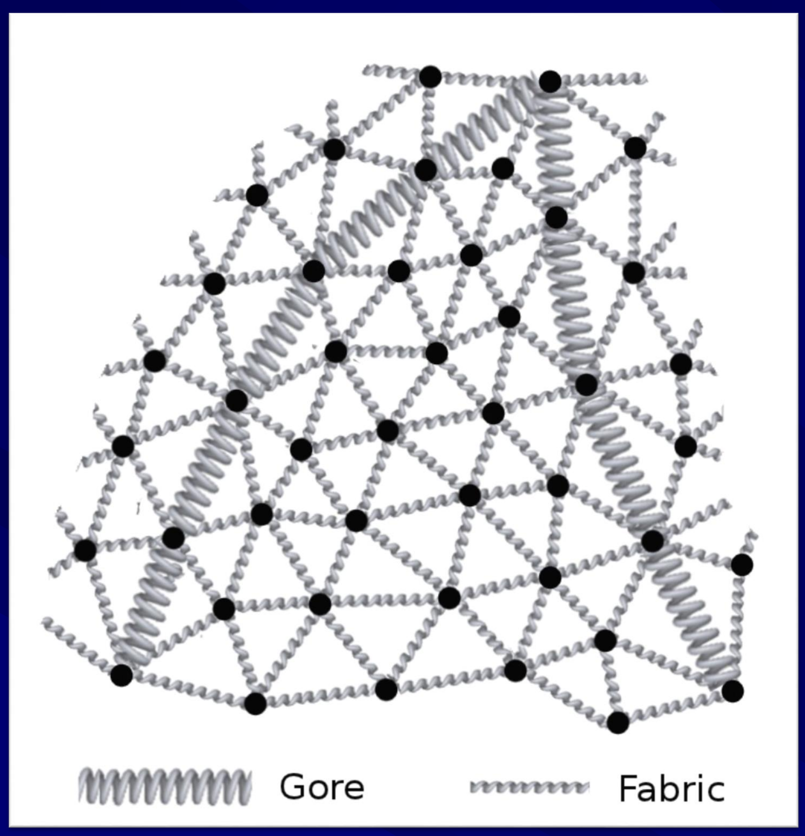
PETSc application in computation of parachute deceleration system

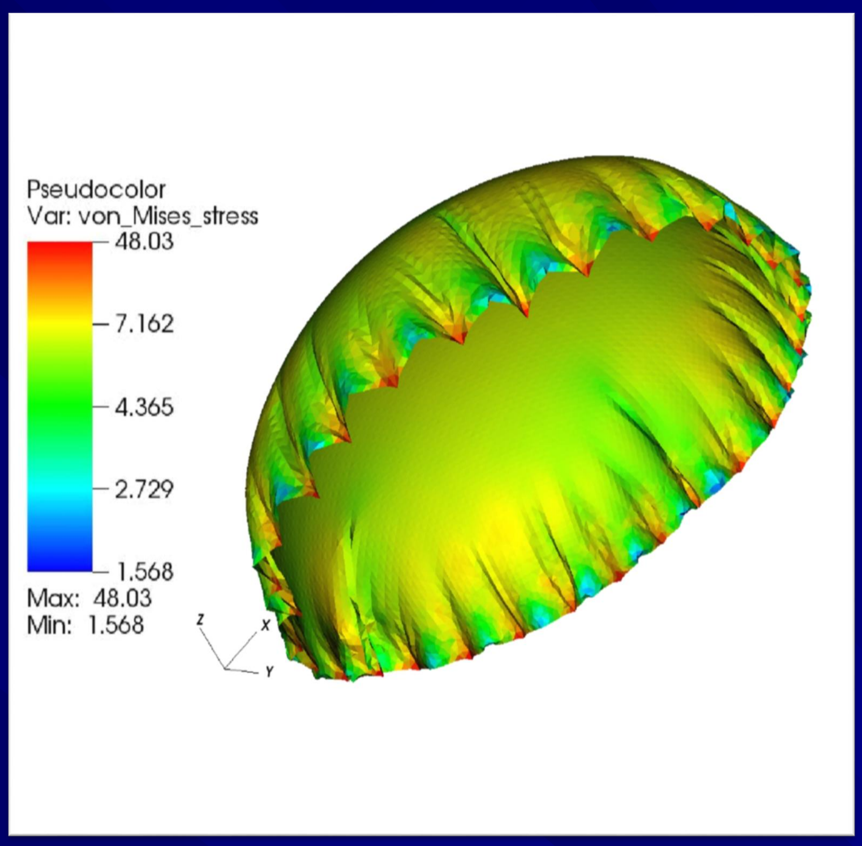
Xiaolin Li, Zheng Gao, Xiaolei Chen
Stony Brook University, NY, USA

