Recent Progress in OVERFLOW Convergence Improvements

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Outline

- Background and motivation
- SSOR/time step improvements
  - Implicit boundary conditions
  - Improved flux linearizations
  - CFL ramping
- Limitations
- Test cases
  - S809 Airfoil
  - NACA 0015
  - DPW3 W1
  - DPW6 WB

Background

- OVERFLOW was originally developed as a finite difference solver, but evolved to include finite volume style discretizations as well
  - Central schemes and Steger-Warming FVS FD: 1980s
  - MUSCL FV: 1990s
  - WENO FD/FV: 2000s
- However, all the linearizations that have driven the linear solvers have remained fixed in the original finite difference framework

Background

- OVERFLOW has a mixture of spatially factored and unfactored linear solver schemes available

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- OVERFLOW has a mixture of spatially factored and unfactored linear solver schemes available
- The factored schemes have been the work horse methods of OVERFLOW, mainly due to time per iteration benefits, but they have some drawbacks
  - Factorization error
  - Need for intermediate boundary conditions
  - A variety of matrix approximations

Motivation

- OVERFLOW converges slowly
  - Time to solution is a more important metric than time per iteration
- What can be done to improve convergence without drastically changing the source code?
  - Evolutionary changes that improve nonlinear convergence

Development Summary

- Improved SSOR scheme
  - Implicit treatment of physical boundary conditions
  - Flux linearizations for the Roe, HLLC, and HLLE++ flux schemes
- CFL ramping via Switched Evolution Relaxation (SER) for steady state problems

Implicit BCs

- Implicit physical boundaries more closely couple the boundary and interior states, resulting in faster propagation of information and better convergence
- For time accurate simulations, forces and moments converge faster within the subiteration process

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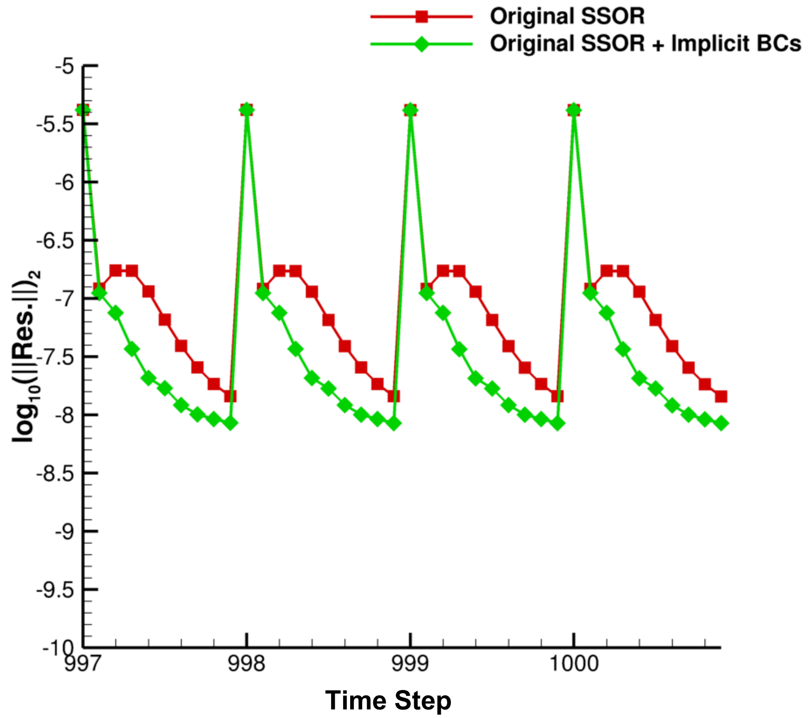

Flux Linearizations

- In the original SSOR scheme, Steger-Warming FVS finite difference Jacobians are used for the upwind schemes
  - Mismatch with the finite volume schemes
- In general, the better you do linearizing a problem, the better your nonlinear problem will converge (we hope)

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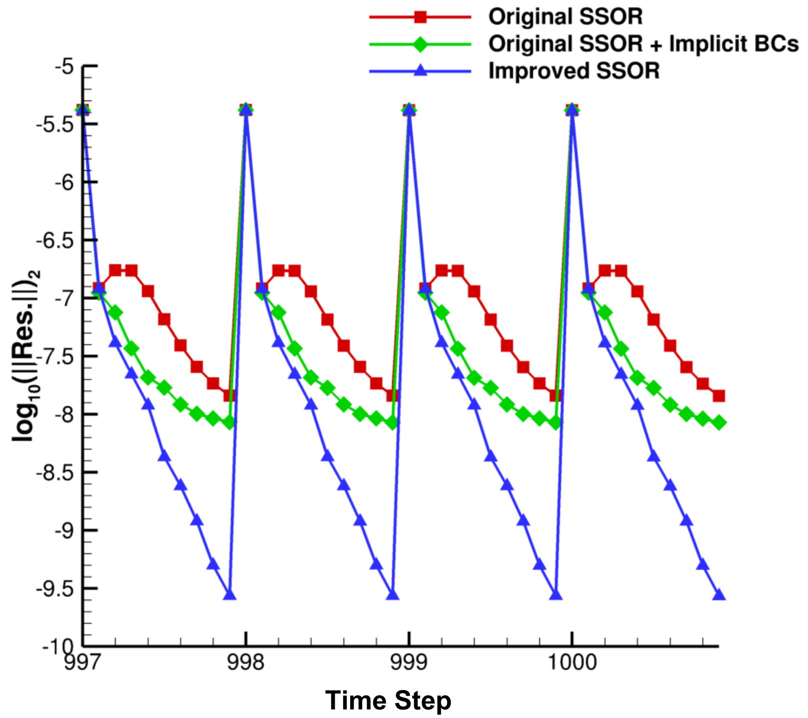


CFL Ramping

- Switched Evolution Relaxation (SER) was developed by Mulder and van Leer* and is probably the simplest CFL evolution scheme that ties CFL ramping to the nonlinear residual

$$CFL^{n+1} = \varepsilon * CFL^{n}$$

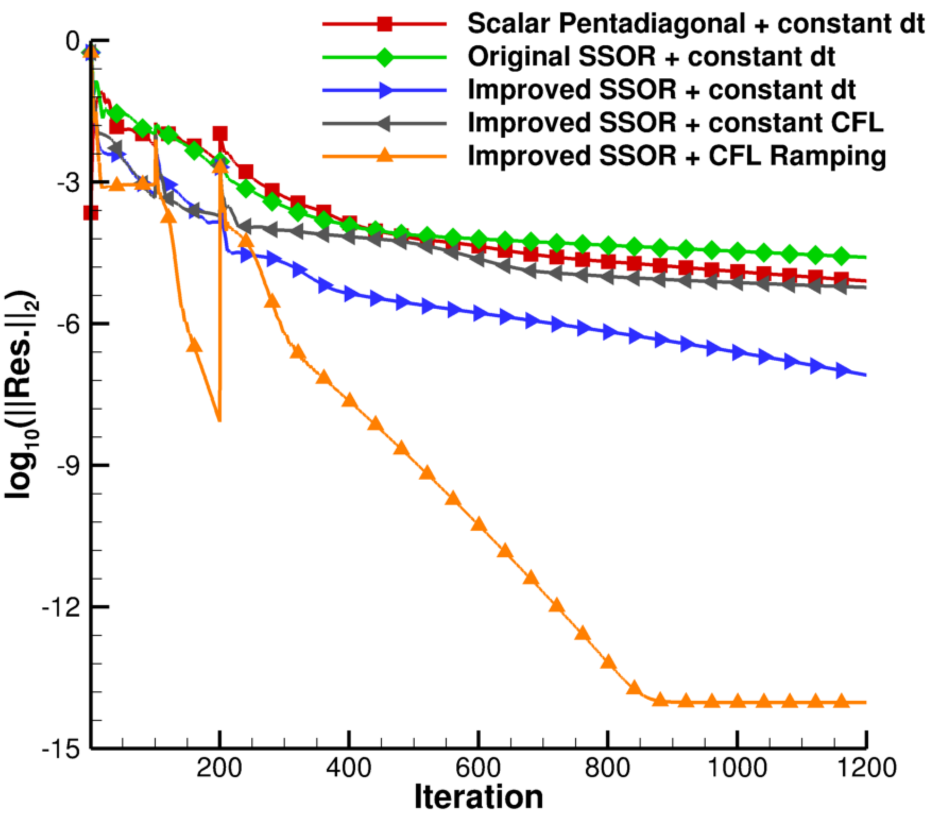
$$\varepsilon = \frac{\|R^{n-1}\|}{\|R^{n}\|}$$

- The current implementation works with ITIME = 3 and 4 and allows for setting a starting CFLMAX on a grid by grid basis, but forms a global ramping factor
  - There are also CFL max and min limits

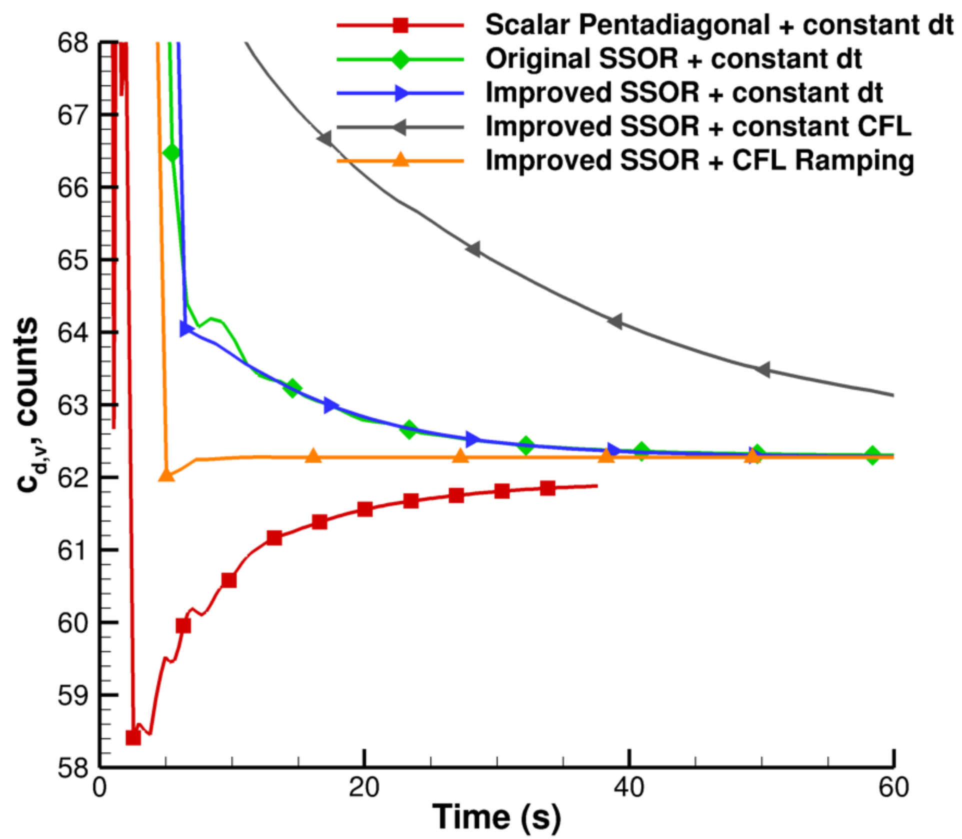
*Mulder, W.A. and van Leer, B., "Implicit Upwind Methods for the Euler Equations," AIAA 83-1930, DOI: 10.2514/6.1983-1930

