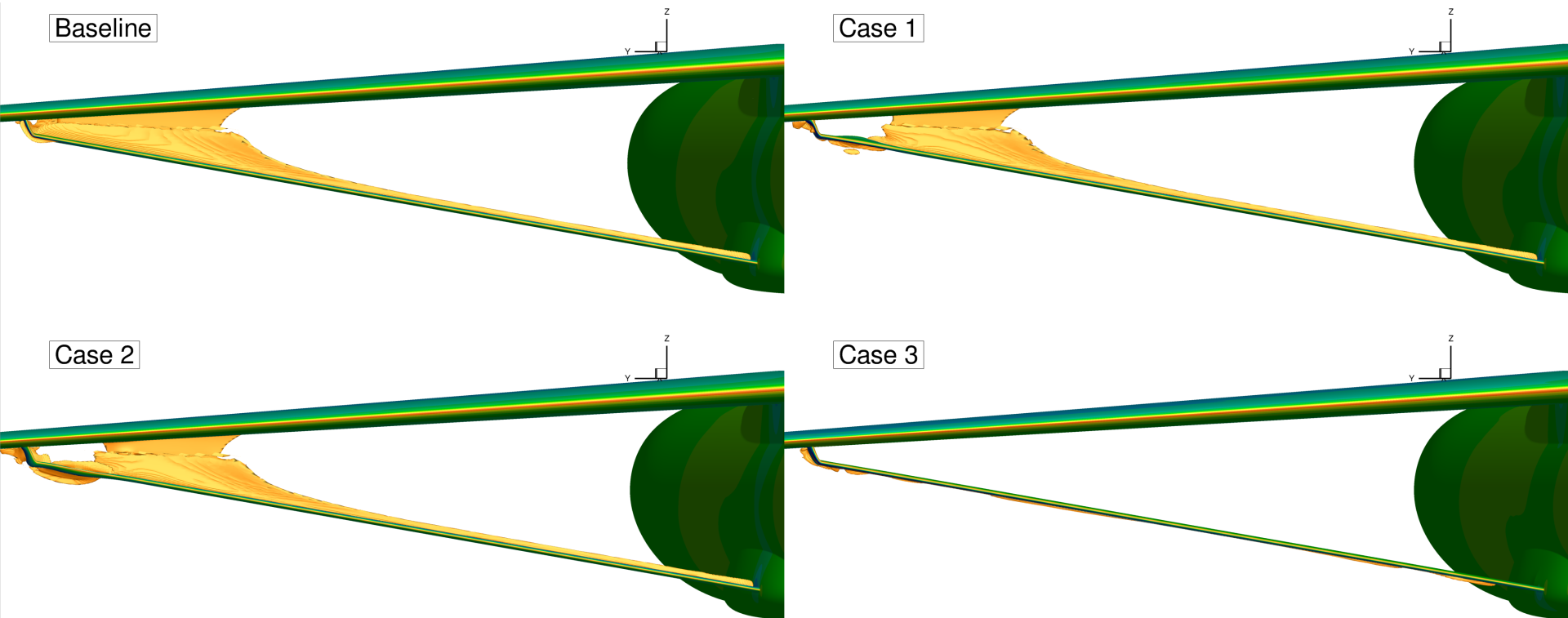


Case 3

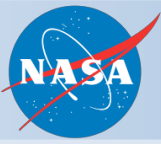
Shock Surface Visualization



- Case 1 successfully removes shock in design region
- Full truss redesign has weak shock on lower surface

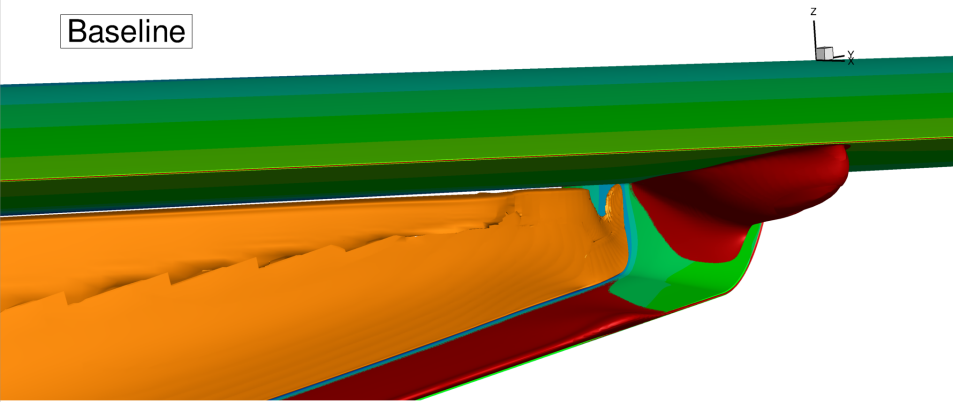


Separated Flow

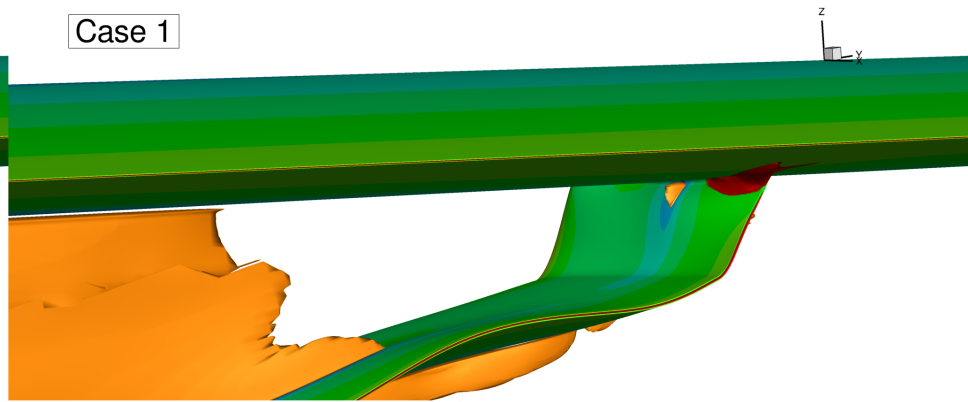


- All designs reduce the amount of separated flow at the strut-wing junction
- Red iso-contour at $V_x = -.0001$

