ADAPTIVE, HIGH-ORDER SIMULATIONS OF LARGE-SCALE COMPLEX FLOWS

Shu-Jie Li
Mechanics Division

CSRC

Abstract

A new class of time discretizations based on the *exponential time integration* is successfully developed to speed up high-order computations of real-world fluid dynamics problems with *hp* adaptation. The resulted *HA3D* solver: an adaptive order discontinuous Galerkin (DG) code for arbitrarily shaped elements is presented including various state-of-art methods, aiming to develop an extreme-capability CFD flow solver for predicting increasingly challenging fluid dynamics problems of real world.

Numerical methods

Time discretizations

1. Implicit methods
   (a) Rosenbrock Runge-Kutta ($s = 2$)
   (b) Pointwise Jacobi iteration
   (c) Lower-Upper Symmetric Gauss Seidel (LU-SGS)
   (d) Symmetric Gauss Seidel (SGS)
   (e) Newton-Krylov: ILU-GMRES(m)
   (f) Dual time stepping
2. Explicit Runge Kutta (SSP, Jameson)
3. PCEXP scheme for unsteady flows
   (*S.-J. Li et al. JCP, 365(2018) 206-225*)
4. EXP1 scheme for steady flows
   (*S.-J. Li et al. JCP, 365(2018) 206-225*)
5. Exponential *p*-multigrid method: eMG
   (*S-J. Li, arXiv:1807.01151*)
6. *p*-adaptive global coupling methods:
   S-J. Li, AIAA 2020 (to be appeared)

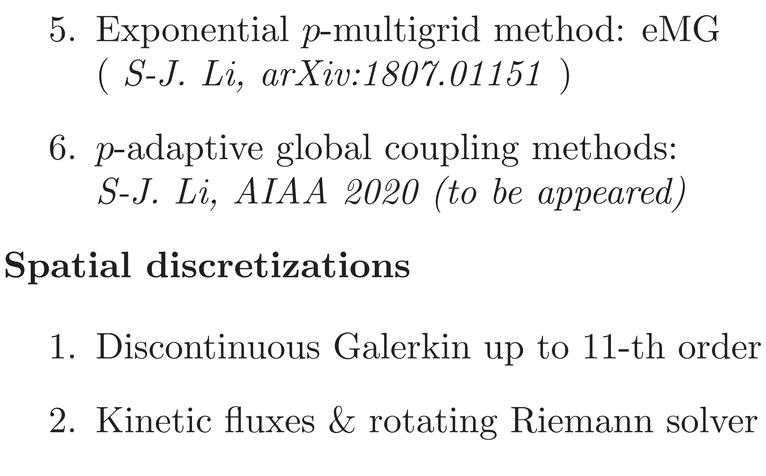
Spatial discretizations

1. Discontinuous Galerkin up to 11-th order
2. Kinetic fluxes & rotating Riemann solver
3. Adaptive *p*-multigrid
4. Rotor source term

Multibody Moving Framwork

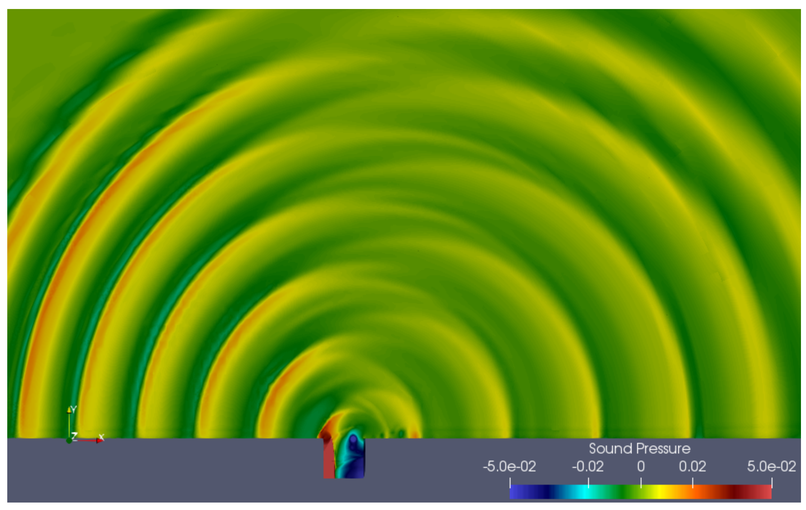
1. Arbitrary Lagrangian-Eulerian (ALE): single and multiple reference frames

Parallel scalability



Strong scaling performance on TIANHE2 supercomputer at Guangzhou, China.