Improvement Summary

Residual



$c_{d,v}$



Limitations

- Not all BCs have been linearized, or they have just been approximately linearized
  - Restricts the maximum stable CFL number that can be reached
  - Overset boundaries are still explicit!
- SSOR is a sweeping algorithm and can sweep in the wrong physical direction
  - Can lead to solution instabilities, especially with strong shocks or unfortunately split grid blocks
- SER can get stuck
  - Balance between steady and unsteady simulations

Examples

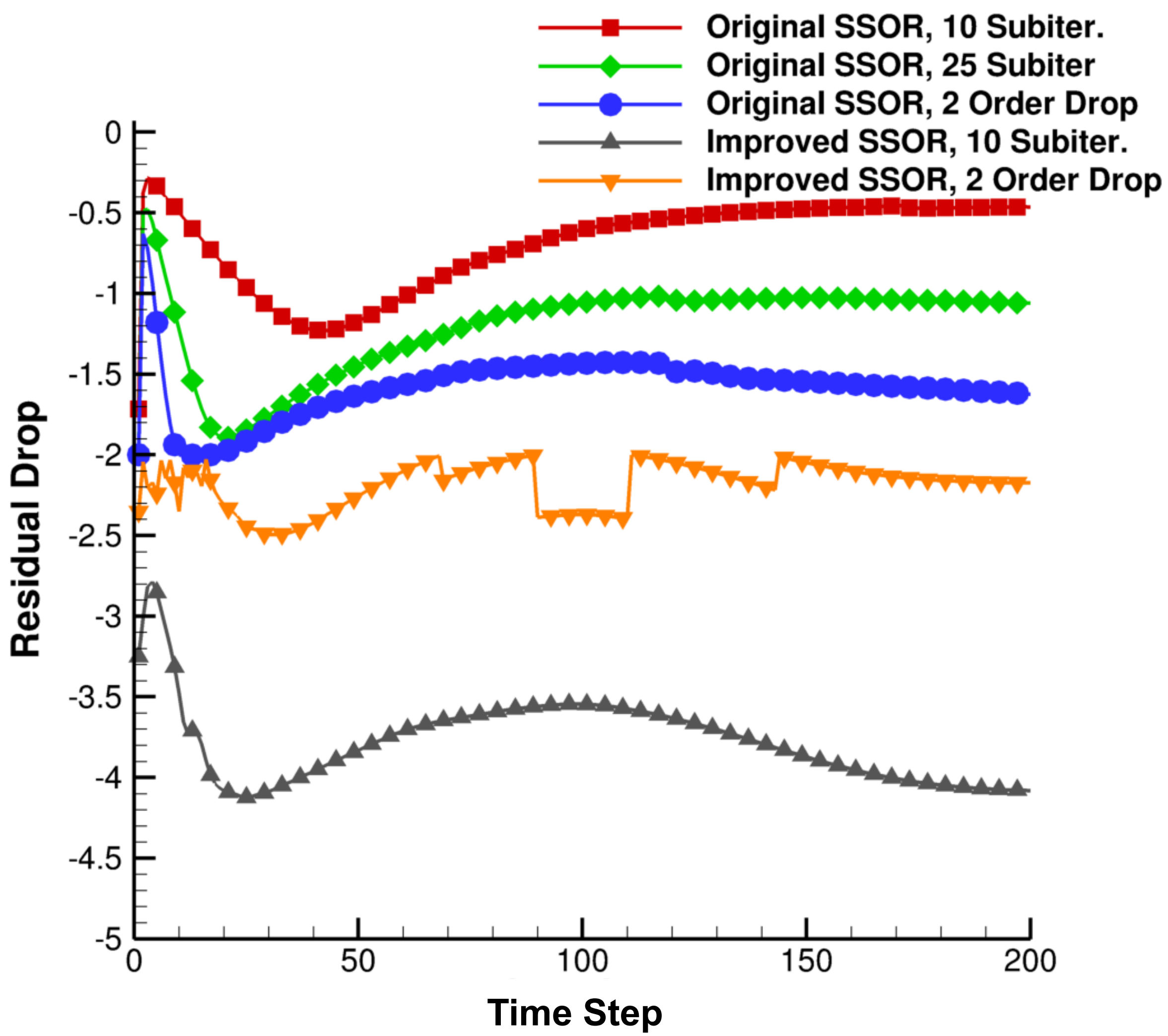
- S809 Airfoil
- NACA 0015
- DPW3 W1
- DPW6 WB

- Only a subset of the results from the paper will be presented

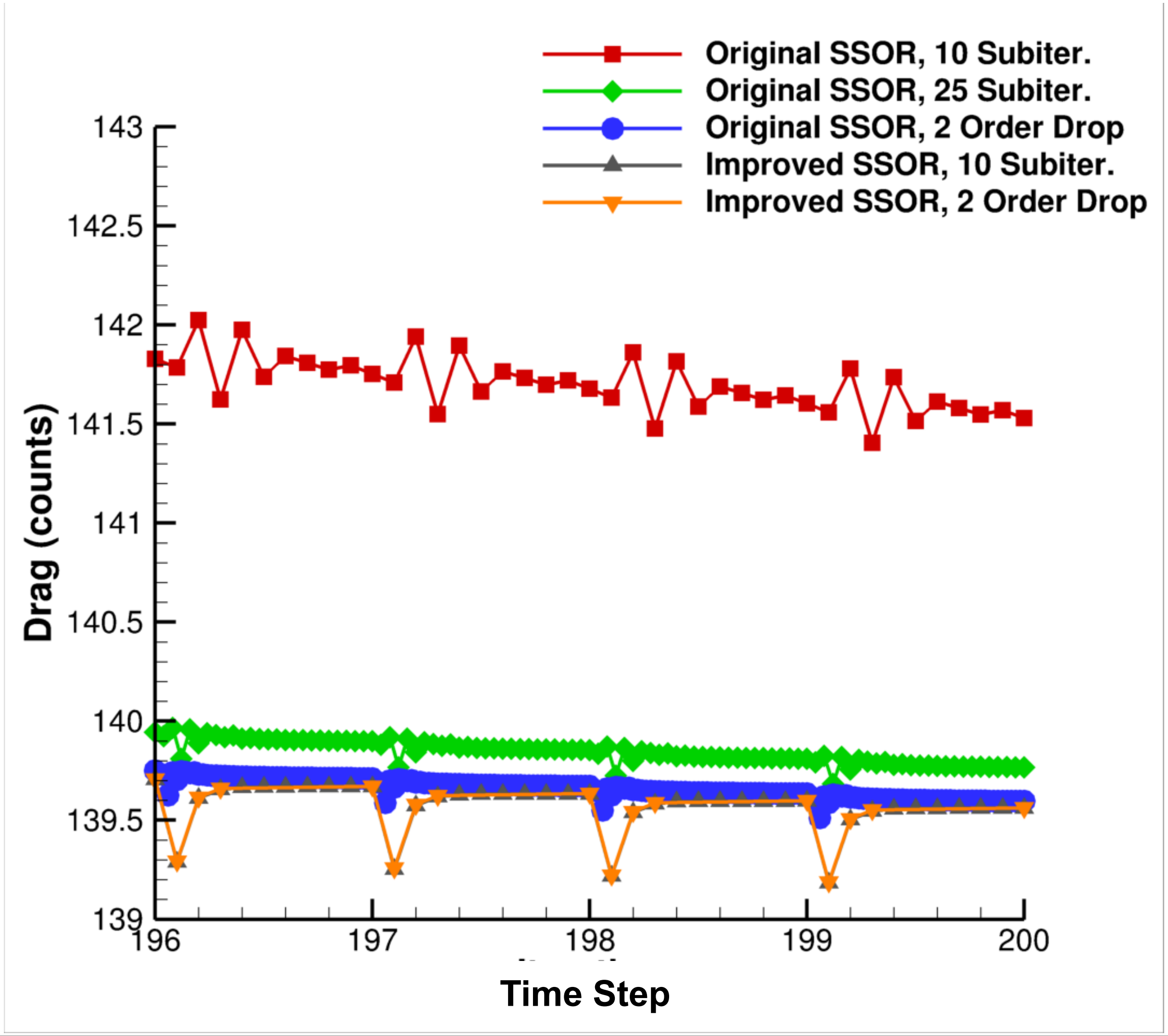
S809 Airfoil

- Fairly high t/c wind turbine section
- Paper includes steady-state calculations with and without low-Mach preconditioning
- Will only discuss ‘unsteady’ results
    - Impulsive start, simulation time equal to two chord lengths of travel
    - Mach = 0.1, AoA = 1.0°, Re = 2 million
    - HLLE++ flux scheme, SA-neg turbulence model, ‘3rd-order’ MUSCL extrapolation