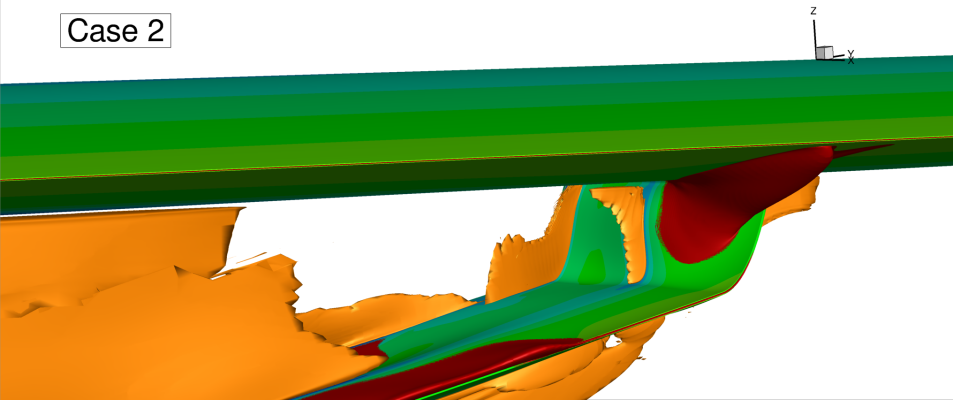
Baseline



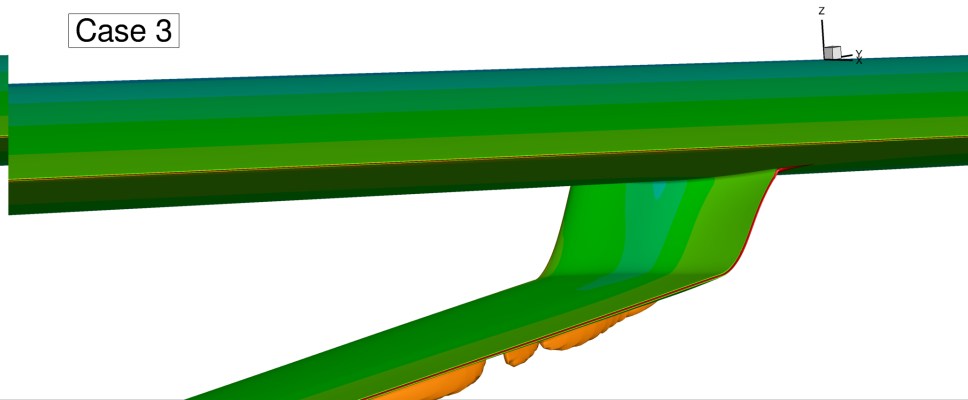
Case 1



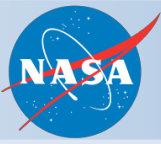
Case 2