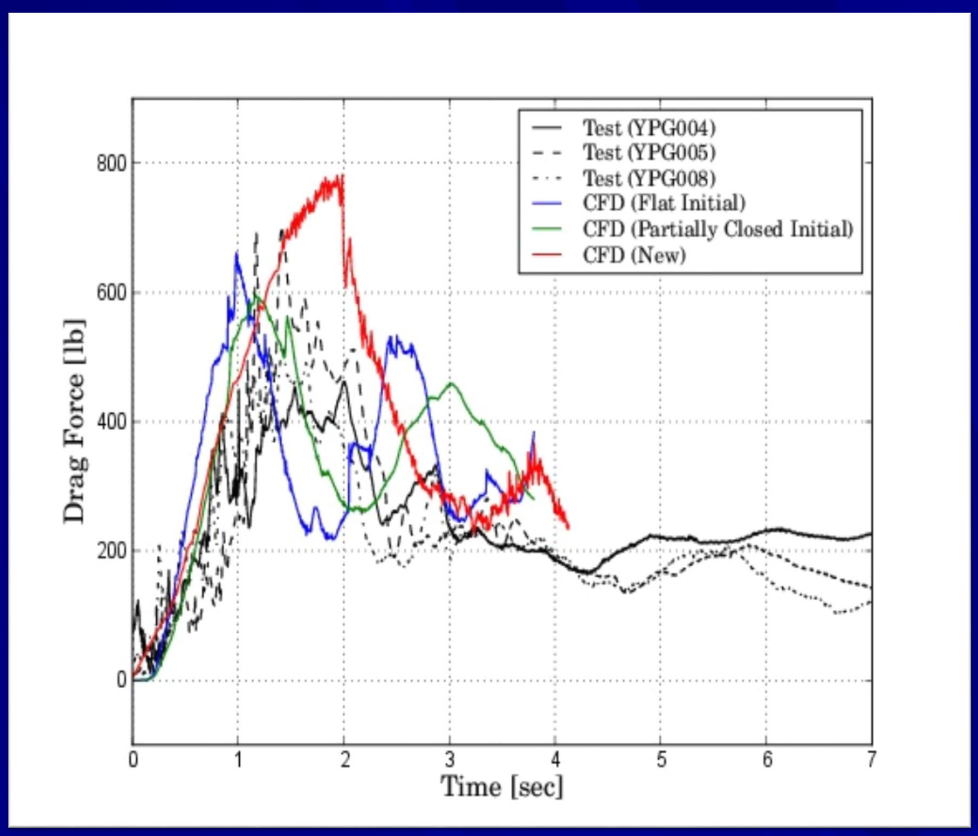
(Project Supported by Army Research Office through Research Grant W911NF-14-1-0428)

In this project, we use the front tracking method on a dual-stiffness spring-mass system to model the dynamic evolution of parachute canopy and risers. Our spring-mass model includes both tensile-stiffness and angular-stiffness, which has the capability of duplicating the realistic strain and stress of the elastic membrane and conforms with both Young's modulus and Poisson ratio. This mechanical structure is coupled with the incompressible turbulence fluid solver through the "impulse method". In addition, GPU-based parallel computing techniques are applied to accelerate the computational speed and increase the resolution of numerical results.