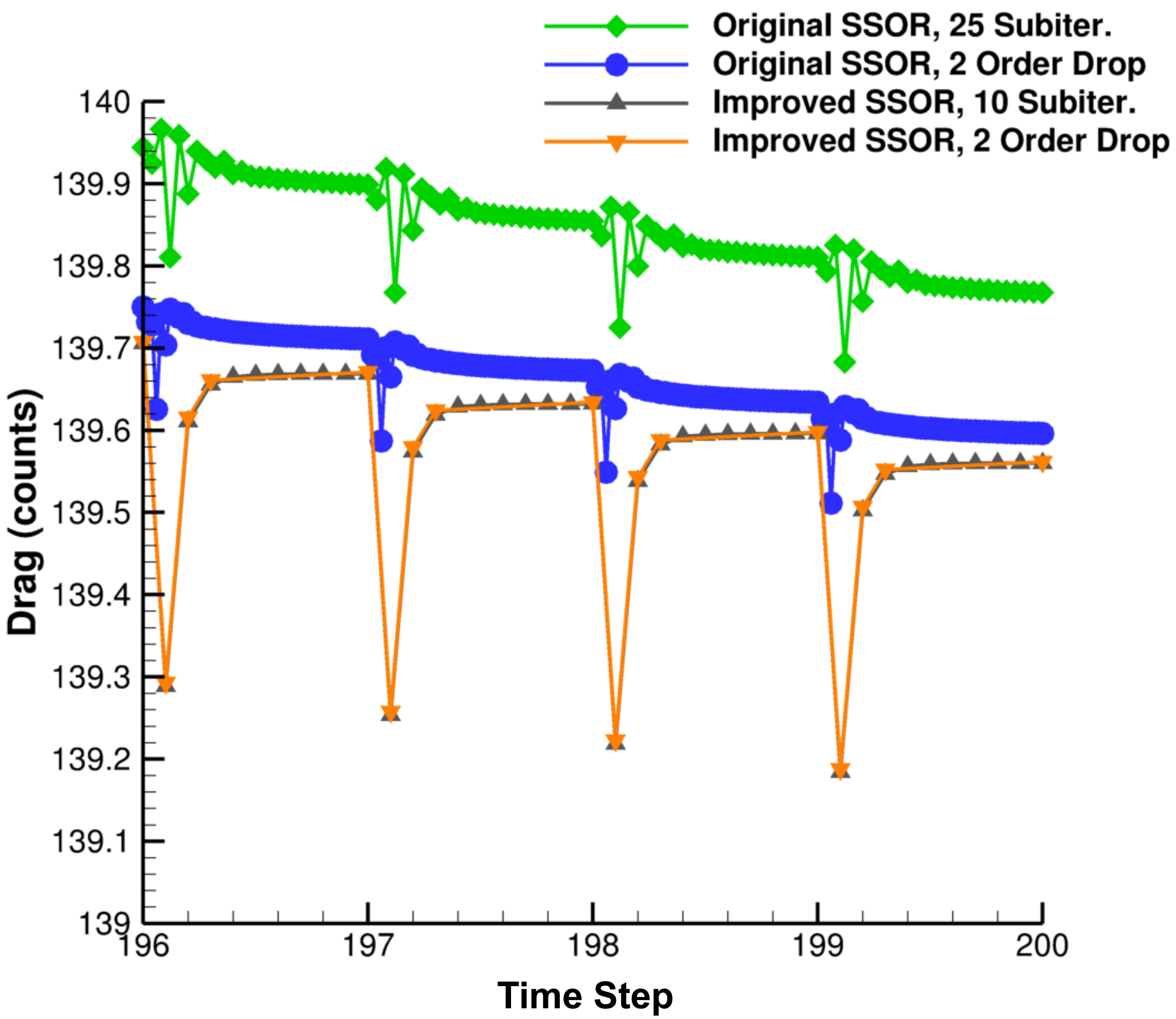
S809 Airfoil



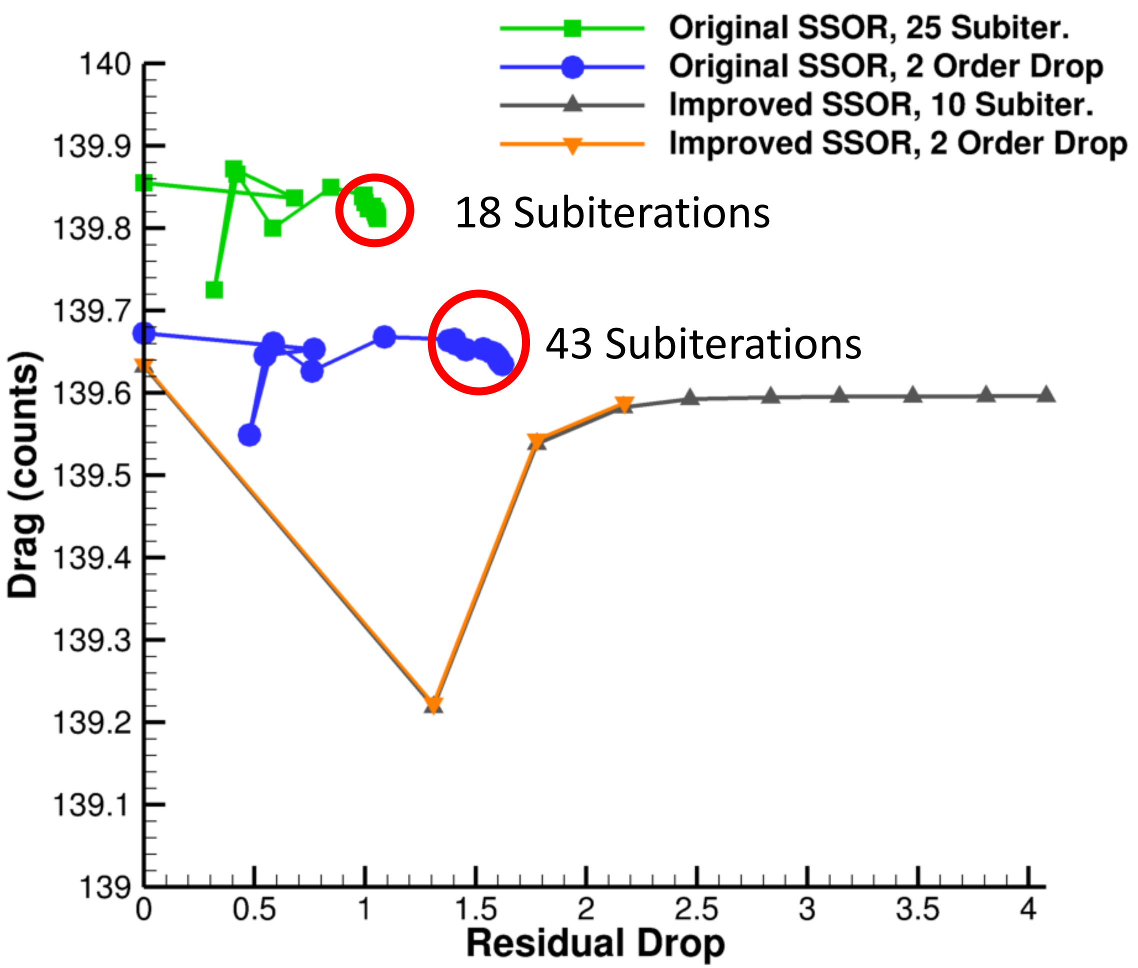
S809 Airfoil



S809 Airfoil



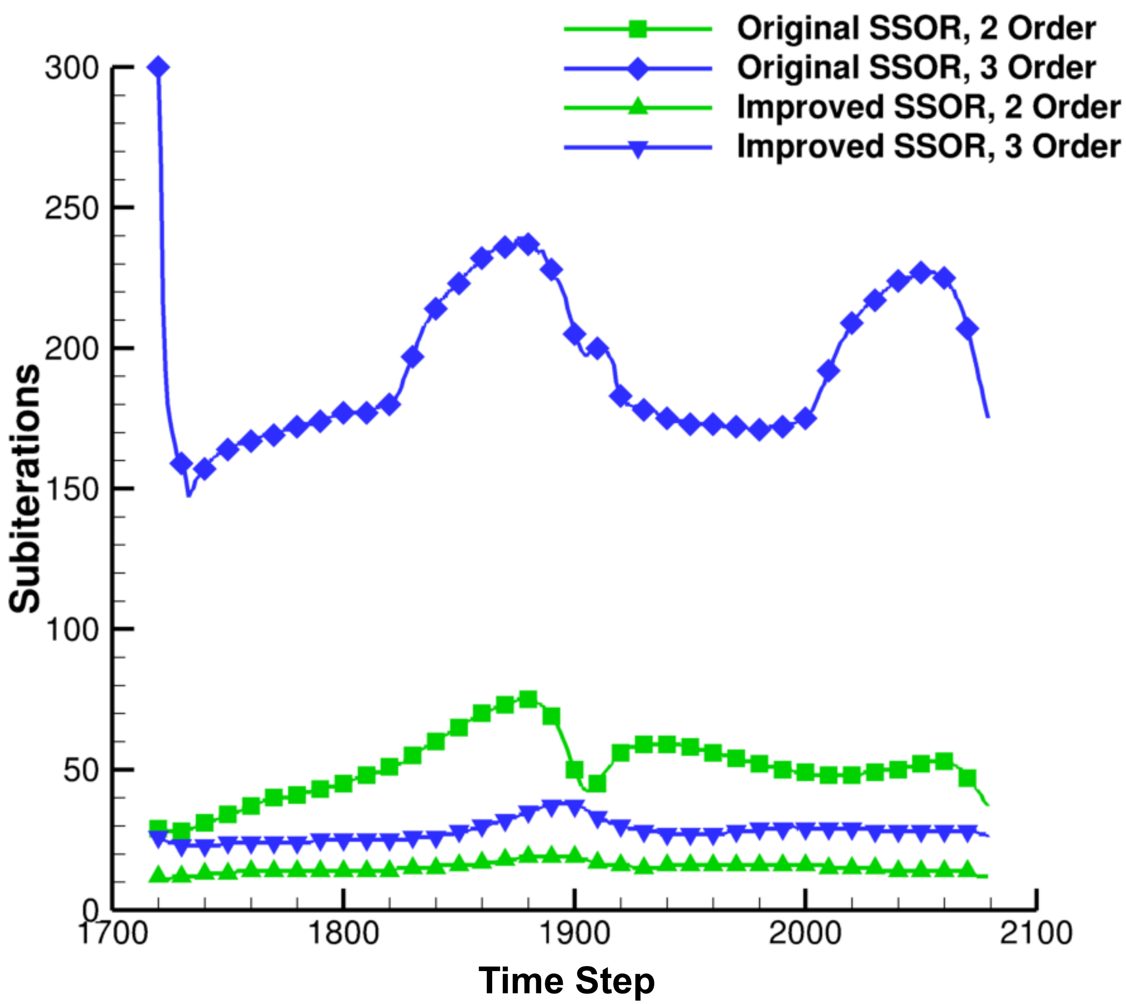
S809 Airfoil



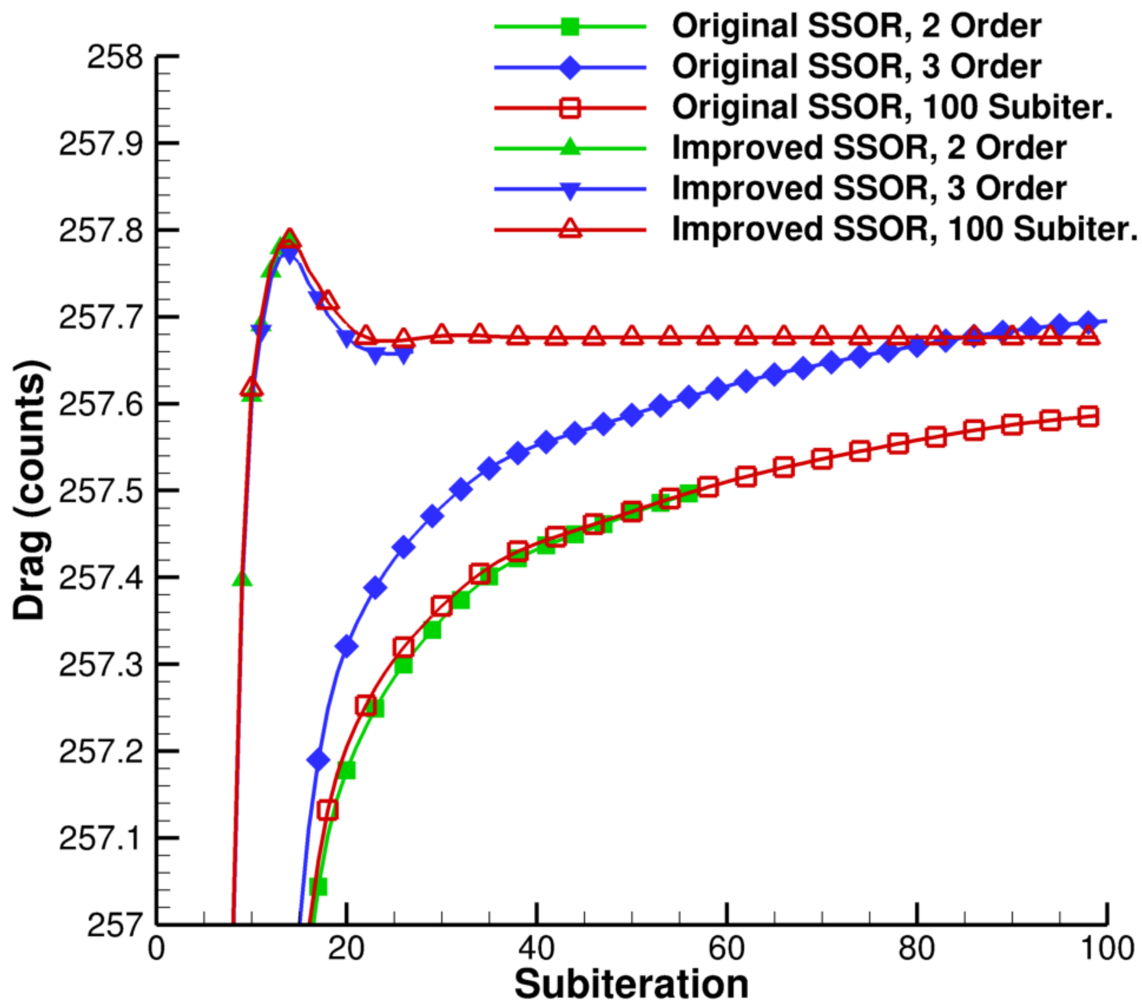
Oscillating NACA 0015

- Oscillates in pitch between 6.8° and 15.2° degrees
  - Mach = 0.29, Re = 1.95 million
  - HLLE++ flux scheme, SA-neg turbulence model, ‘3rd-order’ MUSCL extrapolation
- Addresses startup issues through a multi-stage initialization process
  - Run at steady state at 6.8° to initialize the flow field before switching over to time accurate mode

Oscillating NACA 0015



Oscillating NACA 0015

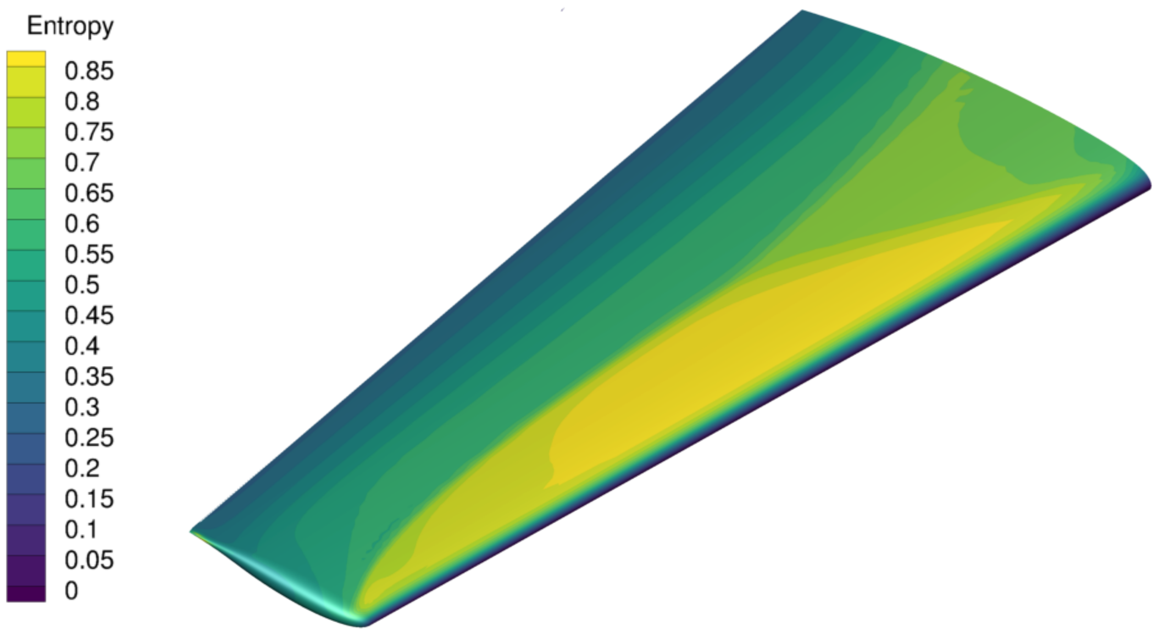


2D Unsteady Summary