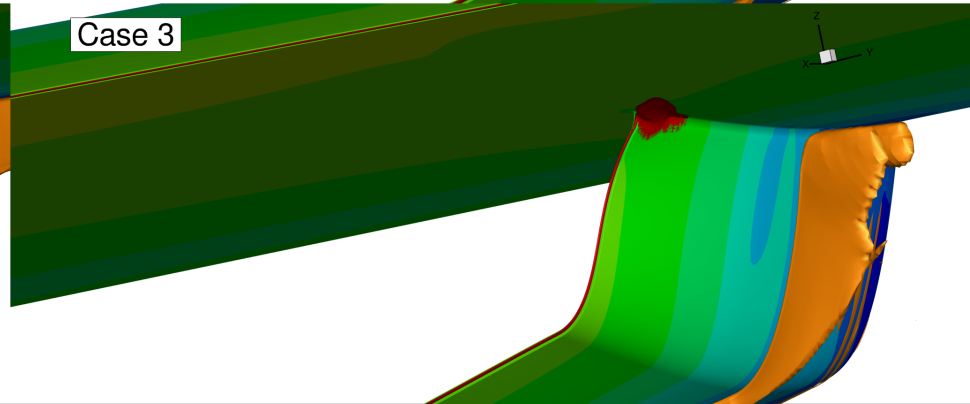
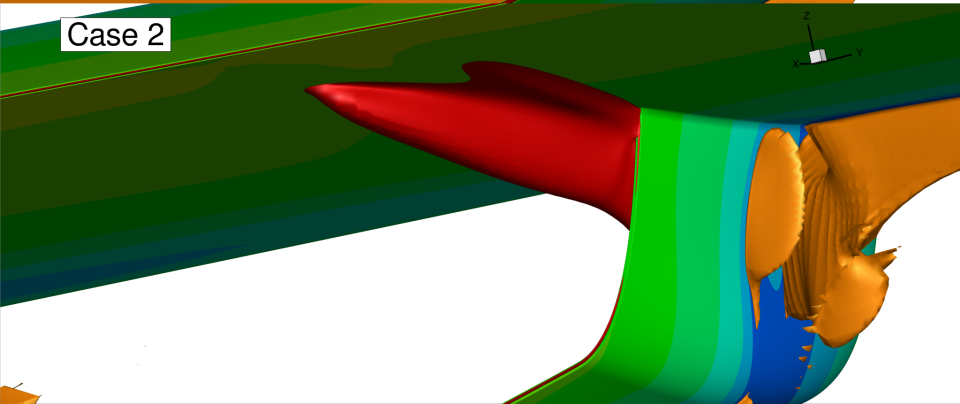
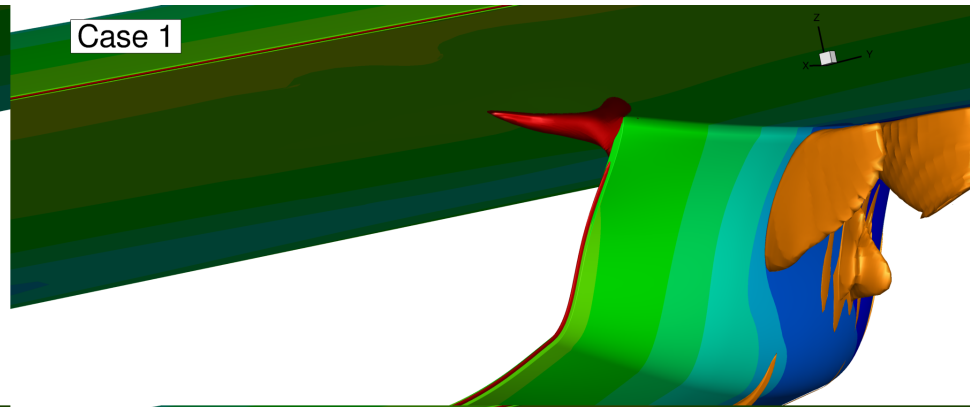
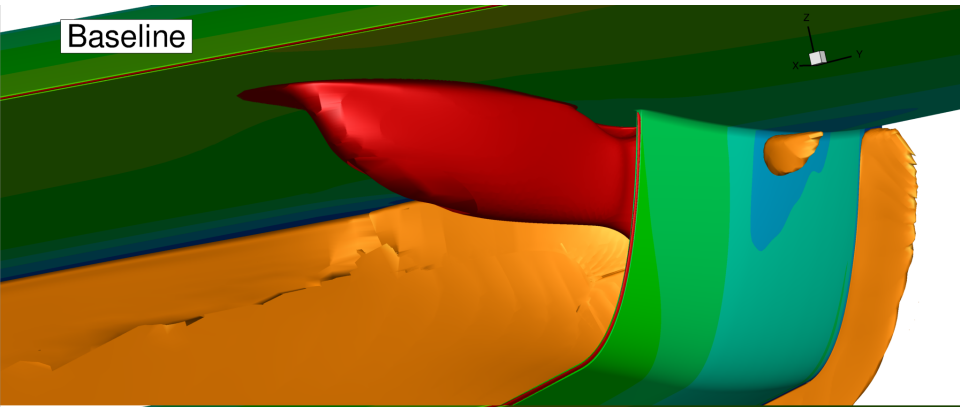
Case 3



