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Numerical Simulations of Turbulent Flow in Pipes

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Motivation

- Particle-Laden flow in industrial application
  - Complex Geometries
  - Erosion
- Geometries of focus
  - Elbow
  - Plugged T-junction
- Computational Method
  - Reynolds averaged Navier-Stokes (RANS)
  - Direct Numerical Simulation (DNS)
  - Lagrangian particle tracking (LPT)

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Objective

Overall objectives

- Conduct high fidelity numerical simulations for detailed insight into the physics of erosion
- Validate simulations with experimental data
- Enhance RANS methods

Current objectives

- Determine ideal turbulence model
- Present DNS duct data (Validation)
- Present coarse DNS elbow data

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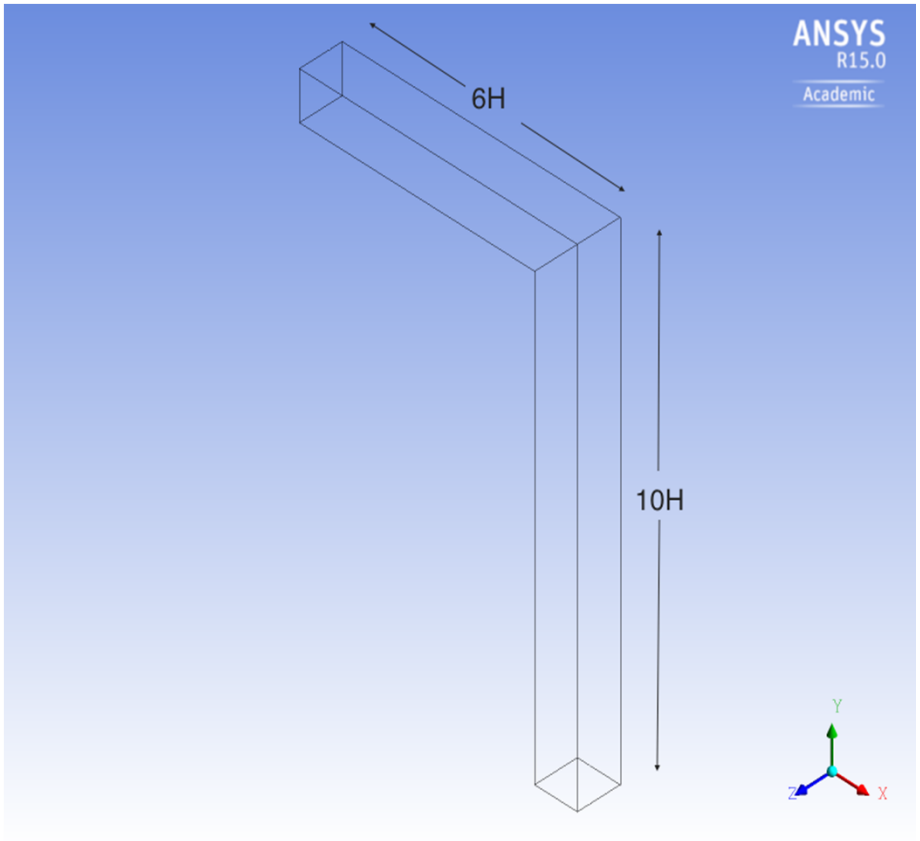
Reynolds Averaged Navier-Stokes (RANS)

- Navier-Stokes decomposed into mean and fluctuating terms
- Closure problem
- k-ε model
  - Two equation model
  - Assumes that the viscosity is isotropic

- Reynolds stress model (RSM)
  - Solves for the Reynolds terms directly
  - Computational expense higher that other RANS models

Reynolds Averaged Navier-Stokes (RANS)

- Cross-section of geometries square
- Re=11,500−115,000
- Entrance and exit length
- Boundary conditions
- Enhanced wall treatment
- 2-4 million elements