- The improved SSOR scheme is a clear winner for unsteady subiteration convergence
- Improved convergence directly results in better force/moment convergence

DPW3 W1

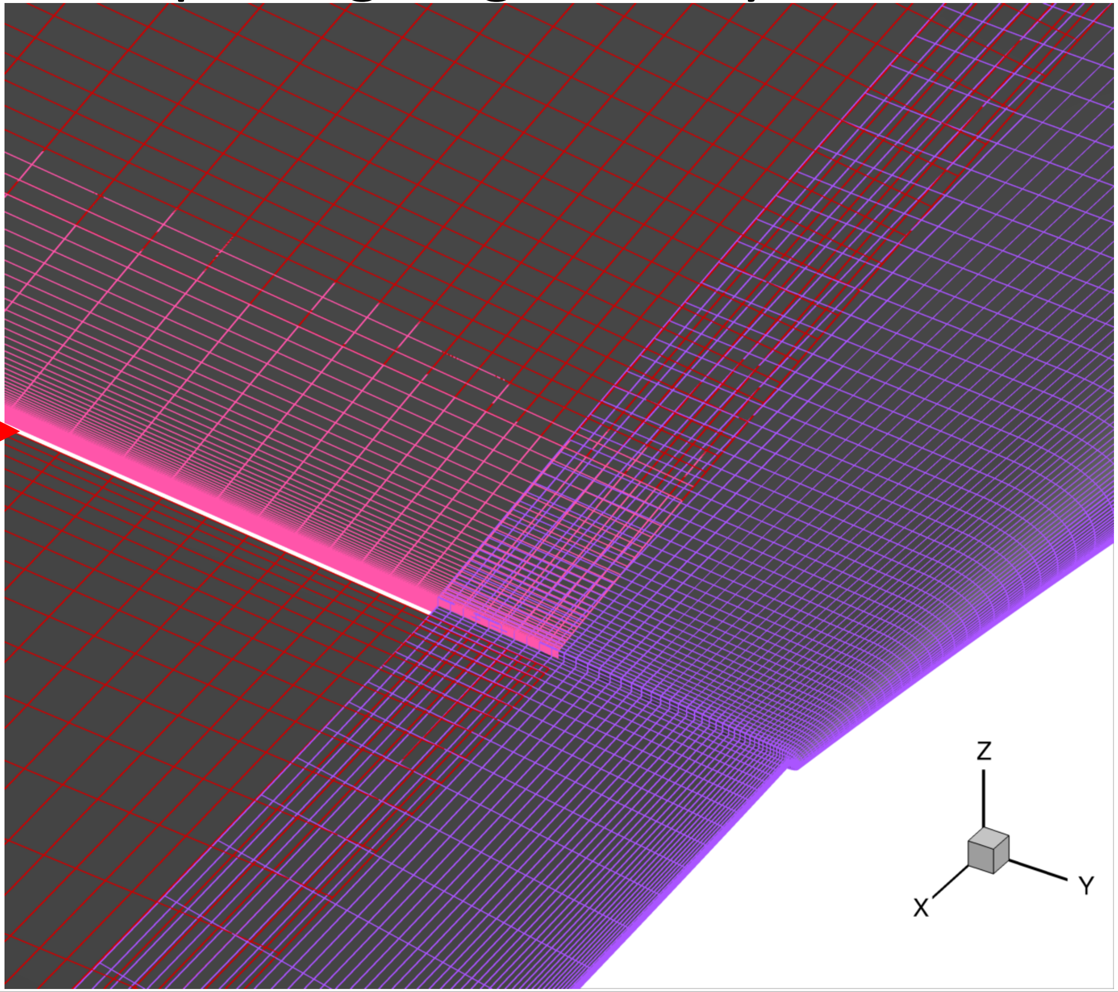
- Transonic wing geometry
  - Mach = 0.76, AoA = 0.5°, Re = 5 million
  - 4.8 million node ‘medium’ grid from the DPW website
- 3rd-order MUSCL, Roe flux, fully turbulent SA-neg



DPW3 W1

- Test of multiple C-grid geometry and boundary IBLANK

Mind the gap

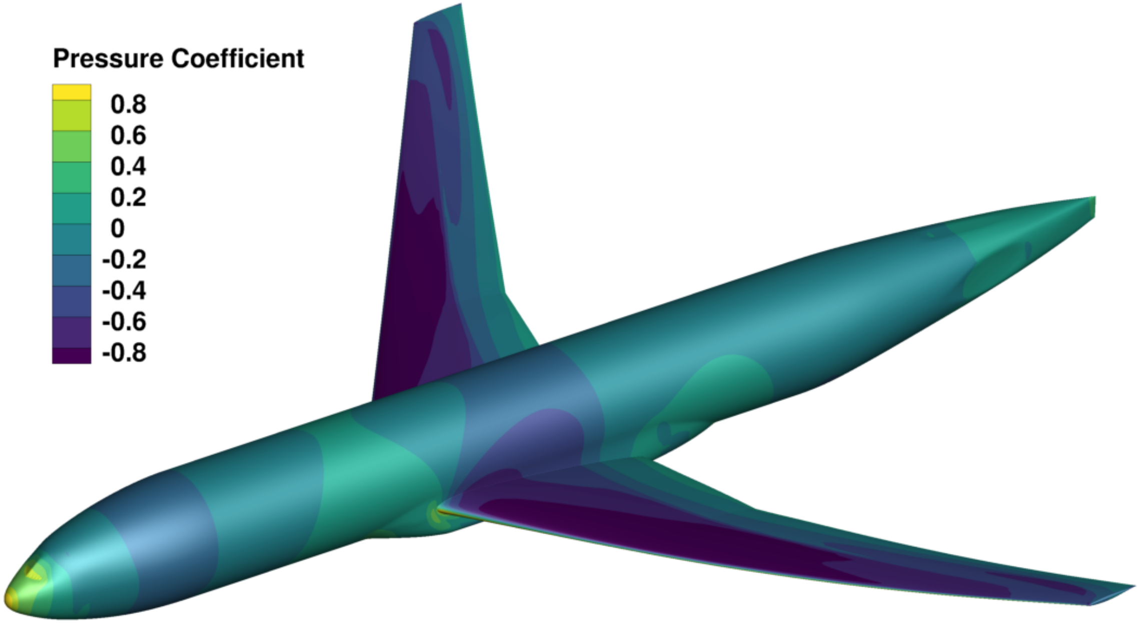


DPW3 W1 Summary

- Dynamic dispatch of C-grids is important
- The scalar pentadiagonal scheme can use CFL ramping, but it is of limited use considering the stability limits of the scheme