Fast Exponential Time Marching for 3-D Fluid Dynamics

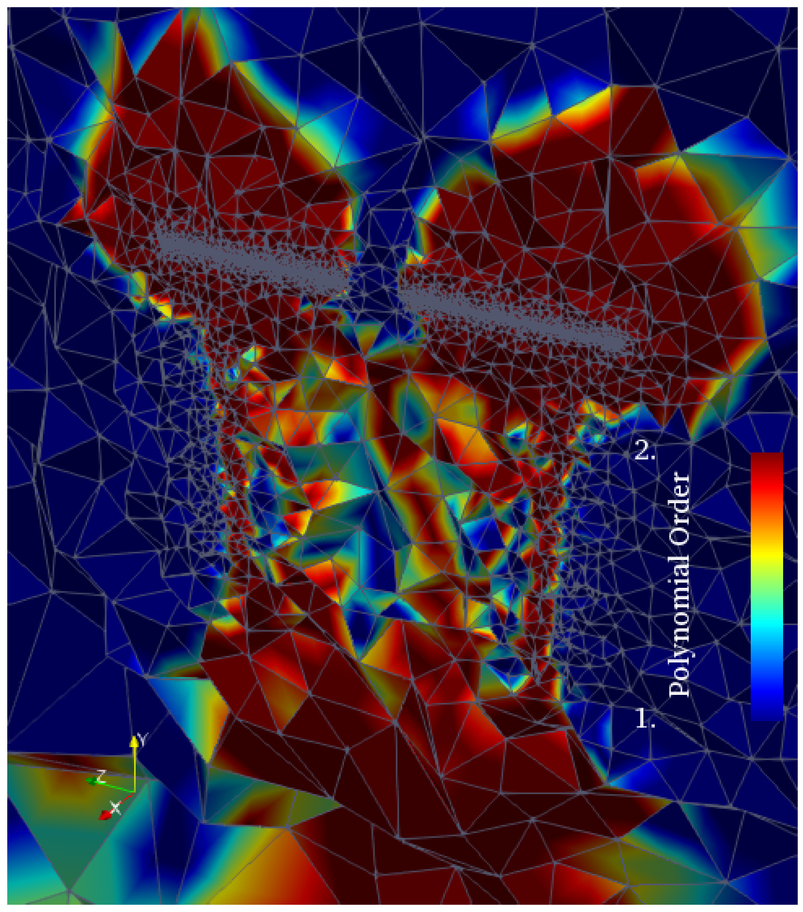


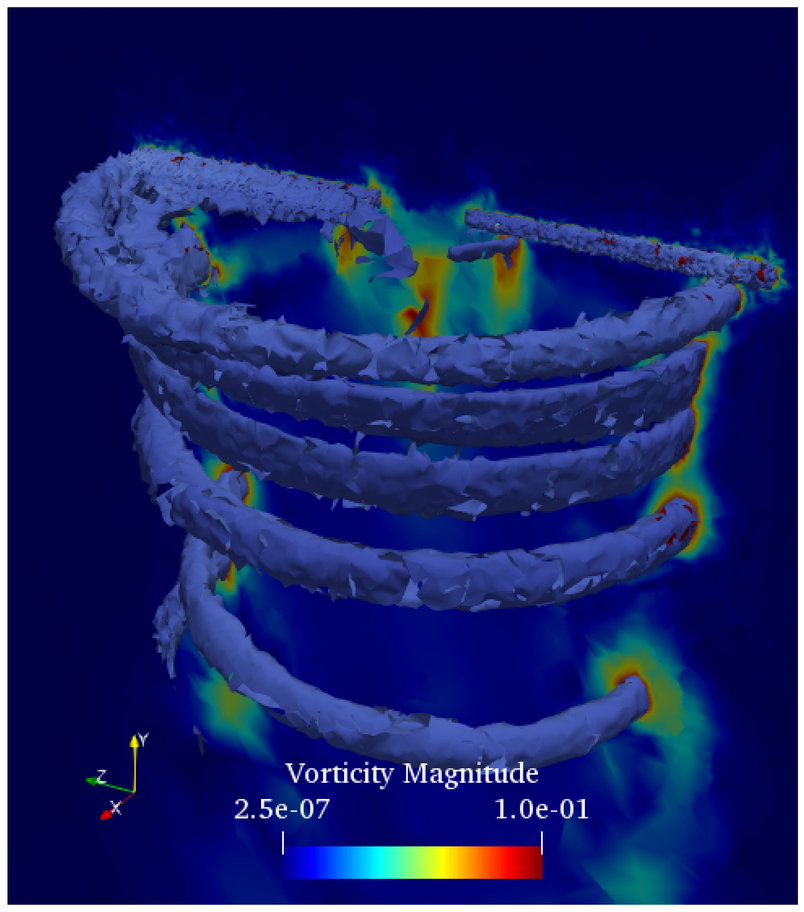
BEYOND EXPLICIT & IMPLICIT: the exponential time discretizations for N-S equations.
Advantages: No CFL restriction; **10–100X** faster than explicit