Cloth Model for Parachute Canopy

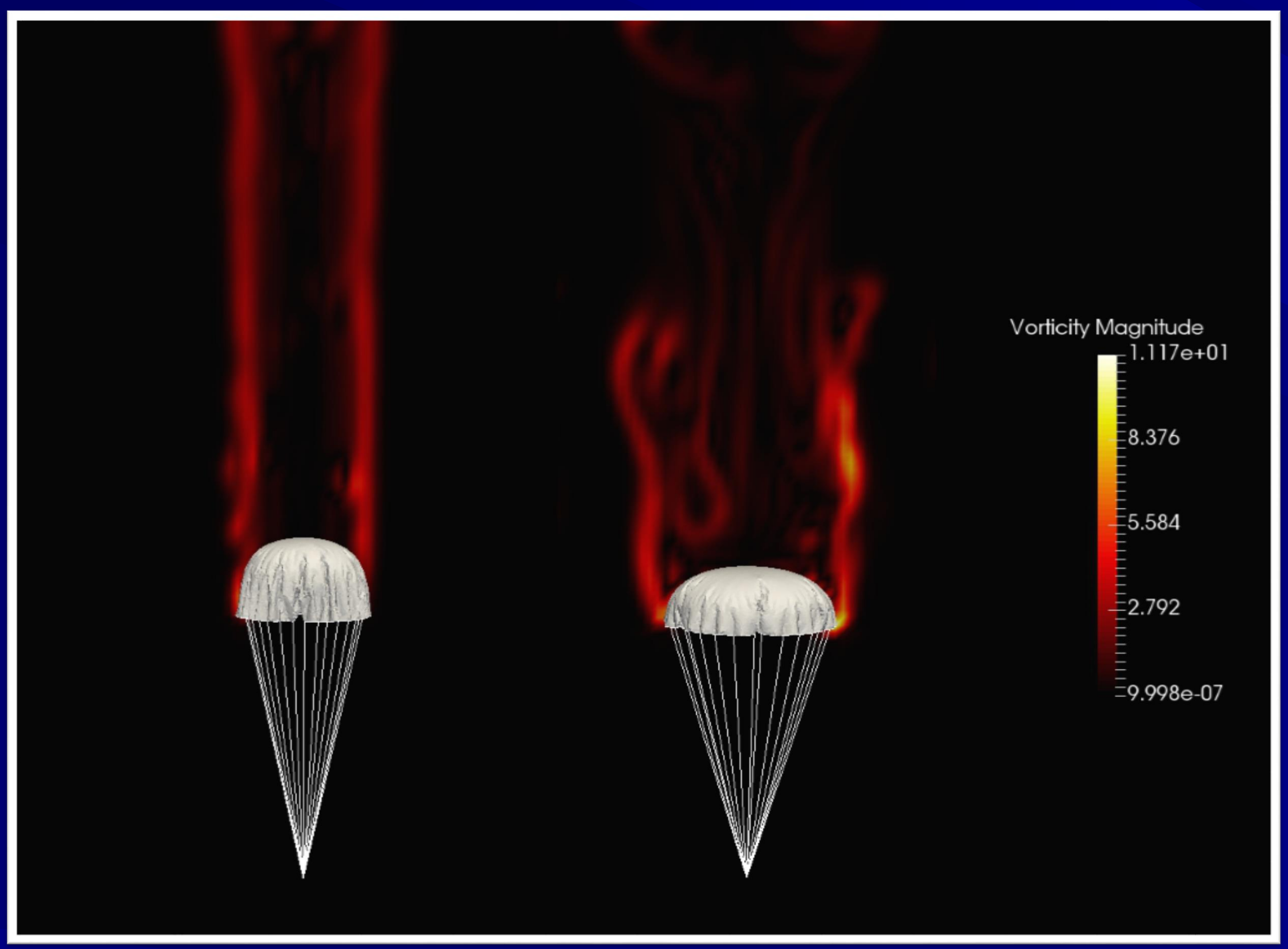






In this project, a mesoscale spring-mass model is used to mimic fabric surface motion. Through coupling with an incompressible fluid solver, the spring-mass model is applied to the simulation of the dynamic phenomenon of parachute inflation (see left figure and center figure for stress measurement). Both the tensile stiffness and the angular stiffness of the spring conform with the material's Young modulus and Poisson ratio.