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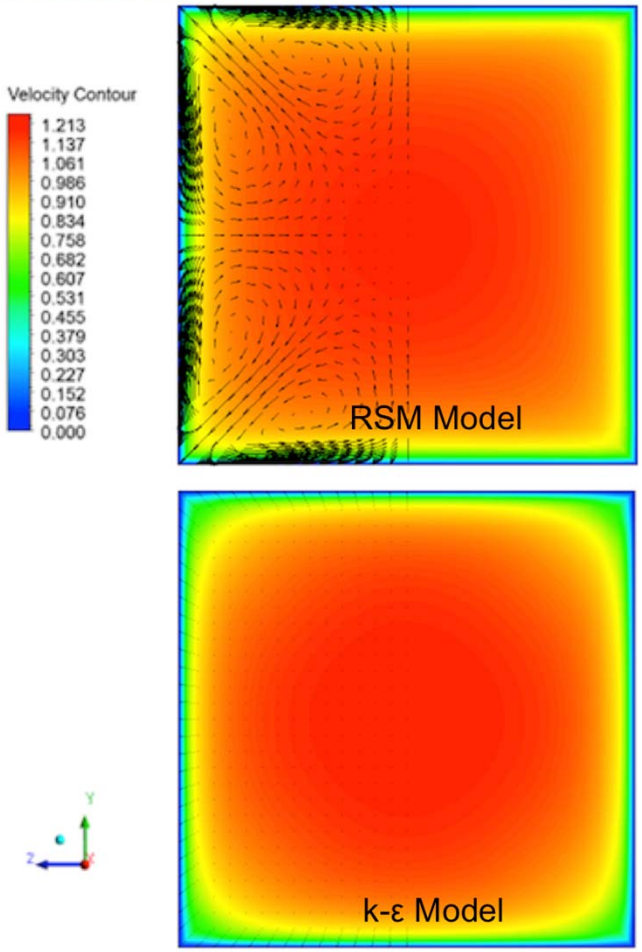
Reynolds Averaged Navier-Stokes (RANS)

Model comparison

- Upstream of bend
- Re =11,500
- Streamwise velocity contours overlaid with secondary flow vectors

Observation

- k-ε model does not show secondary flow vectors
- The secondary motion directs the flow into the corners making the flow more uniform



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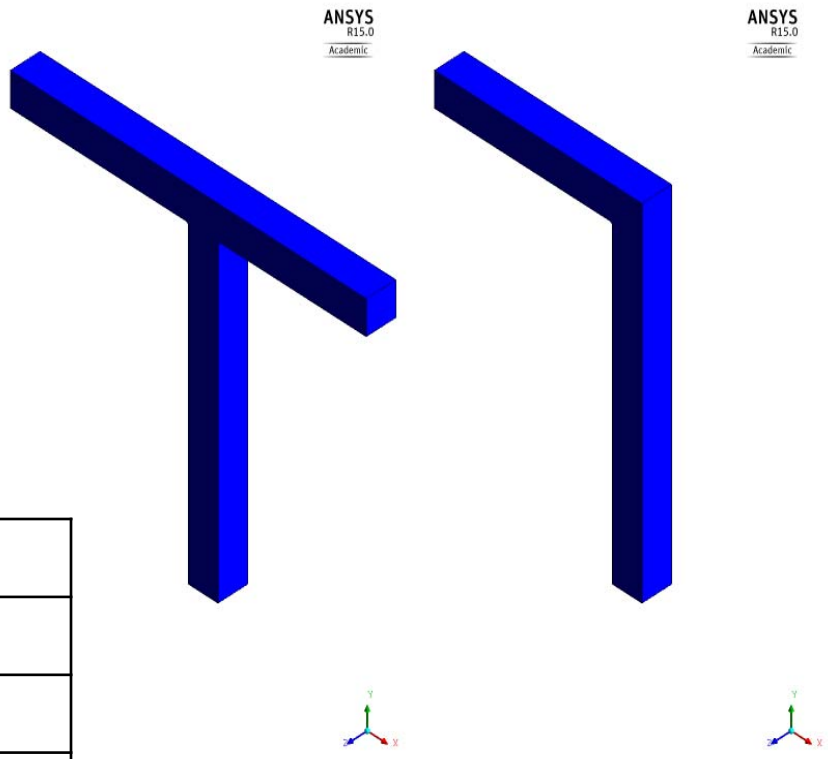
RANS RSM model

Particle-Laden Flow

- Steady RSM RANS
- Ducted elbow and plugged T-junction
- Fully turbulent inlet
- Particles are introduced at inlet
- Dilute particle concentration
- Tulsa angle dependent erosion model

Particle diameter	1.6×10^{-3}
Density ratio	2.0
Stokes number	4.6
Volume fraction	1.0×10^{-6}
Number of particles	7.0×10^{5}



