RANS Turbulence Modeling Sensitivity of Parachute-like Bodies

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Motivation

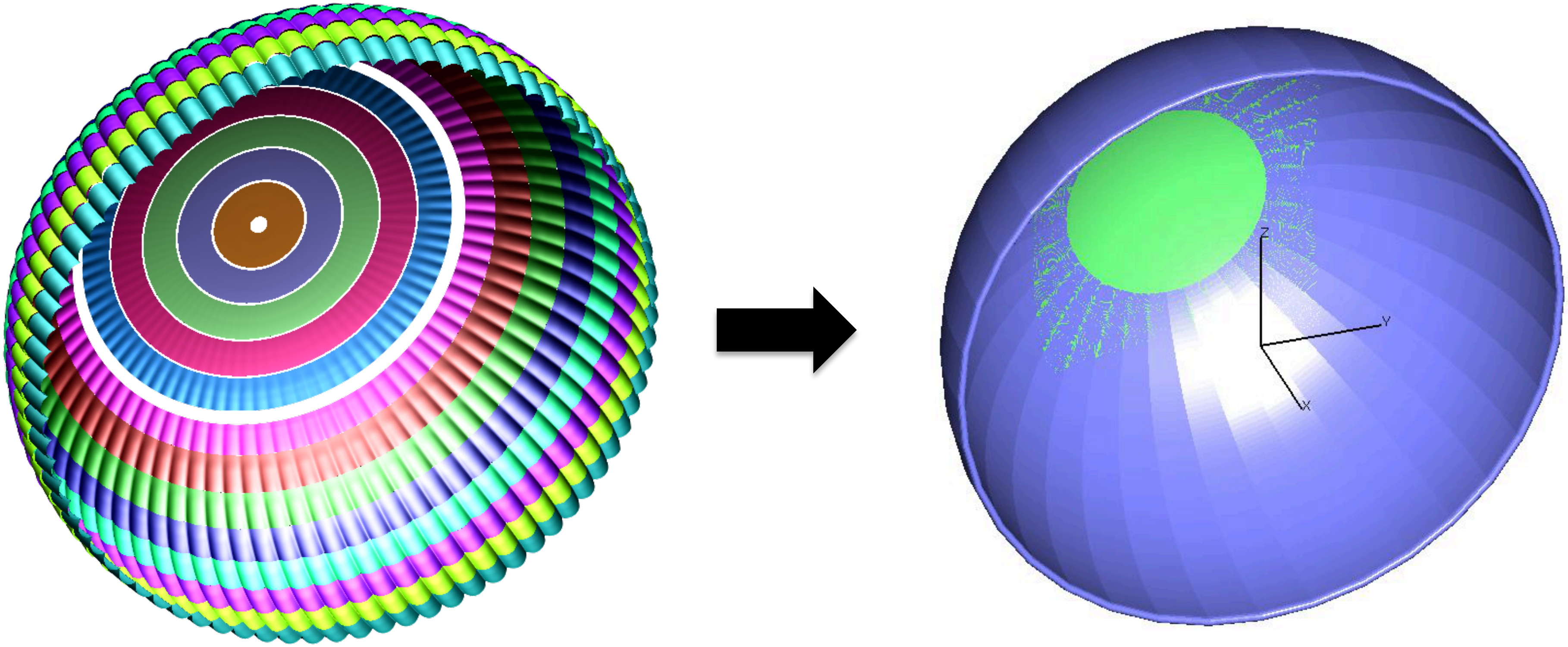
- Orion parachutes can exhibit pendulum motion
  - During two-chute failure mode
  - Unstable motion
  - Potential hazard to crew/vehicle

Motivation

- Use CFD to model dynamic motion
  - High-fidelity, rigid geometry model

Goals

- No turbulence model study has been performed for chute
  - Run simulation with SST and SA models, compare results
  - Develop simple test model
    - Coarse grid, low-fidelity geometry: reduce computational demand
    - Future use as sandbox for parachute simulations



2,000,000,000 points

3,200,000 points

OVERFLOW CFD Tool

- Structured, overset grids
  - Interpolation between overlapping grids
- Implicit, Navier-Stokes, finite-differencing
  - SSOR, BDF2, etc
- Dual-time stepping
  - Unsteady solution from physical time stepping
  - Converge between time steps with steady-state “sub”-iteration
    - Helps pre-condition low-Mach cases
- Multi-species gas continuity equation capability
  - High-Mach flows (super and hyper sonic)
  - Reactive flows (thrusters, etc) but no chemistry
- Geometry Manipulation Protocol
  - Easy relative grid motion/interpolation
  - Primary reason for using OVERFLOW for this simulation