The canopy appeared to expel the excess air by means of the breathing. In the experiment, the breathing motion was also caused by the constraint on the parachute, imposed by the guide wire. The breathing motion in the simulation is smaller because there is no vertical motion restriction such as guide wire.

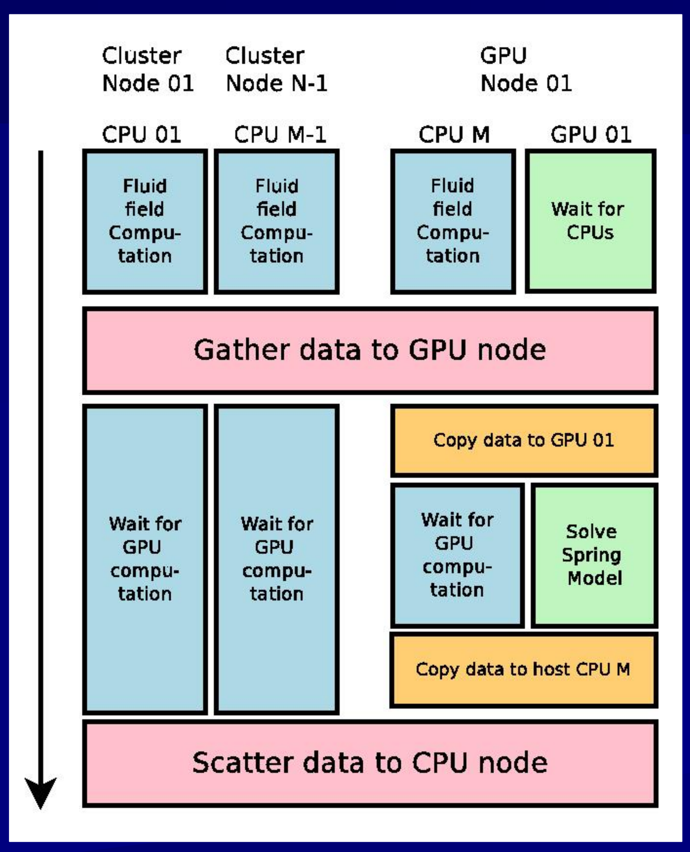


Turbulence and Porosity Model

Recently we have developed many new features to increase the quality of the simulation, such as Re-Normalization Group (RNG) $k-\varepsilon$ turbulence model and simplified porosity model.

The left figure shows the qualitative comparison of vorticity magnitude (1/s) of the G11 cargo parachute with high porosity and low porosity. The numerical result suggests that applying porosity model will stabilize the parachute through lowering the pressure difference on the parachute as well as affecting the turbulent flow around it.

Parallel Computing



The right figure illustrates the parallelization strategy. The parallel computation of fluid field is through domain decomposition and the spring solver is accelerated by GPU computation with CUDA library. We have achieved 10 times speedup for computation of spring model.

PETSc in FronTier

For subsonic parachute, we applied the eddy viscosity model based on Reynolds Averaged Navier-Stokes (RANS) equation, which can be converted into a linear system Ax=b with the help of finite difference and projection method. In order to solve these large sparse systems efficiently on parallel machines, we have used PETSc as our linear solver. Thanks to PETSc's capability of combining with external packages, we applied the algebraic multigrid preconditioner in Hypre and dramatically reduced the number of iterations each time step by adding only a few lines in the original code. However, parallel scaling declines as the number of processors surpasses 512.

STONY BROOK UNIVERSITY