TVD-RK3 and implicit BDF2; Low absolute temporal error.

References:

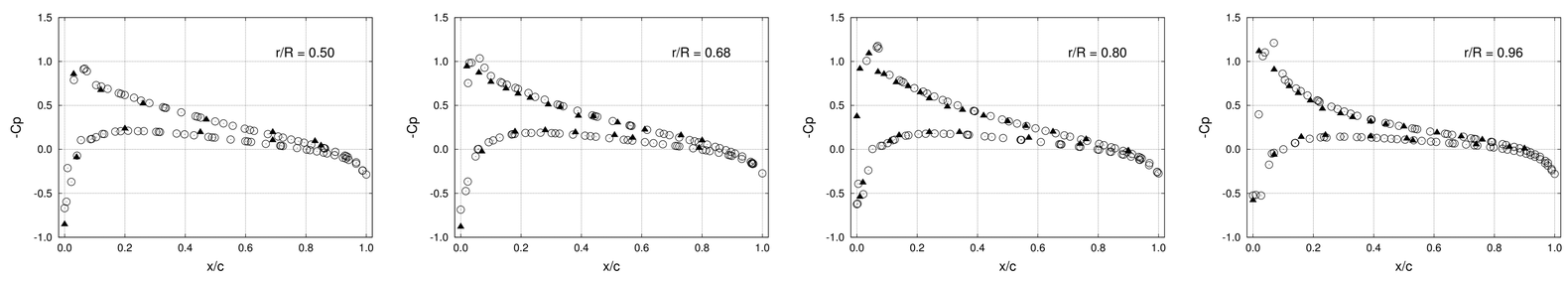
1. S.-J. Li. arXiv:1807.01151
2. S.-J. Li et al. AIAA-2019-0907
3. S.-J .Li et al. JCP, 365(2018) 206-225
4. S.-J. Li et al. AIAA-2018-0369
5. S.-J. Li et al. AIAA-2017-0753