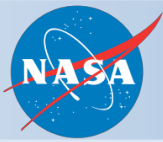
Separated Flow



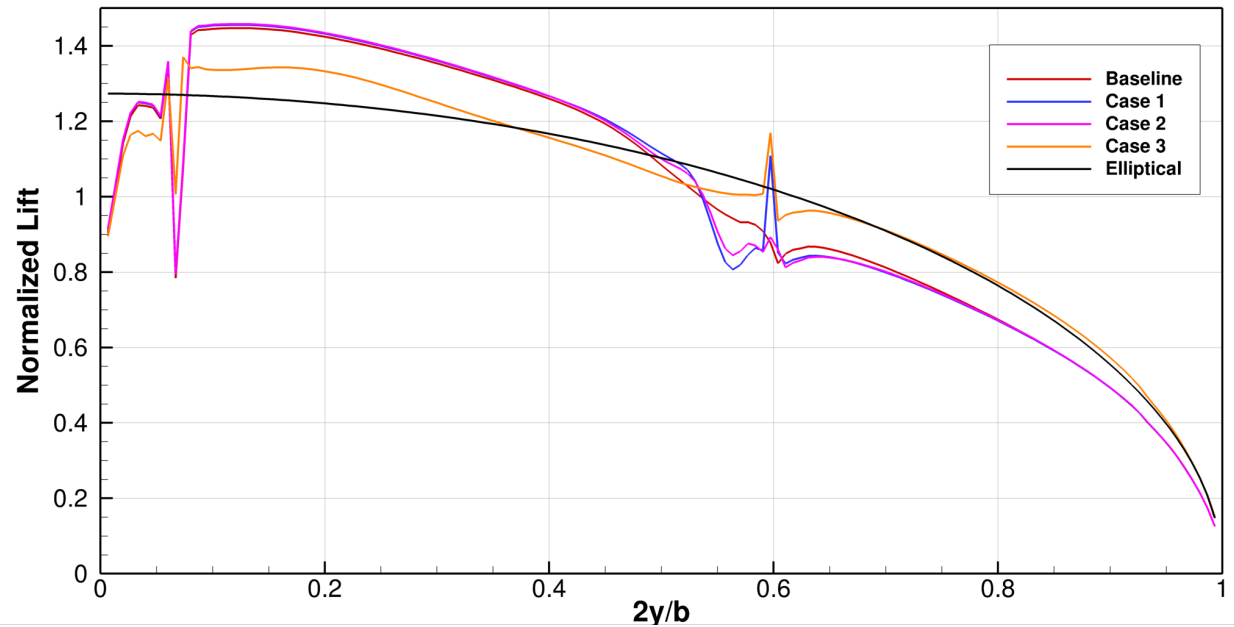
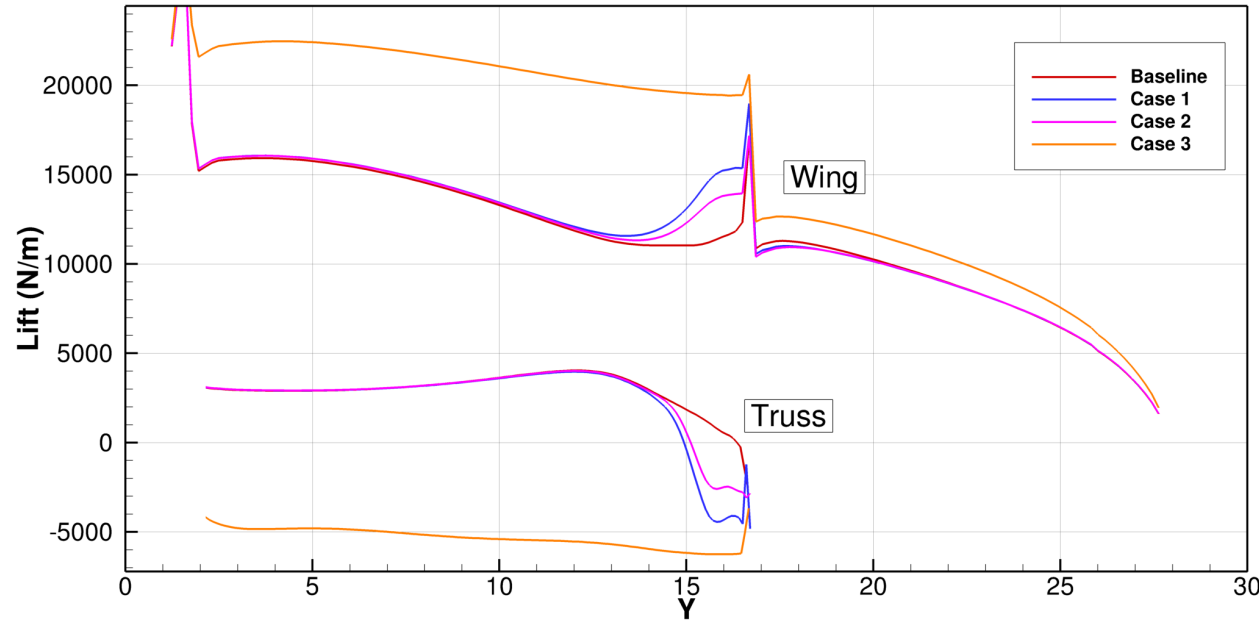
- All designs reduce the amount of separated flow at the strut-wing junction
- Red iso-contour at $V_x = -.0001$