Turbulence Models

- Spalart-Allmaras (SA)
  - One-equation: solve for viscosity-related variable (TKE)
  - 2nd-order Backward Differentiation Formula in OVERFLOW

- Shear-Stress Transport (SST)
  - Combines best characteristics of traditional two-equation models
    - Convection equation: account for energy of turbulence
    - Dissipation equation: account for scale of turbulence
  - Use k-ω for inner boundary layer
    - No need for damping functions
  - Use k-ε for freestream
    - Not as sensitive as k-ω
  - Successive Symmetric Over Relaxation (SSOR) in OVERFLOW

Run Parameters

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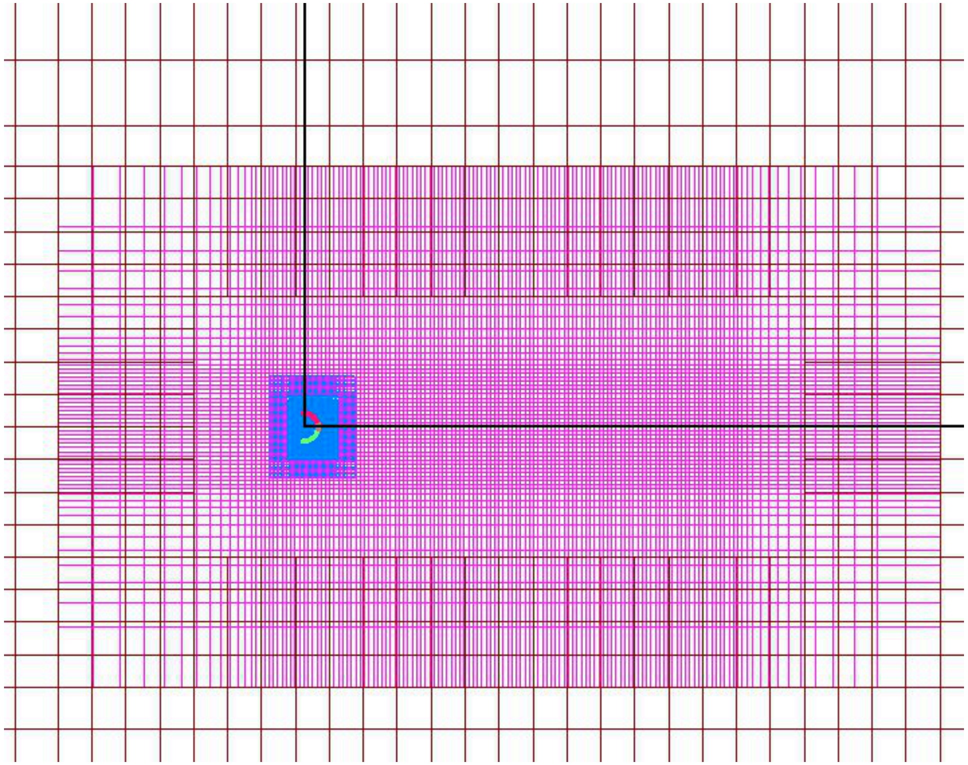
- Match hemisphere run parameters to high-fidelity chute
  - Match flight parachute geometry scale (Lref)
  - Scale up flight Mach number x5 (enhance low-Mach convergence)
  - Preserve flight Reynolds number