DPW6 WB

- Case 2A, 2.75 degree aerodynamically deformed geometry with alpha seek to find $C_L = 0.5$
  - Mach = 0.85, AoA ≈ 2.475°, Re = 5 million
- 3rd-order MUSCL, HLLC flux, fully turbulent SA-neg
  - 14 million node ‘coarse’ grid, FMG and MULTIG

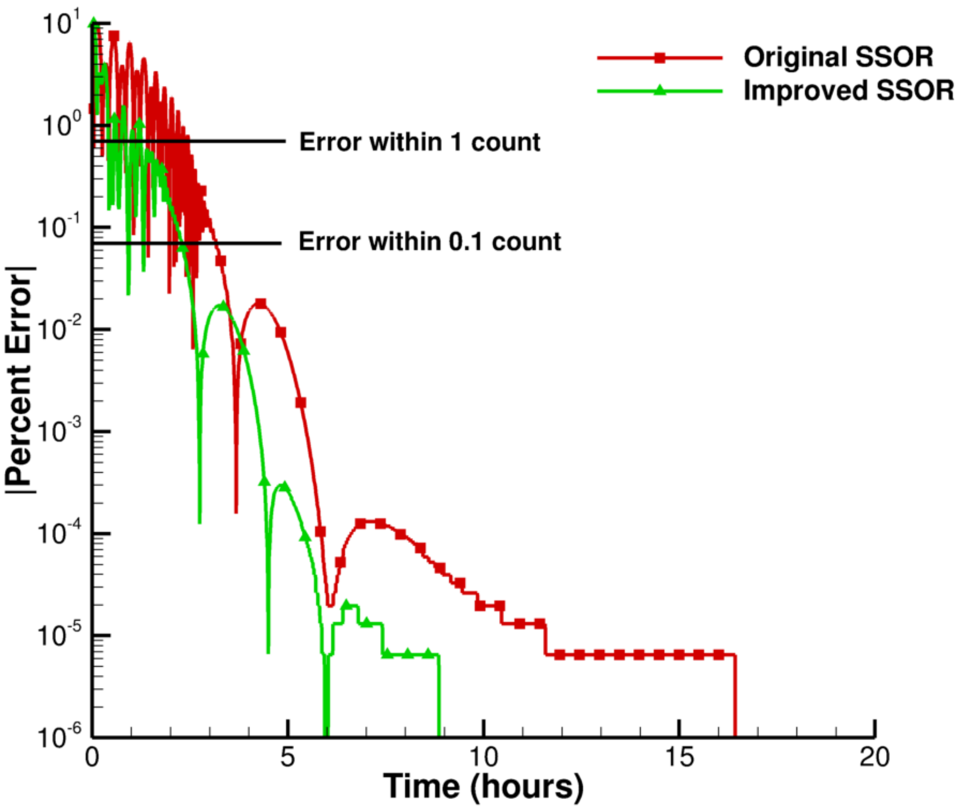


DPW6 WB

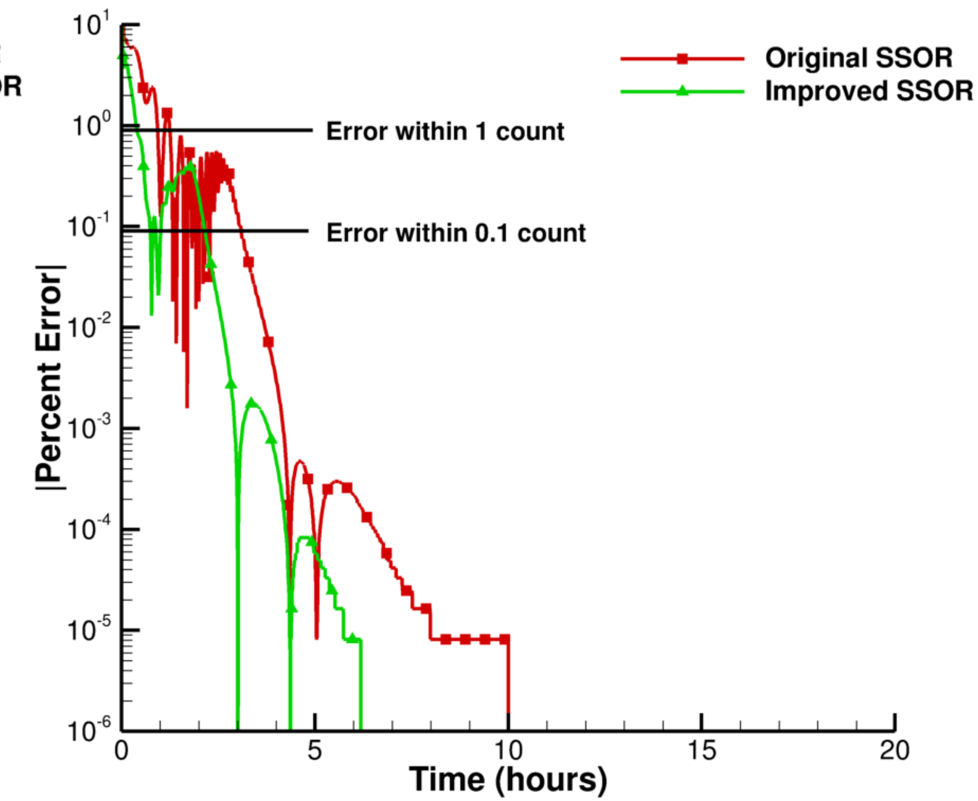
- Head-to-head test case using the same settings between the original and improved SSOR schemes
  - The maximum CFL number (50) was chosen to keep the original SSOR scheme stable
  - The improved scheme can run at a higher maximum CFL and reaches a higher CFL faster due to its higher convergence rates
- Both methods converge to the same solution, even with stalled convergence due to side-of-body separation

DPW6 WB

$C_{D,p}$



$C_{D,v}$

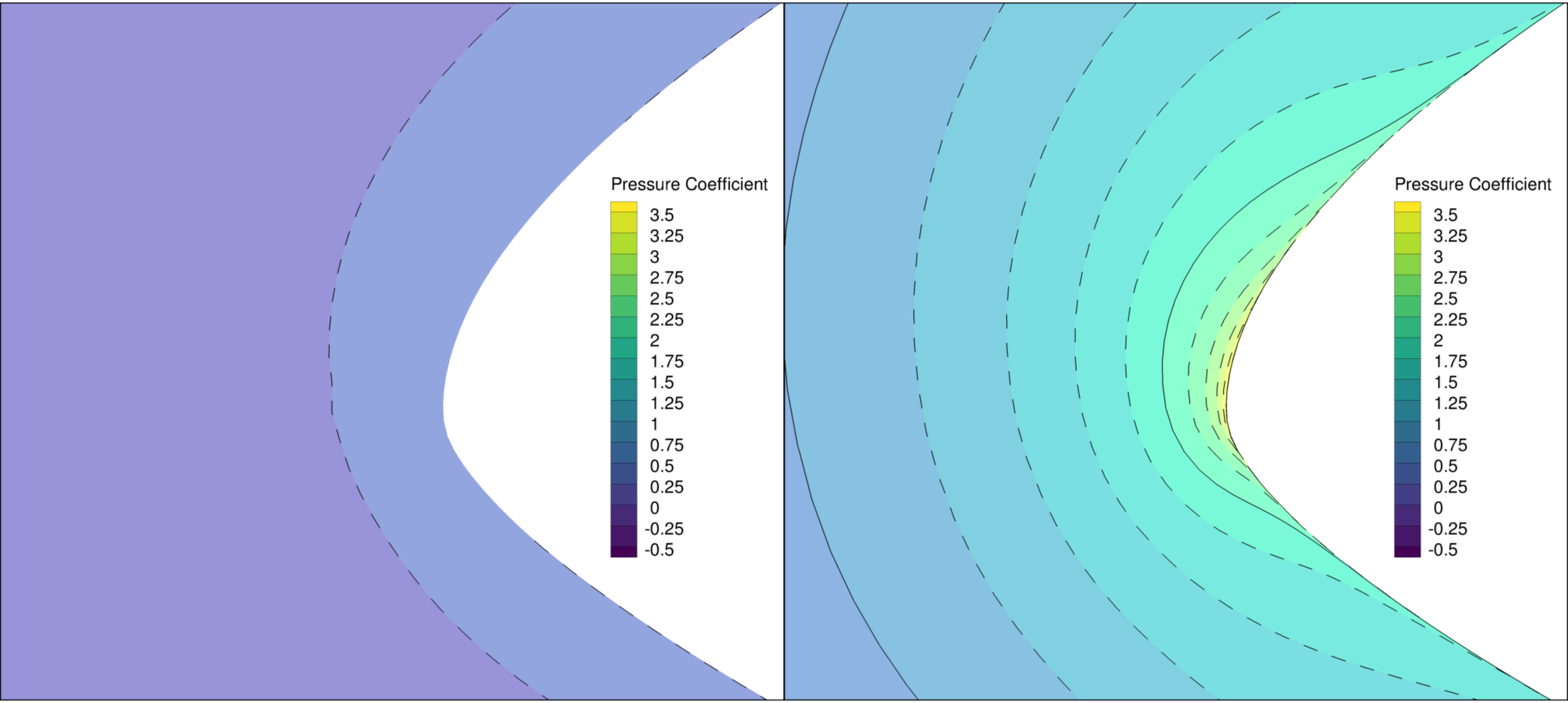


Summary

- A series of evolutionary changes have been presented all of which are available in OVERFLOW 2.3
- Try them out, you may like them!
  - Faster solution convergence
  - Faster functional output convergence
  - Definitely worthwhile for unsteady problems
- But, there are limitations…
  - Some BCs are not linearized, including overset boundaries
  - Inherent weakness of the SSOR solver
  - Flow initialization

What's Next?