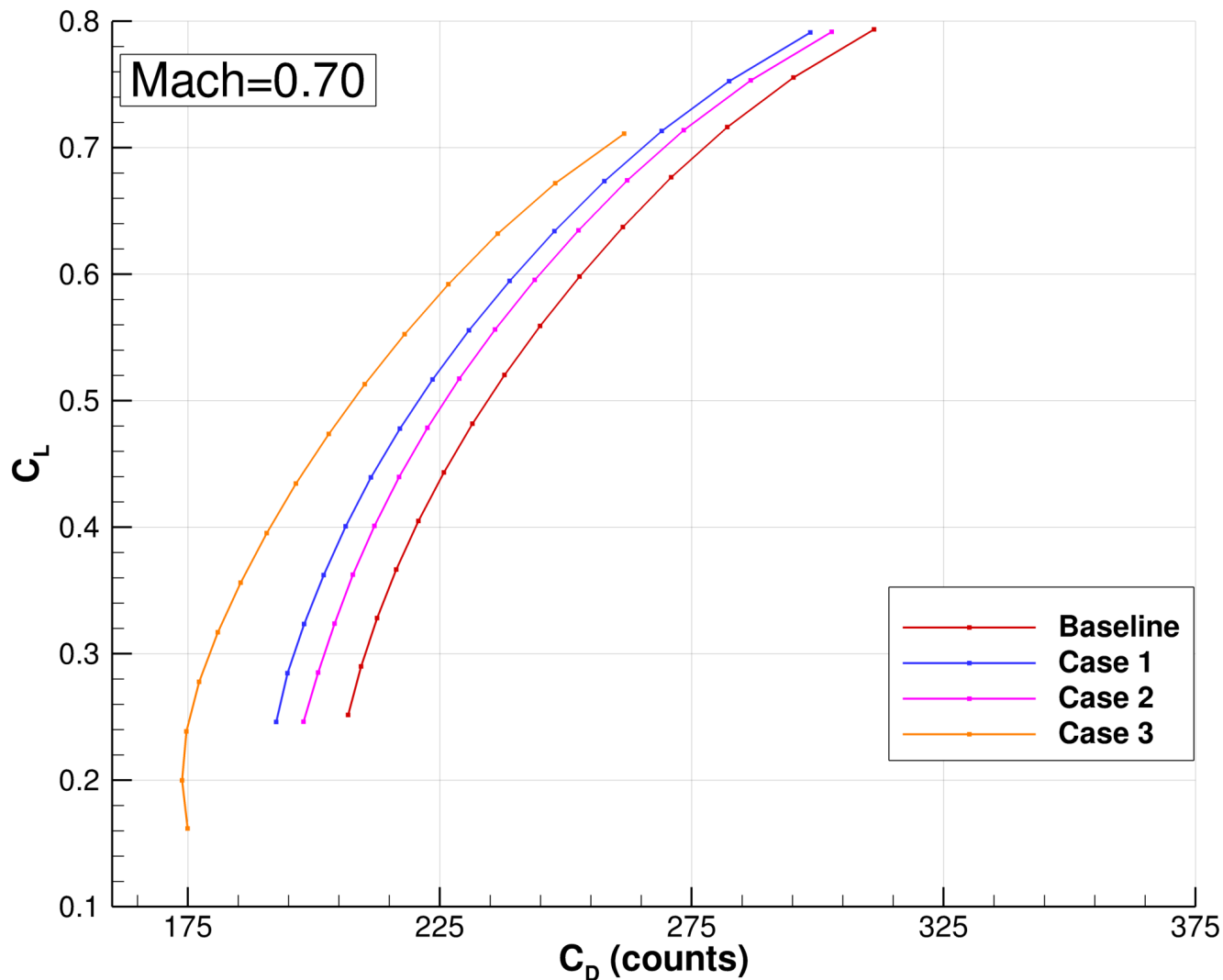
Lift Distributions



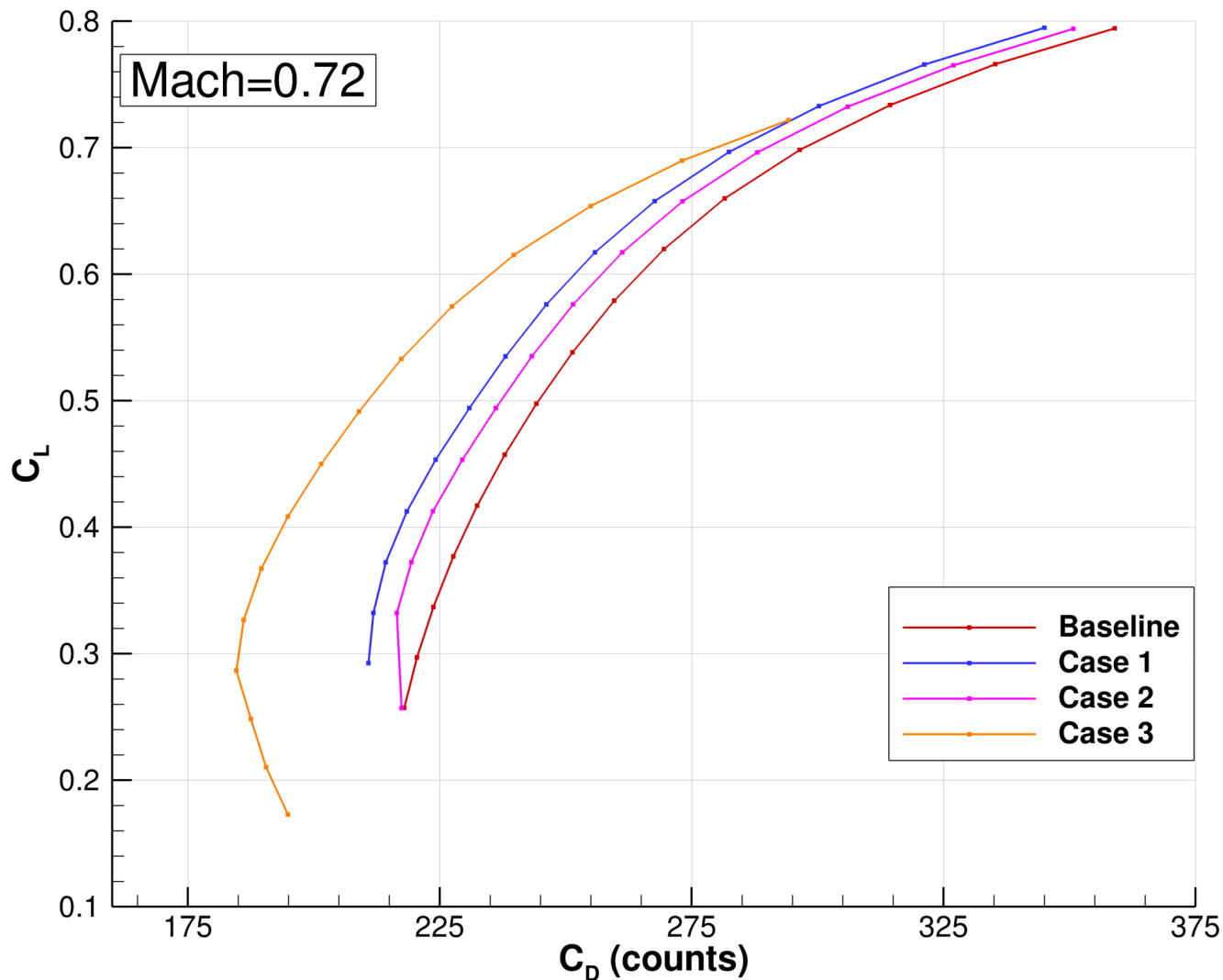
- All optimized designs reduce truss lift
- Nearly elliptical lift distribution and increased angle of attack for case 3
- Negative truss lift is optimal!