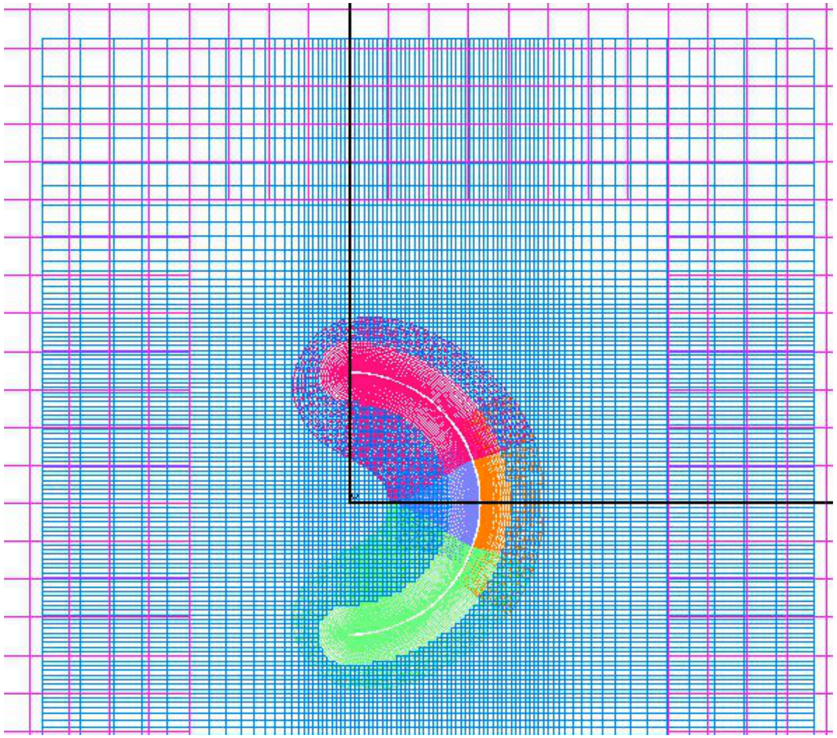
Parameter	**Simulation Value**	**Notes**
Mach Number	$M = 0.15\ (V = 1988 in/s)$	Scaled up from flight
Density	$\rho = 2.61x10^{-7} slug/in^3$	Scaled down to preserve Re
Temperature	$T = 508^o R$	Yields: $\mu = 3.07x10^{-8} slug/in \cdot s$
Reynolds Number	$Re/in = \frac{\rho V}{\mu} = 16965/in$	Full: $Re = 2.36e7$
Reference Length	$L_{ref} = 1392 in$	Parachute Diameter
Turbulence Models	SST, SA	NQT=205, 102

Table 1: CFD simulation run parameters

Grid Development

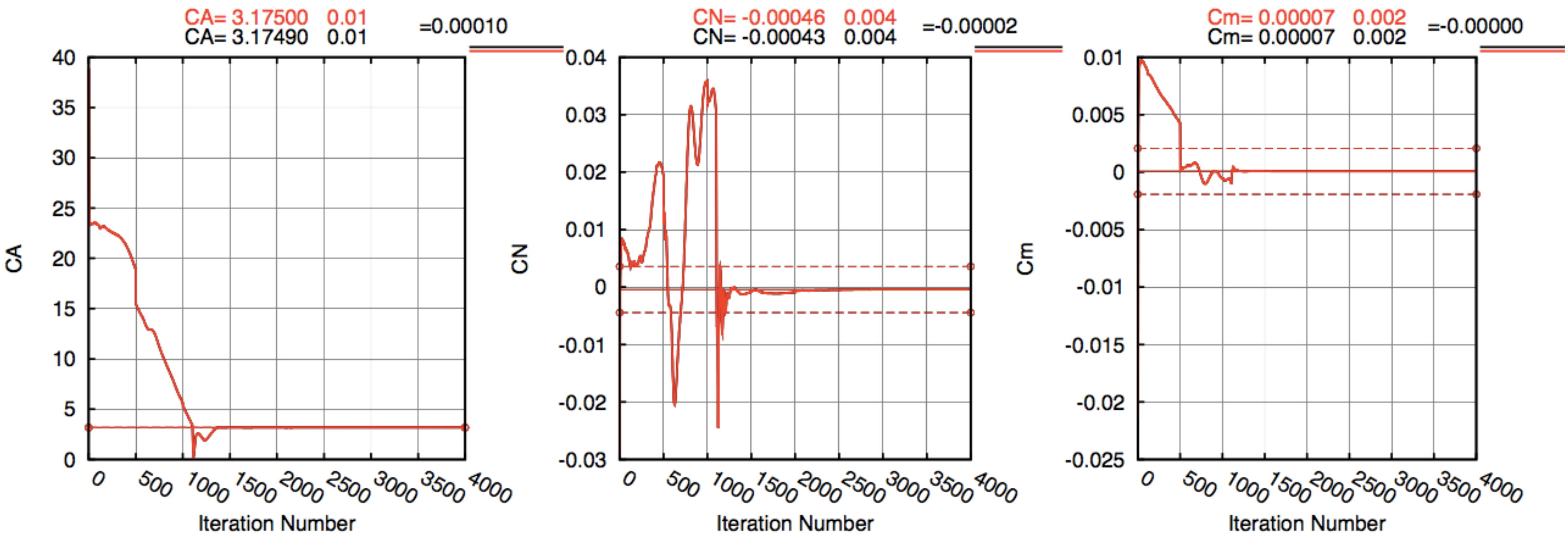
- Use same overset grid strategies as high-fidelity chute
  - Cascading box grids propagate flow around body
  - Chute box compensates for inadequate, concave near-body grids