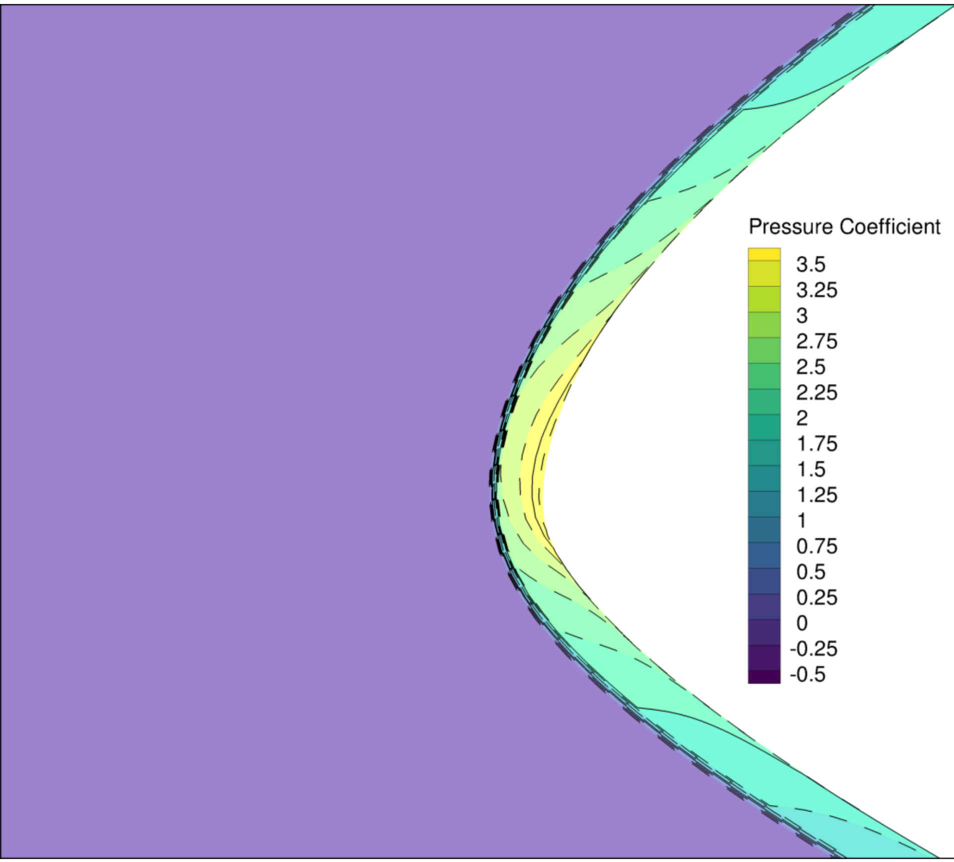
Old SSOR, 1 proc. | Improved SSOR, 1 proc.



Impulsive start, one step, no grid splitting

What's Next?

Improved SSOR, 8 proc.



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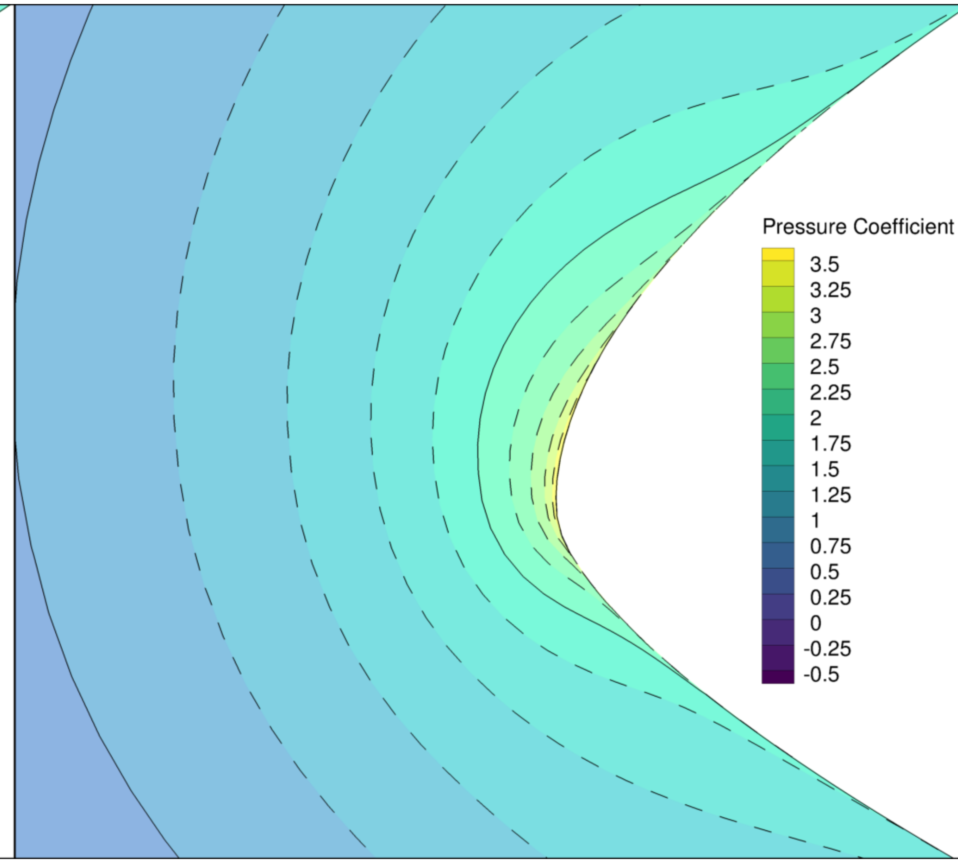
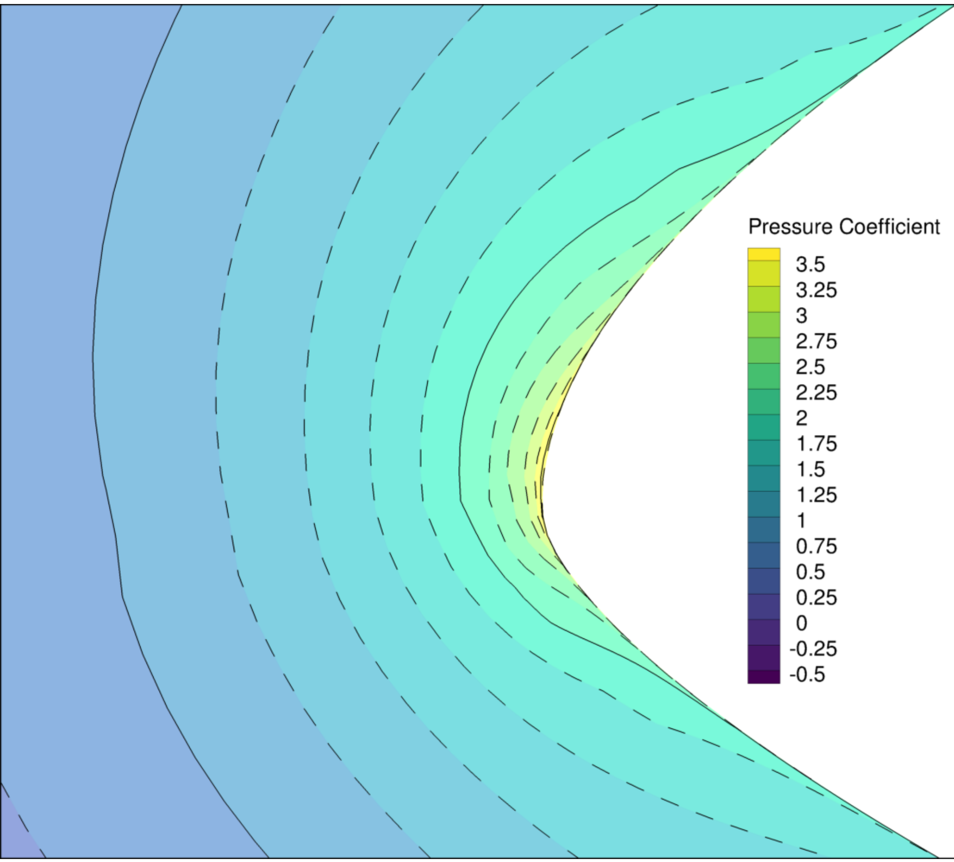


What's Next?

Implicit Overset BC's, 8 proc.



