

Progress Towards a High-Accuracy 4D Computational Aeroacoustics (CAA) Prediction Tool

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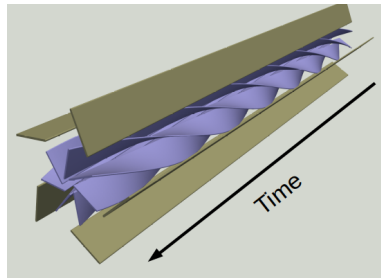
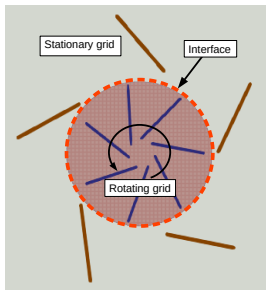
March 19, 2024

Acknowledgements

- This work is supported by the NASA Advanced Air Transport Technology (AATT) Project.
- Dr. Edmane Envia of the NASA Glenn Research Center is the technical monitor for this work.

Continuing The Story...

- The goal: High-accuracy predictions of unsteady flow and noise.
- The idea: Solving the problem in 4D space-time provides new efficiencies for unsteady flow prediction.



A revolutionary CAA prediction tool is being developed at NASA

The Advantages of Space-Time

- Some of the practical advantages of the space-time approach are:
 - Can use a *lot* of existing technology:
 - Robust and efficient CAA differencing schemes.
 - Fast CFD steady-flow convergence techniques.
 - Smooth elliptic grid generation methods.
 - This also sidesteps a *lot* of existing problems with time marching:
 - How to resolve a range of time scales?
 - How to determine solution accuracy for an unsteady simulation?
 - How to achieve large-scale parallel efficiency?
 - Gives a pathway to quantum computing...

The space-time method could solve a lot of problems!

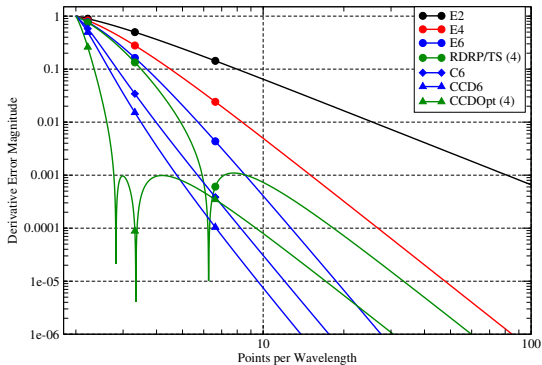
Current Status

- Progress since the Fall 2023 TWG:
 - Flow Solver:
 - Implementation of Boundary Conditions and Artificial Dissipation (Jeff Severino)
 - 3D single-block grid sequencing and convergence testing (Zaid Sabri)
 - Structured Grid Generation:
 - Multiblock Grid Generation and Flow Solver Implementation (Hixon)

Progress is being made!

Making This Work...

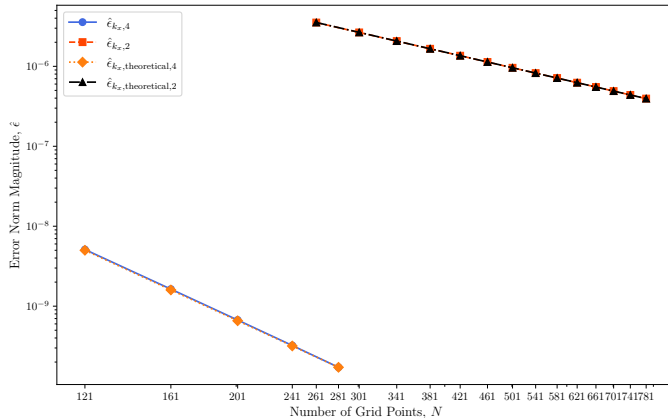
- High-accuracy numerical differencing schemes show *amazing* performance in theory...
- All of these schemes have stable boundary treatments – they can be used in this code.



Structured grids are required for these schemes

Numerical Testing/Code Verification (Severino)

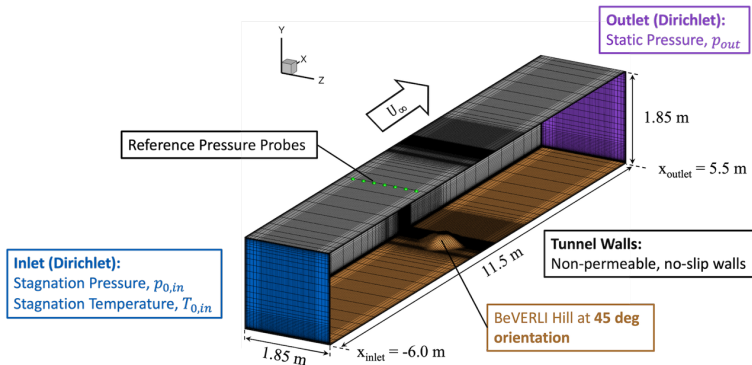
- This data is from SWIRL code verification tests by Jeff Severino.



The proposed schemes are much better than the E4 scheme!

3D Flow Solver Testing (Sabri)

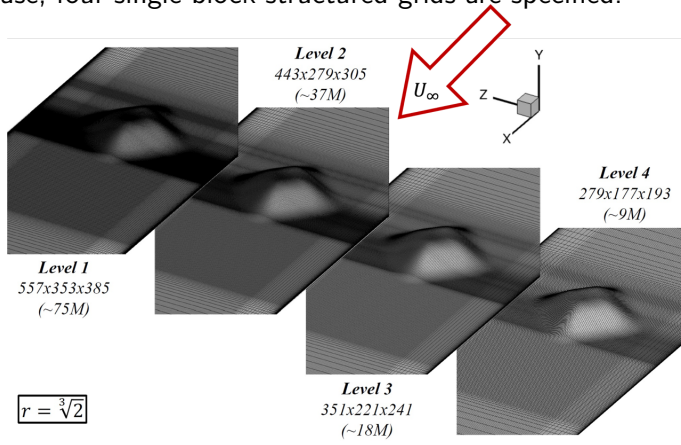
- The test case is the **Benchmark Validation Experiments for RANS and LES Investigations (BeVERLI Hill)** geometry.
- This is a blind CFD turbulence modeling challenge using the Spalart-Allmaras turbulence model.