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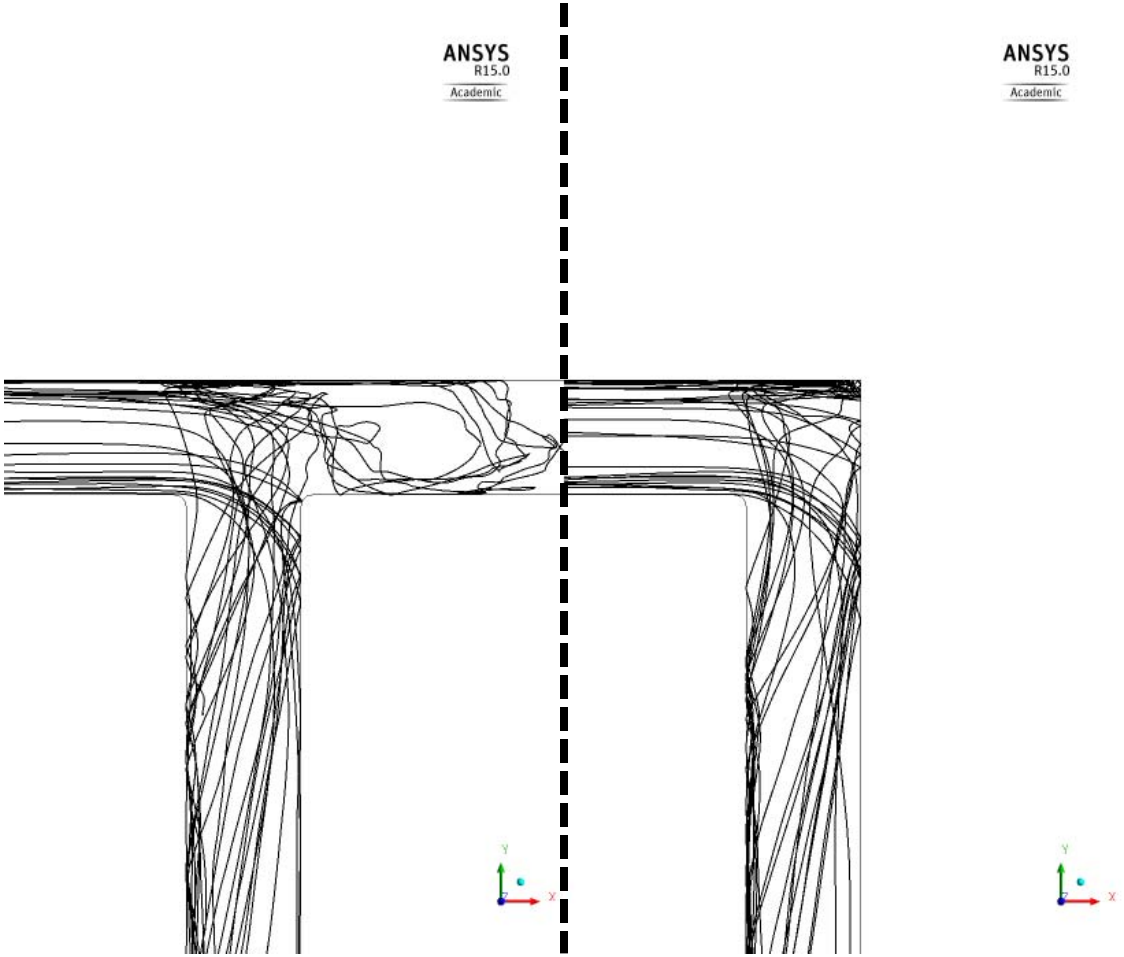
RANS RSTM Model