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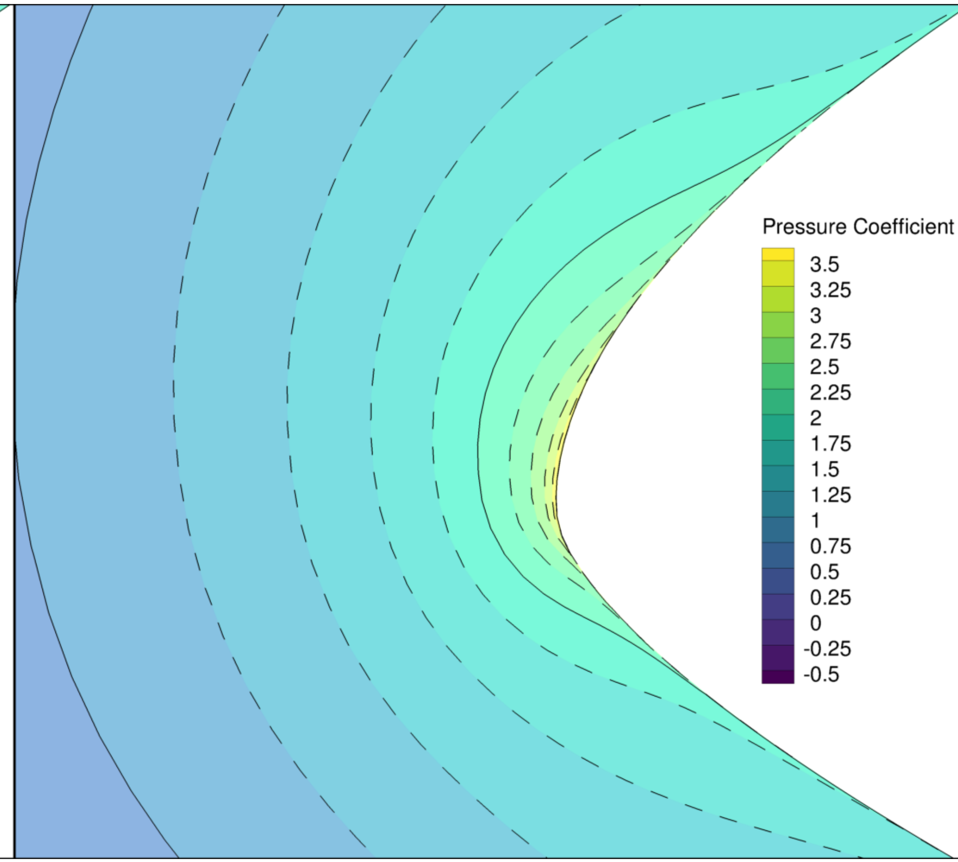
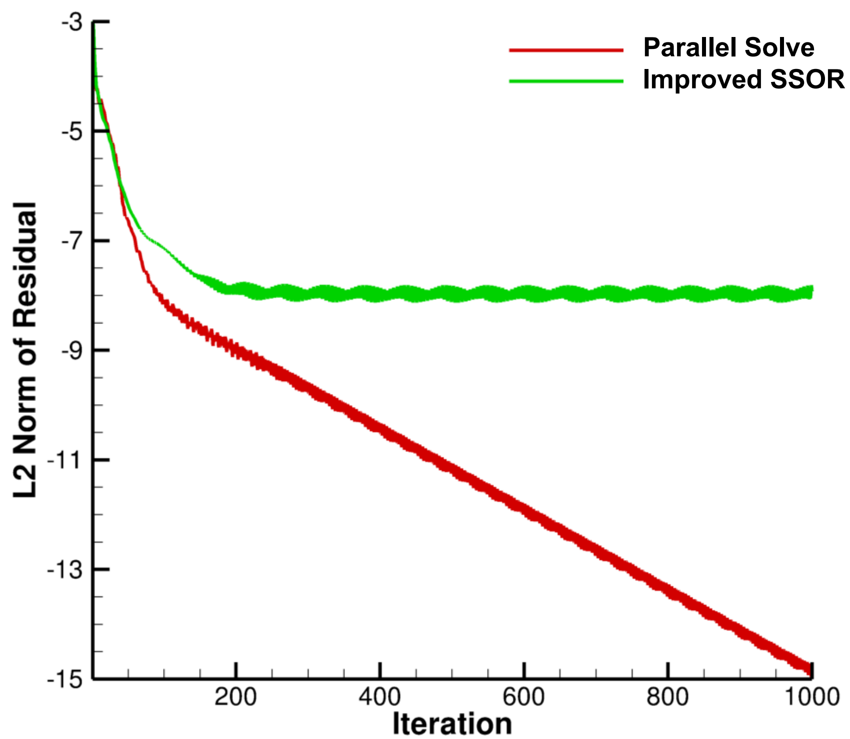
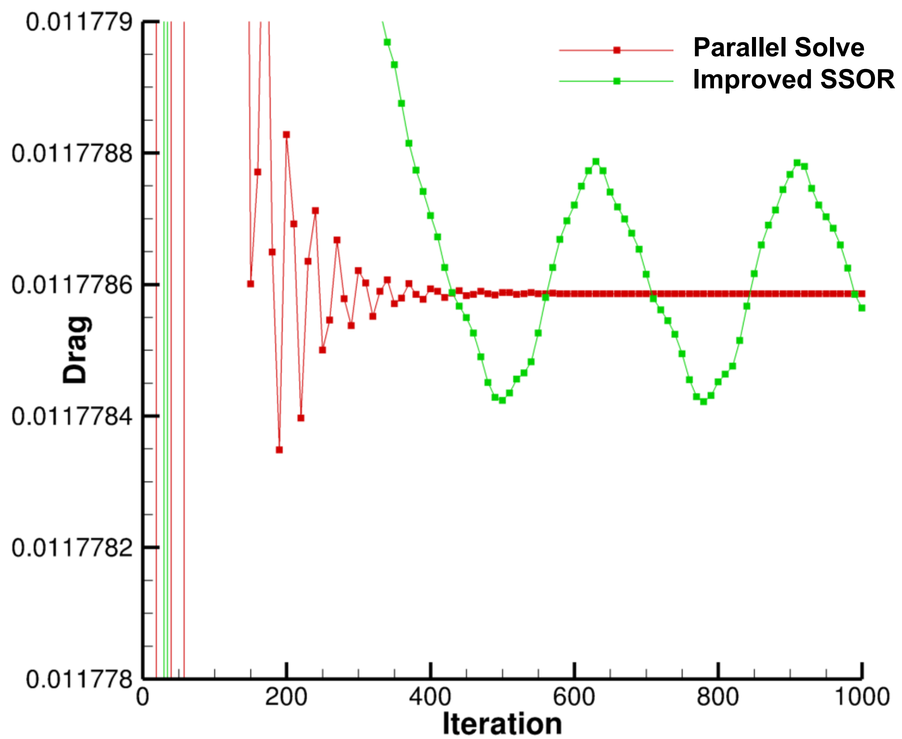


What's Next?

Residual Convergence, 8 proc.



Drag Convergence, 8 proc.



NB: the scale is 1/100th of a count

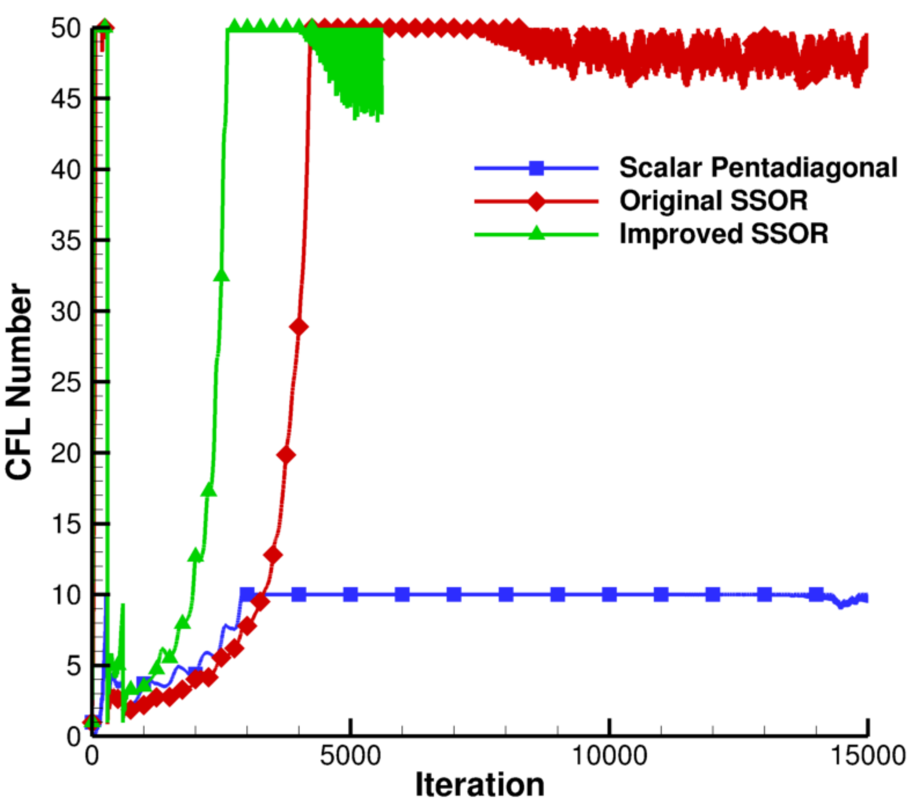
Questions?

- This work was funded by the Revolutionary Vertical Lift Technology project of the Advanced Air Vehicles Program
- Special thanks to Doug Boyd (LaRC) and Tom Pulliam (ARC) for being beta testers