This is a test of stability, convergence, and accuracy

BeVERLI Hill Test (Sabri)

- For this test case, four single-block structured grids are specified:



The specified grids have radical stretching rates!

Initial Inviscid Tests (Sabri)

- The flow solver is currently solving the compressible Euler equations.
- The 'ghost point' boundary condition implementation is used:
 - The Euler equations are solved on the boundaries as in the interior.
 - Boundary conditions are imposed by modifying the normal flux derivatives at the boundary.
 - At corner points, multiple boundary conditions are being simultaneously imposed.
- The flow is essentially incompressible ($M_\infty \sim 0.05$).

This is a pretty harsh test for high-accuracy schemes!

Grid Sequencing (Sabri)

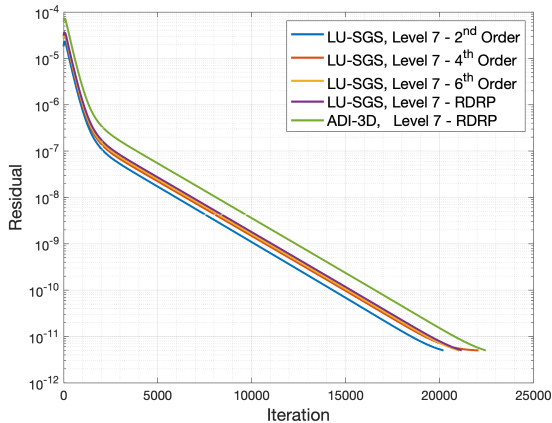
- Three additional families of grids have been generated and used for grid sequencing purposes (Levels 5, 6, and 7).

	Computational Grid	Total Points
Level 1	$557 \times 353 \times 385$	<i>75.7M</i>
Level 2	$443 \times 279 \times 305$	<i>37.7M</i>
Level 3	$351 \times 221 \times 241$	<i>18.7M</i>
Level 4	$279 \times 177 \times 193$	<i>9.5M</i>
Level 5	$141 \times 89 \times 97$	<i>1.2M</i>
Level 6	$93 \times 59 \times 65$	<i>357K</i>
Level 7	$71 \times 45 \times 49$	<i>157K</i>

This is a *lot* of grid points!

Preliminary Inviscid Results: Stability and Convergence (Sabri)

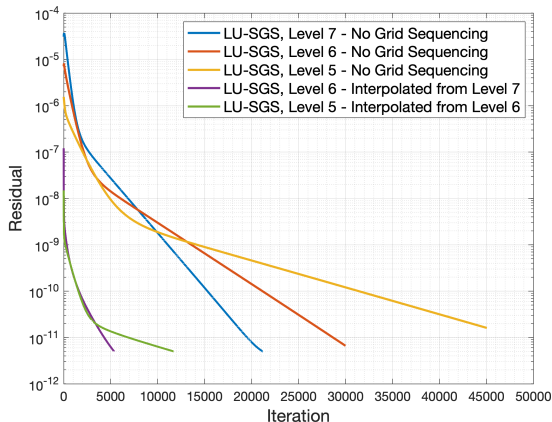
- The implicit steady-state flow solver is converging to machine precision for *all* explicit numerical schemes (Level 7 shown):



Both ADI and LU-SGS are effective!

Preliminary Inviscid Results: Grid Sequencing (Sabri)

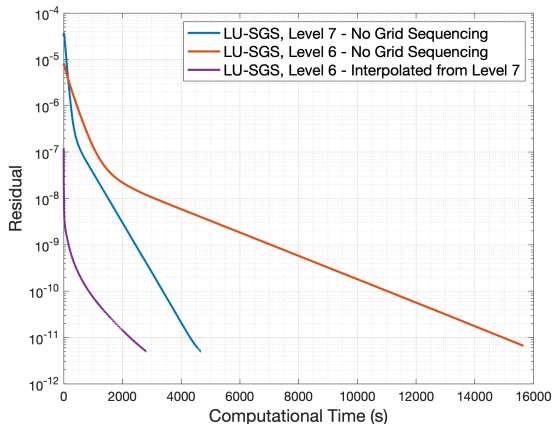
- The effect of grid sequencing is dramatic for this test case (optimized RDRP scheme):



This is very promising for the 4D solver!

Preliminary Inviscid Results: Efficiency (Sabri)

- The grid sequencing gives a **50%** speedup just for the second grid (optimized RDRP scheme):



A multigrid method is planned for the multiblock solver...

Progress on the Multiblock Solver

- The **S**tructured **M**apping **A**t **R**educed dimension **T**opological element (SMART) method obtains high-order derivatives at grid singularities.
- Work is focused on incorporating the SMART method into a general multiblock code.
- The grid generator and flow solver are being developed simultaneously, with the initial focus on the grid generator.
- There are a lot of moving parts in the SMART formulation!
- It's coming together – but I'll tell you more about it once it's working...

A multiblock demonstration is the next step!

Coming Attractions

- The next steps in the process:
 - Multiblock implementation and testing of 4D flow solver
 - Code parallelization
 - Multigrid
 - 4D automatic topology generation and improved grid generation
 - Grid adaption

All objects are coded in 2D, 3D, and 4D for use in other codes...

Questions?