Results: Convergence

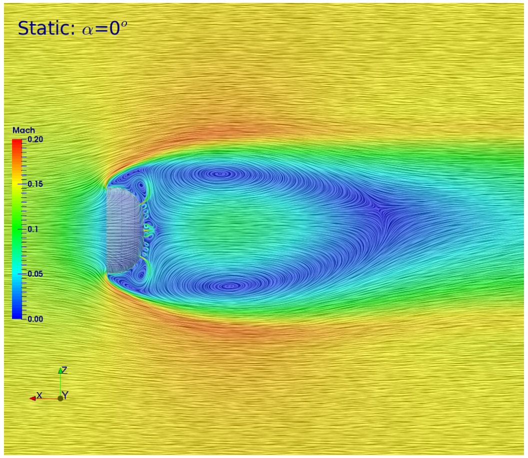
- Co-plot results show nearly identical convergence



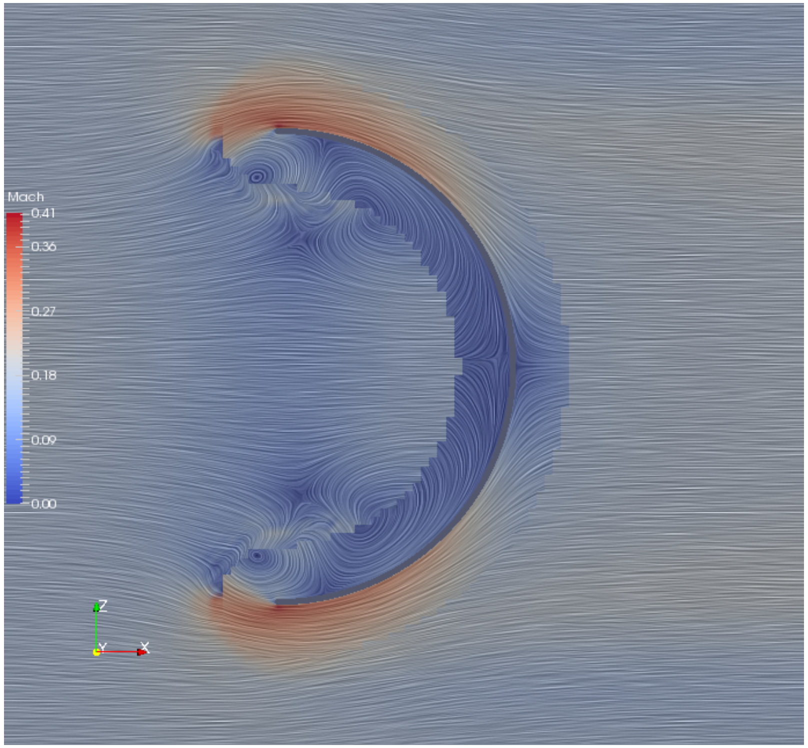
- One possibility: solution is independent of turb. Model
- Another possibility: solution is more dependent on <u>grid</u>

Results: Flow

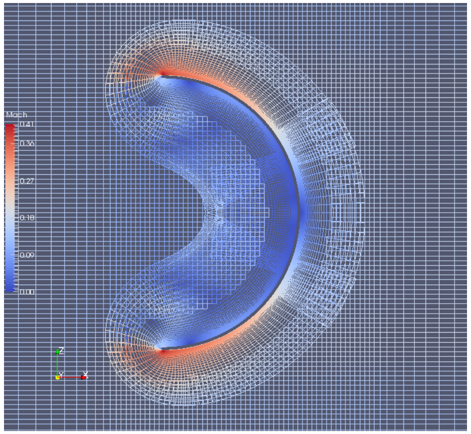
- Grid dependency observable in flow behavior
  - Flow is better resolved/constrained in near-body grids
  - Discontinuities at grid interpolation regions