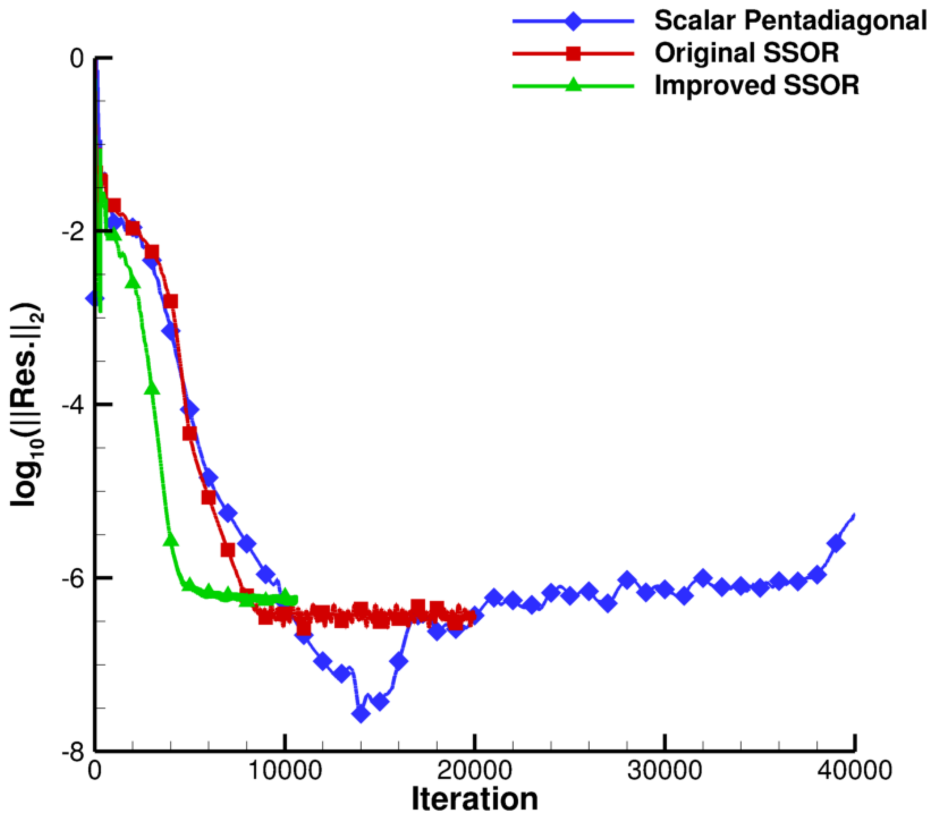
Backup

DPW3 W1

CFL Ramping

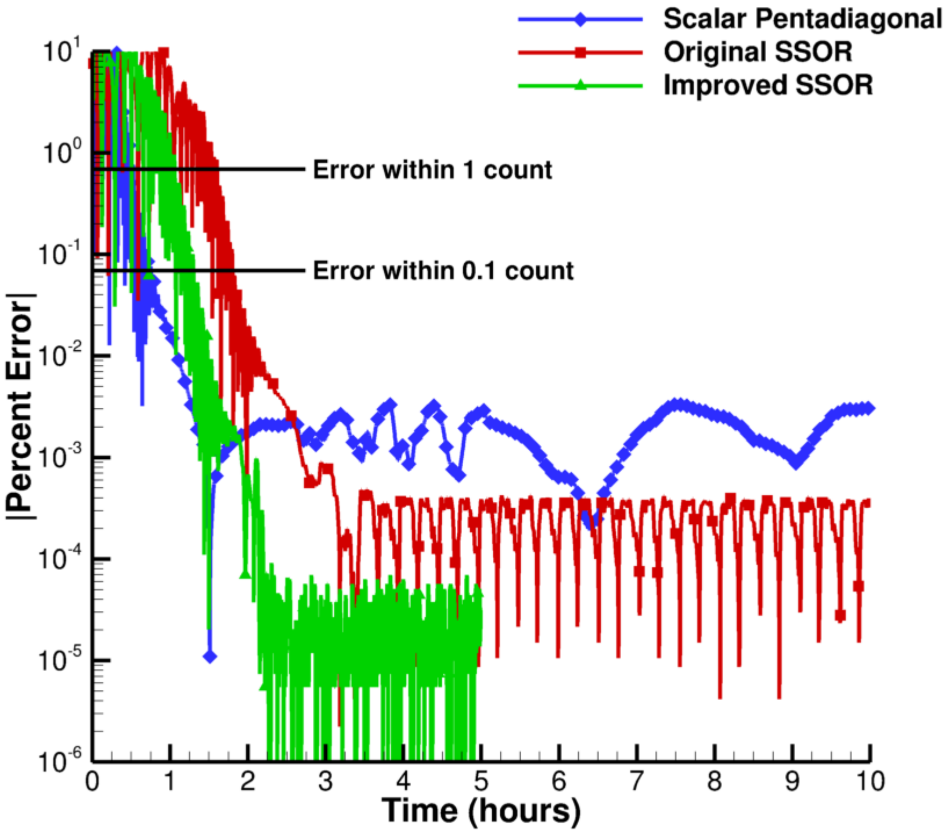


Residual

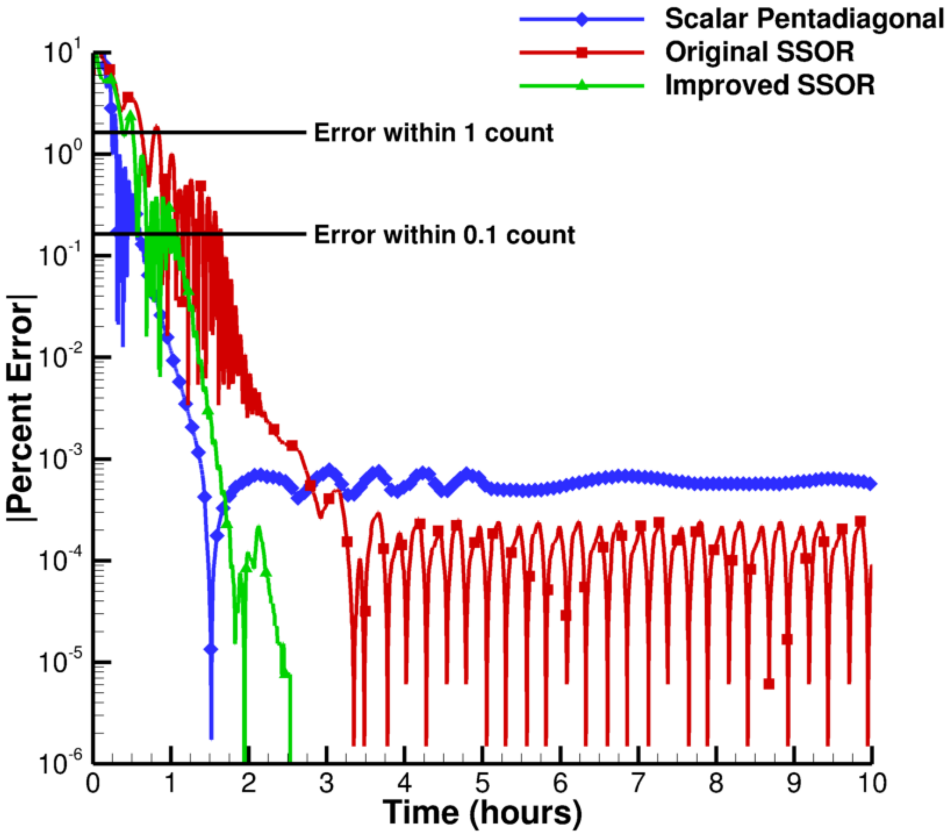


DPW3 W1

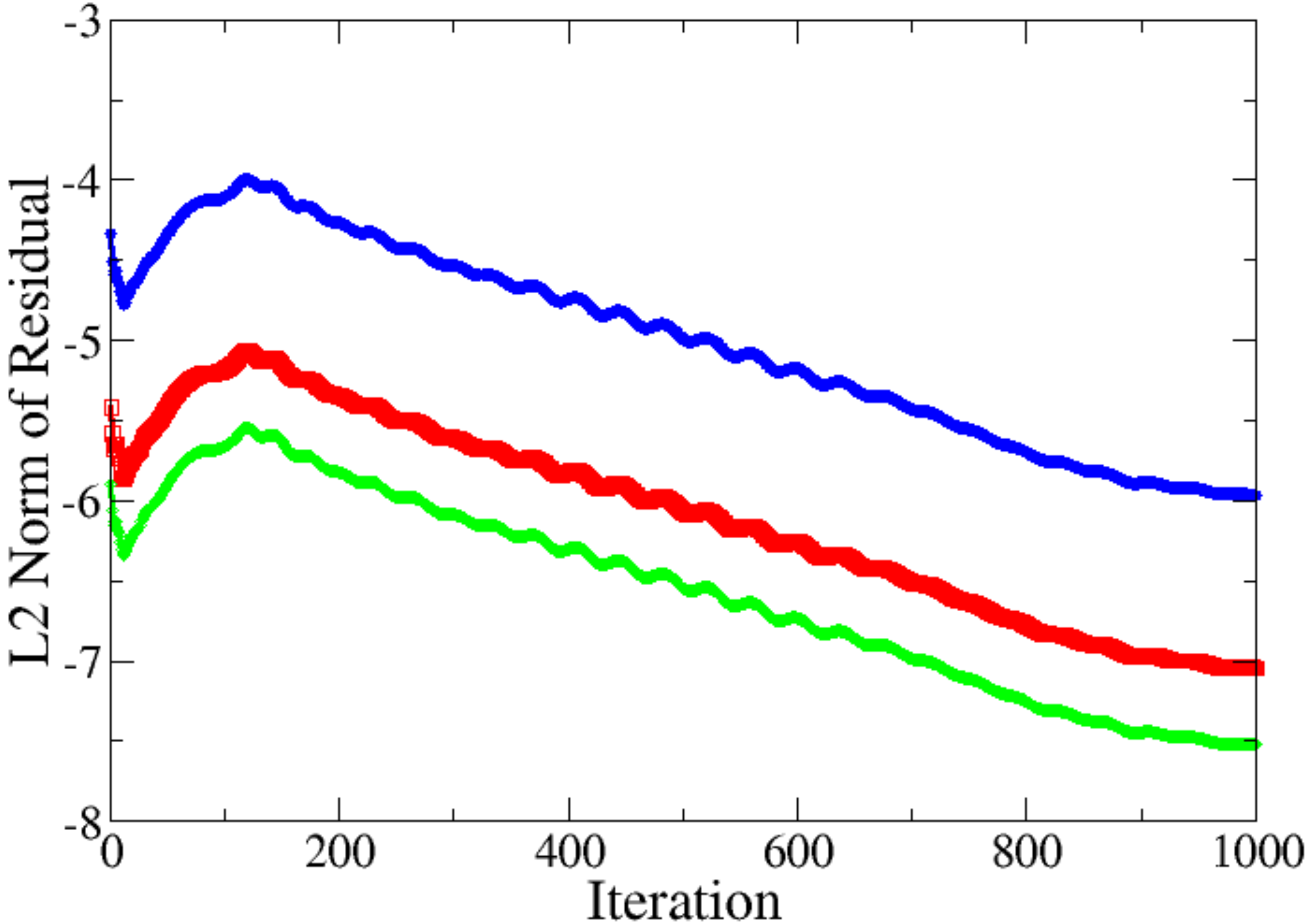
$C_{D,p}$



$C_{D,v}$



Changes to Residual Reporting



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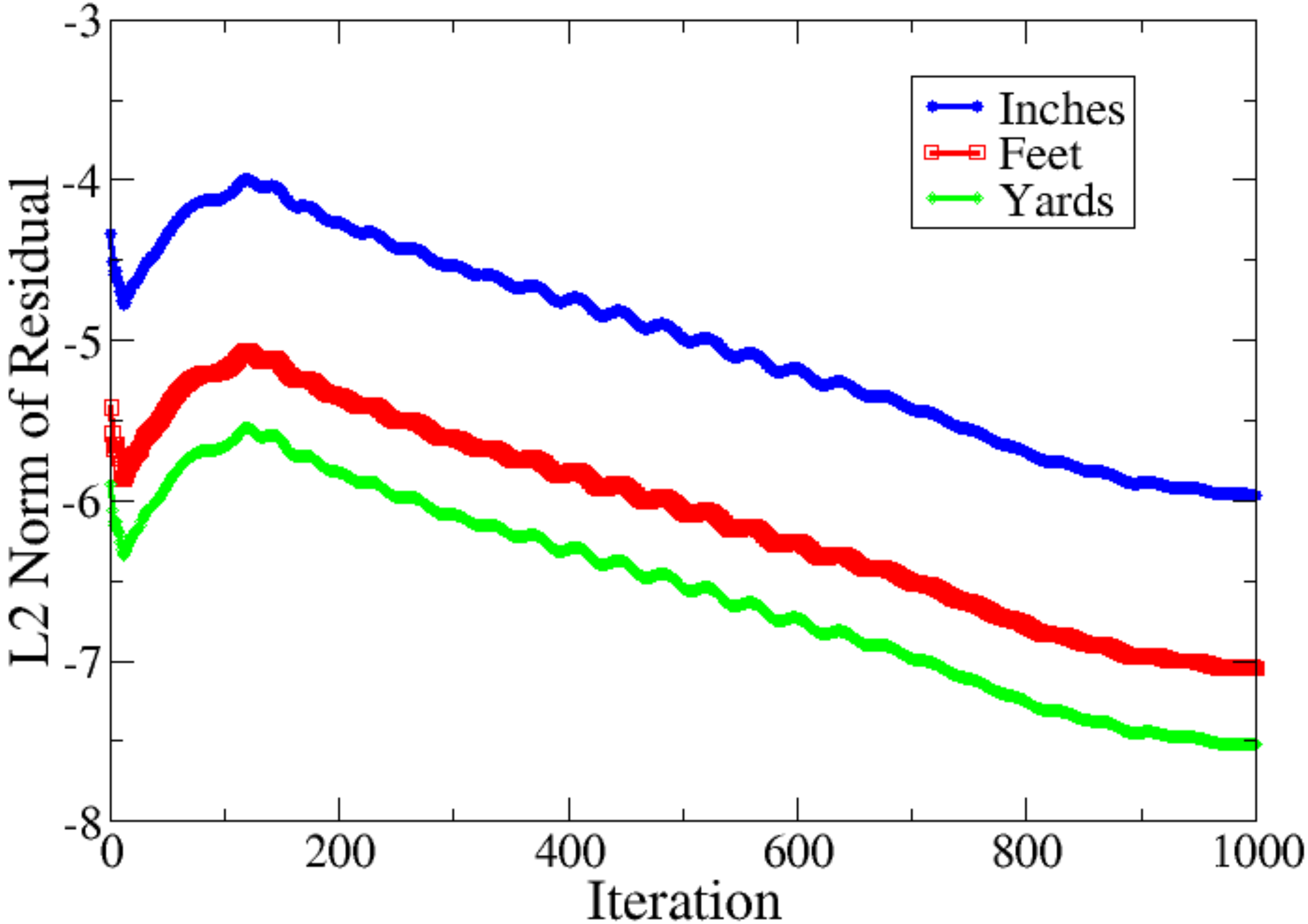

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