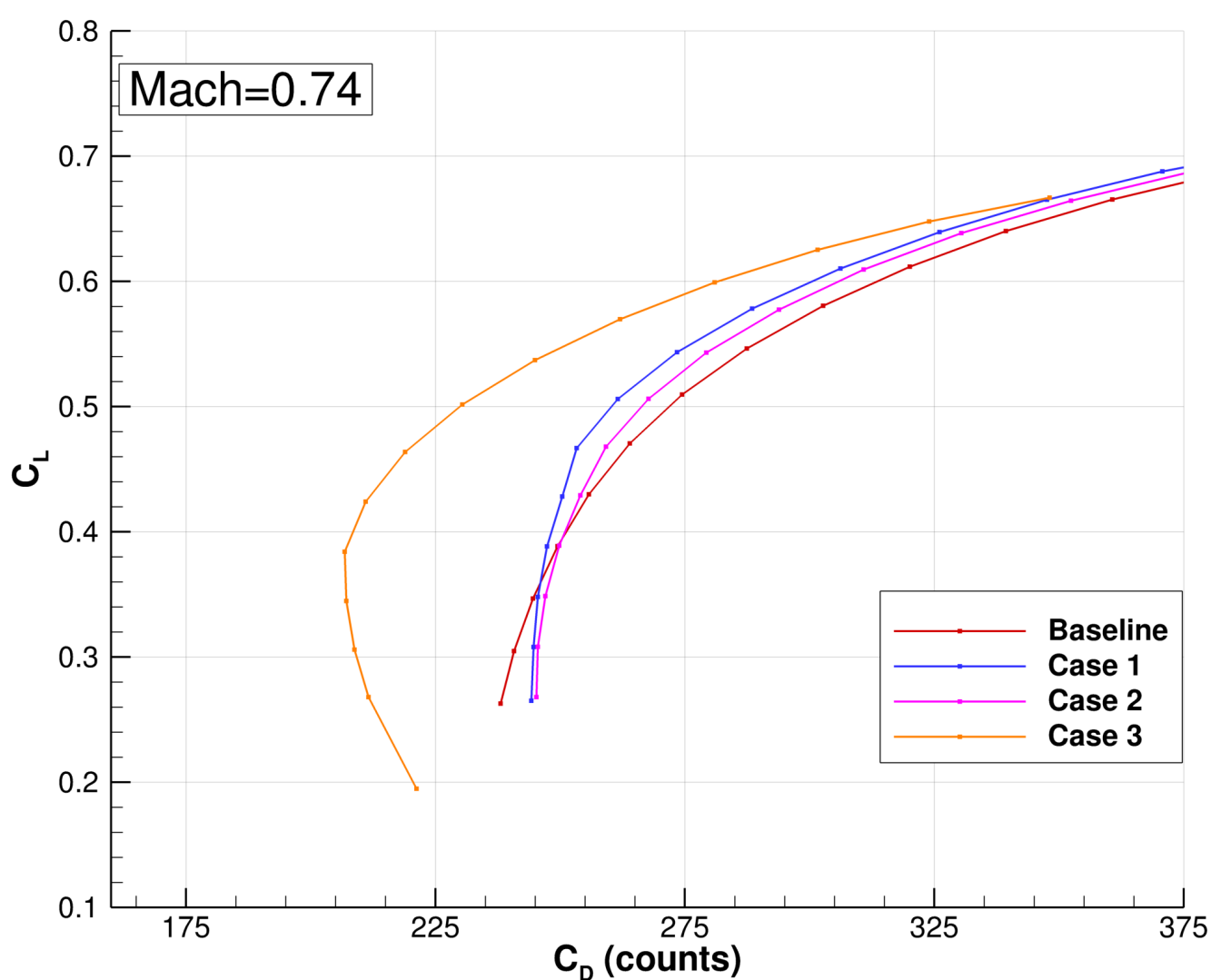
- Consistent improvement across Mach and angle of attacks



- Consistent improvement across Mach and angle of attacks



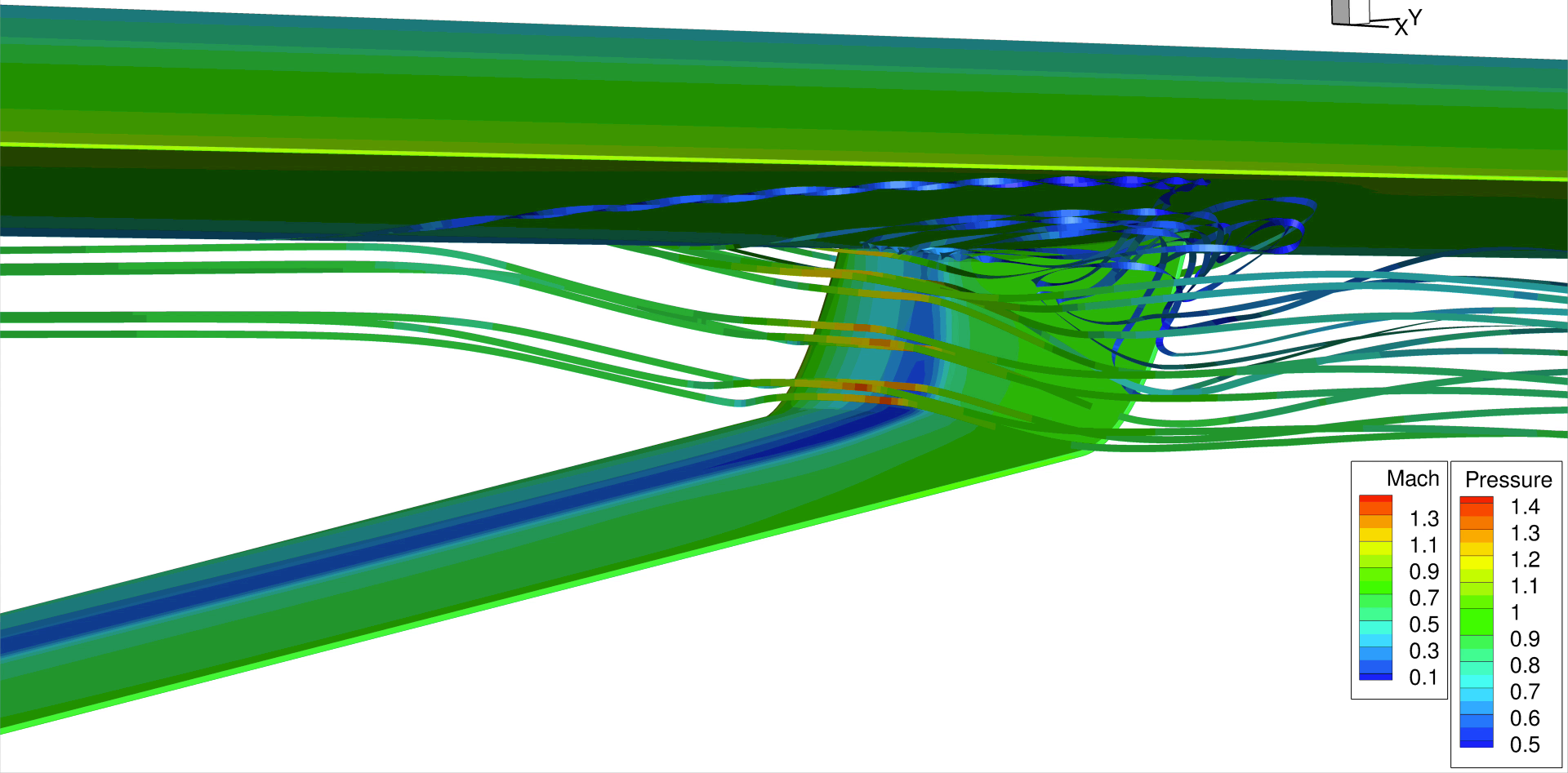
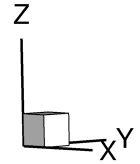
- Consistent improvement across Mach and angle of attacks