Predicted Particles Trajectories



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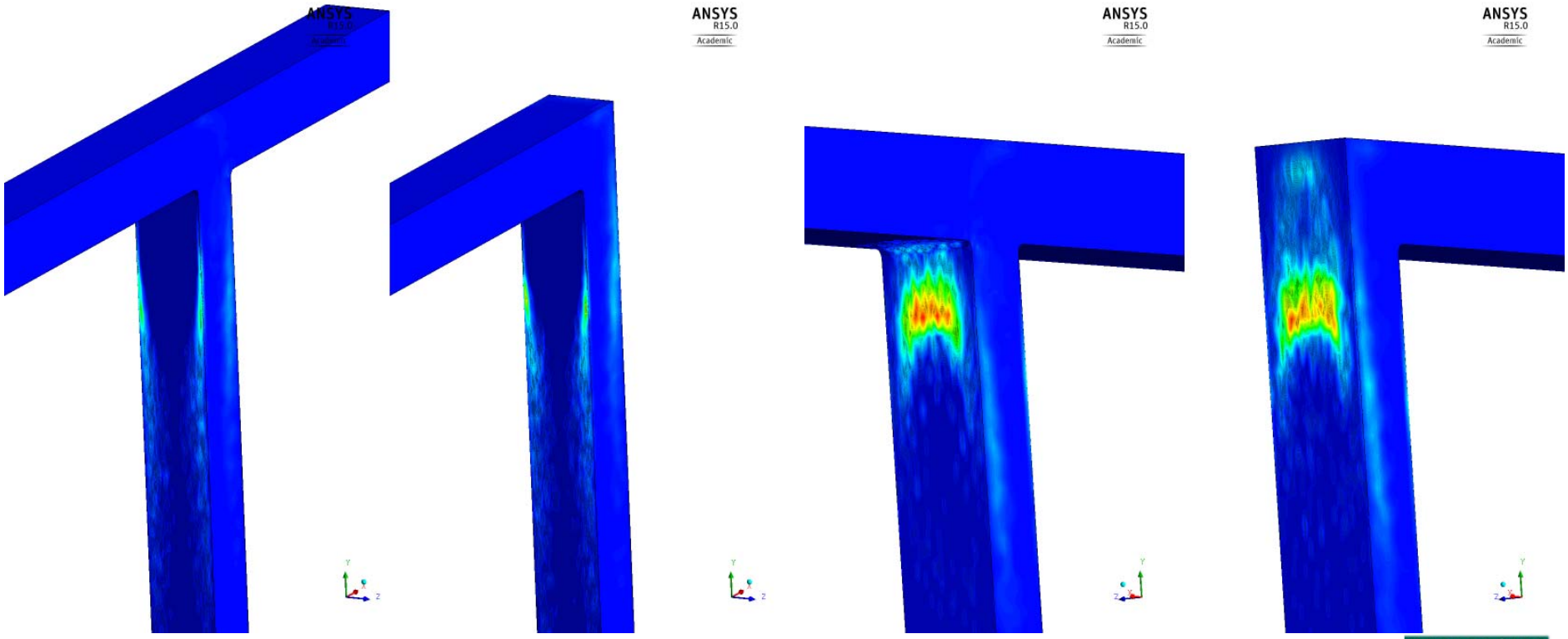
RANS RSM Model

Predicted Erosion Patterns



DNS Duct

- Simulation started with a laminar profile
- Turbulence was initialized using random noise
- Grid will be refined once steady turbulence is achieved
- Periodic boundary condition

Reynolds Number (Re)	11,500
Duct length (L/H)	12.5
# of elements	202, 176
Polynomial degree	9
y^+ of first nodal point	1
$\Delta y^+_{max}, \Delta z^+_{max}$	16
Δx^+_{max}	40
Timestep ($\Delta tU/H$)	$2.5x10^{-4}$
Sample time (tU/H)	27