High-fidelity solution



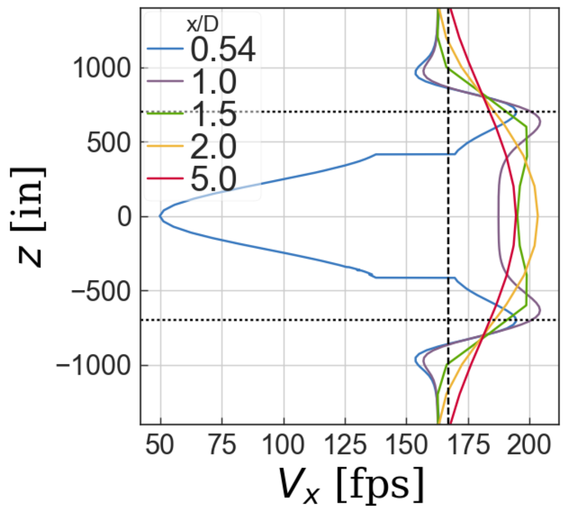
Hemisphere solution

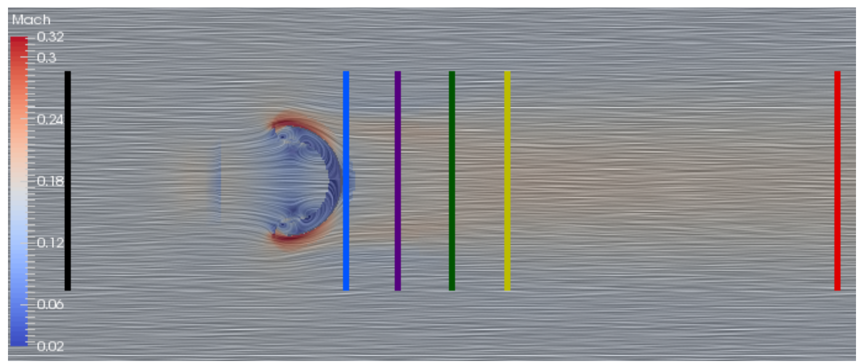


Hemisphere wireframe

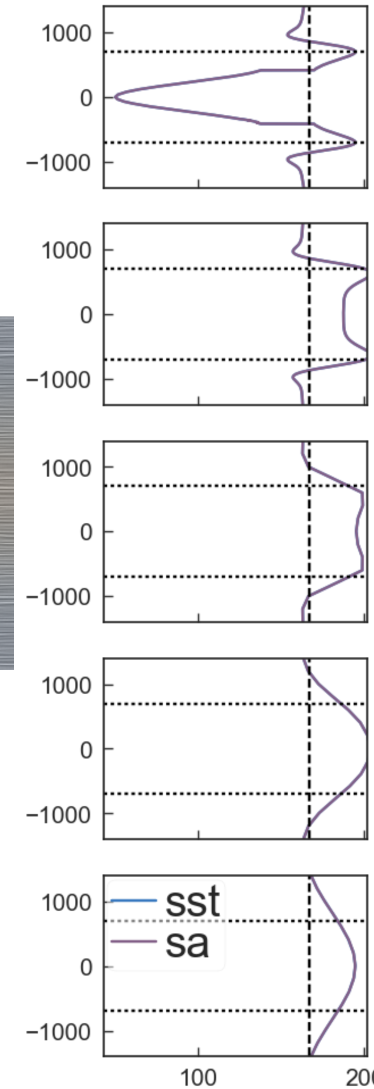
Results: Wake

- Sample x-velocity in wake at spanwise stations
  - Results overlap: no influence from turb. Model
    - Differencing results reduces to floating point error
  - Discontinuities due to bad grid interpolation





Wake velocity sample locations



- Drag Coefficient
  - CFD: 3.2, Experiment (semicircle): 2.3
  - Possible causes: 2D vs 3D, massive separation, grid

Conclusions and Next Steps

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- Turbulence study inconclusive
  - Solutions were independent of turbulence model BUT…
  - Obvious dependency on grid resolution, need refinement studies
- Future work
  - Testbed for 6DoF pendulum simulations
  - Avenue for further grid refinement and turbulence studies

Other Models (Not RANS)

- Compressible LES coupled with FSI
  - Supersonic MSL parachute (Karagiozis, Et al.)
  - Stretched-vortex model
    - Flow in cell assumed to result from straight, axisymmetric vortices aligned with local strain