Optimization Case 1



Solution: 0

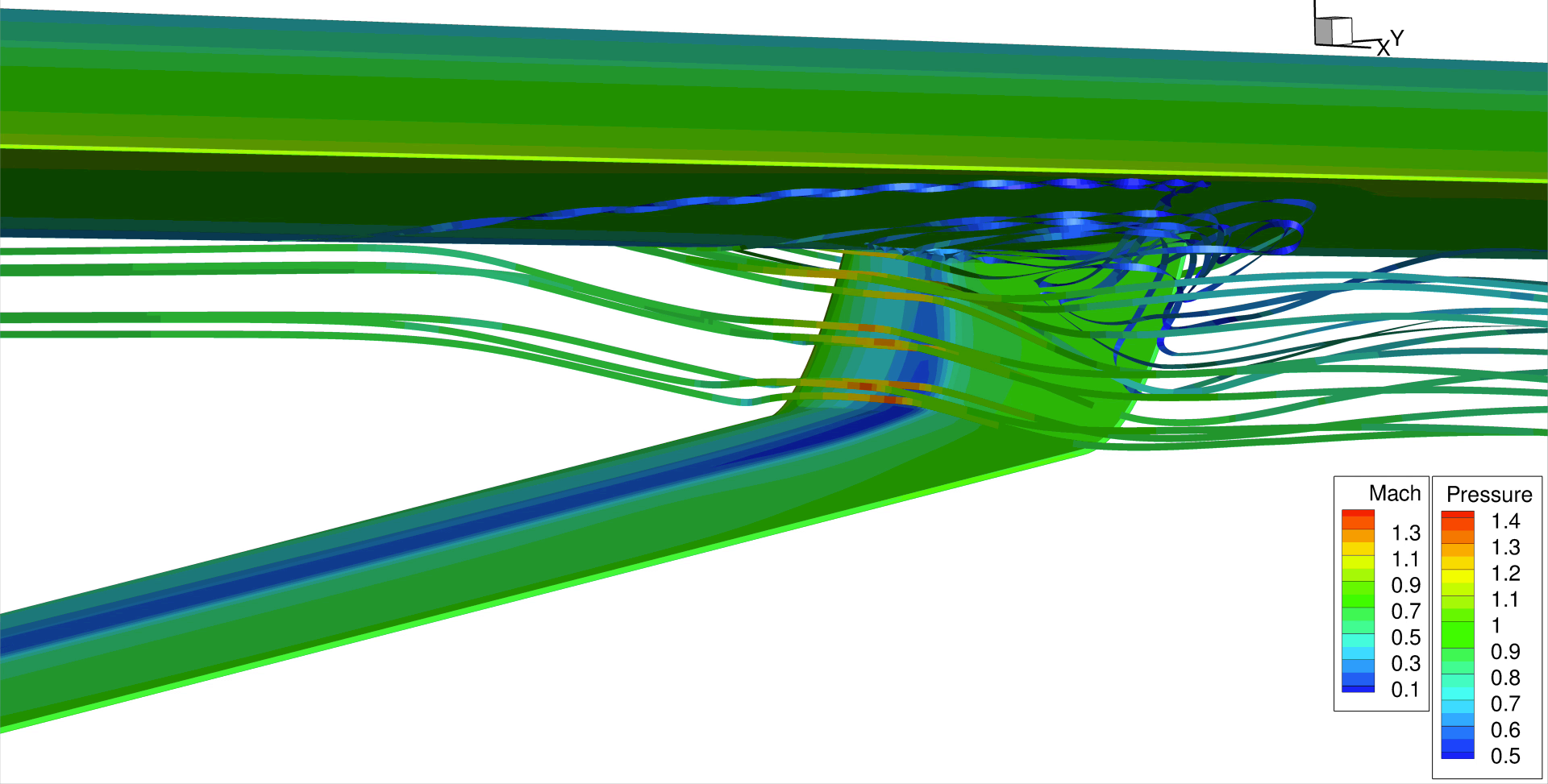
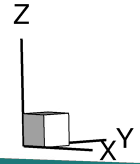


Pressure is shown on the surface. Stream ribbons are colored by Mach number.