Adaptive-order simulations of rotor flows

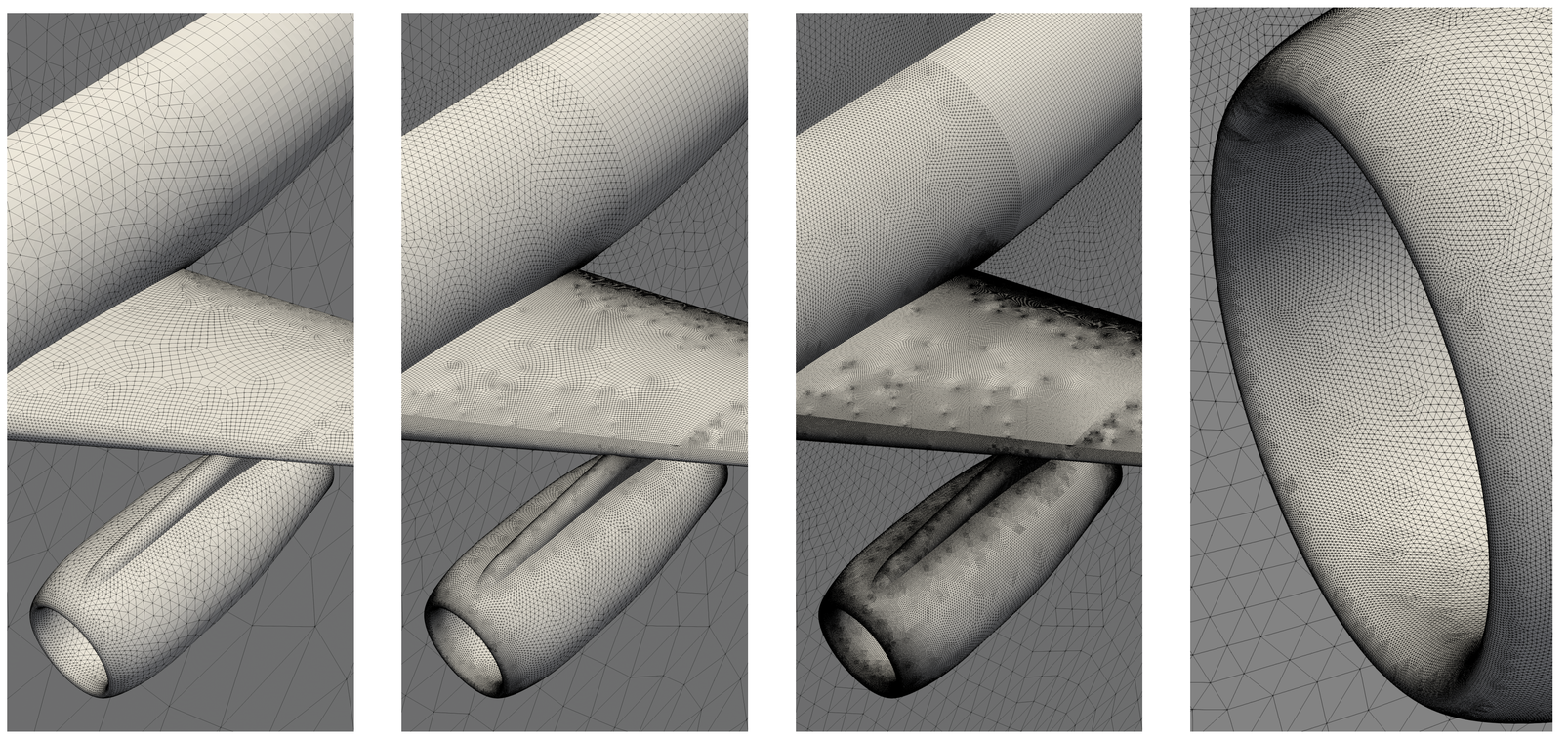




HA3D solves tough complex 3-D fluid problems with the state-of-art methods in a fully adaptive, parallel framework. The results are in excellent agreement with experimental data.



The 0.9 *Billon* Hybrid, Curved grid generation



Shu-Jie Li, *Mesh curving and refinement based on cubic Bézier surface for high-order discontinuous Galerkin methods*, **Computational Mathematics and Mathematical Physics** (2019 in press, a RAS journal).