Optimization Case 2



Solution: 0

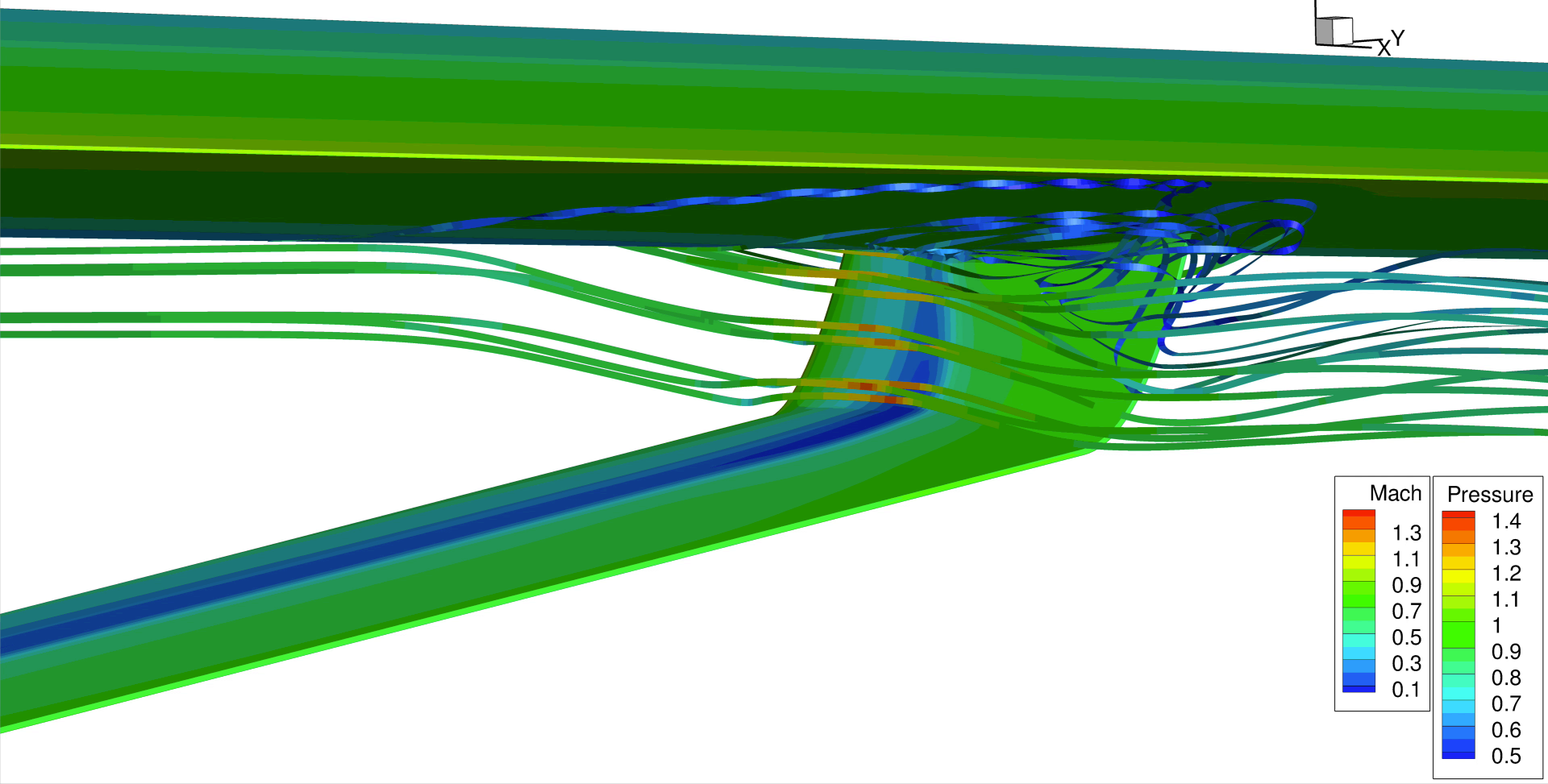
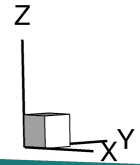


Pressure is shown on the surface. Stream ribbons are colored by Mach number.

Optimization Case 3

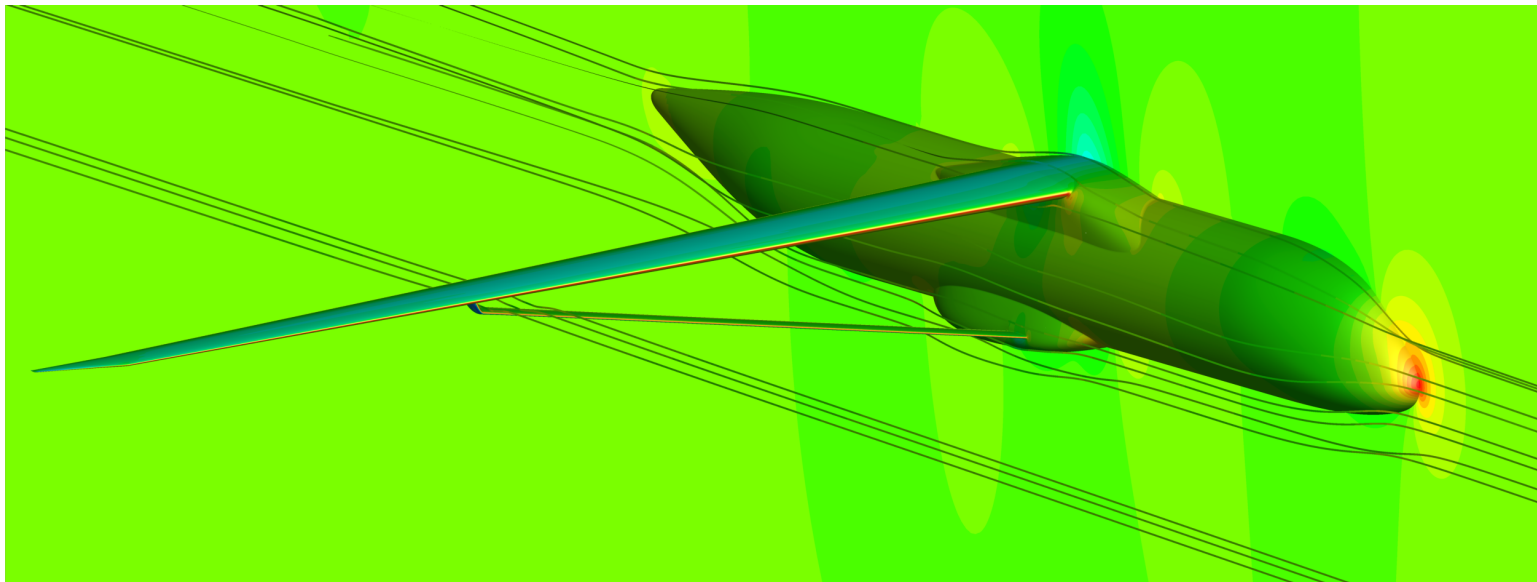


Solution: 0



Pressure is shown on the surface. Stream ribbons are colored by Mach number.

- Successfully redesigned truss-junction intersection
- Fast optimization turn-around times of under 2 hours
- 13.5 drag count reduction for Case 1
- 33.5 drag count reduction for Case 3
- In transonic flow, truss may have negative lift
- No cost associated with flow control device other than initial development costs
- Future work should include aero-structural trade-offs





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