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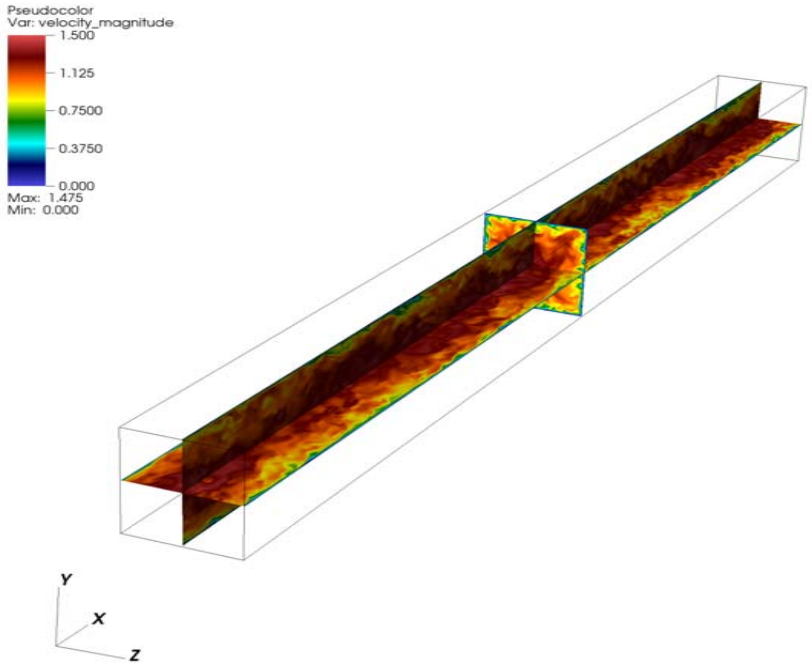
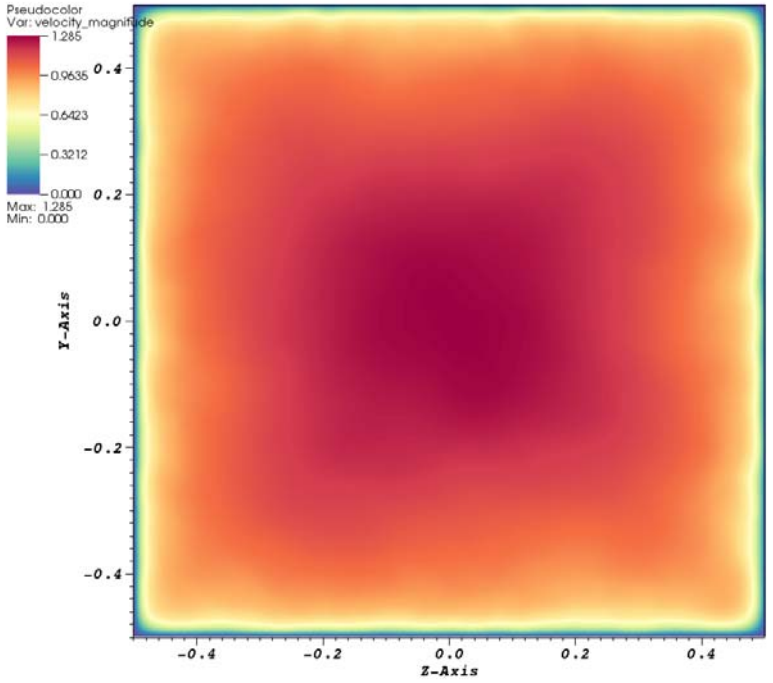
DNS Duct

Instantaneous Velocity Pseudocolors



Cross-section Mean Velocity Pseudocolors



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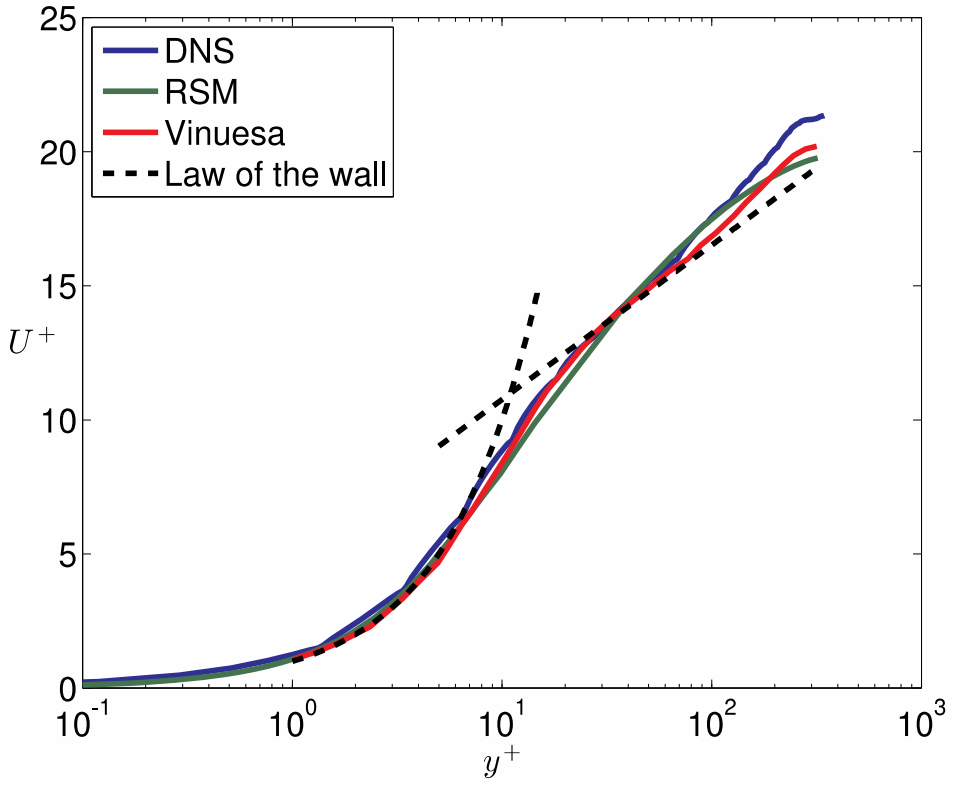
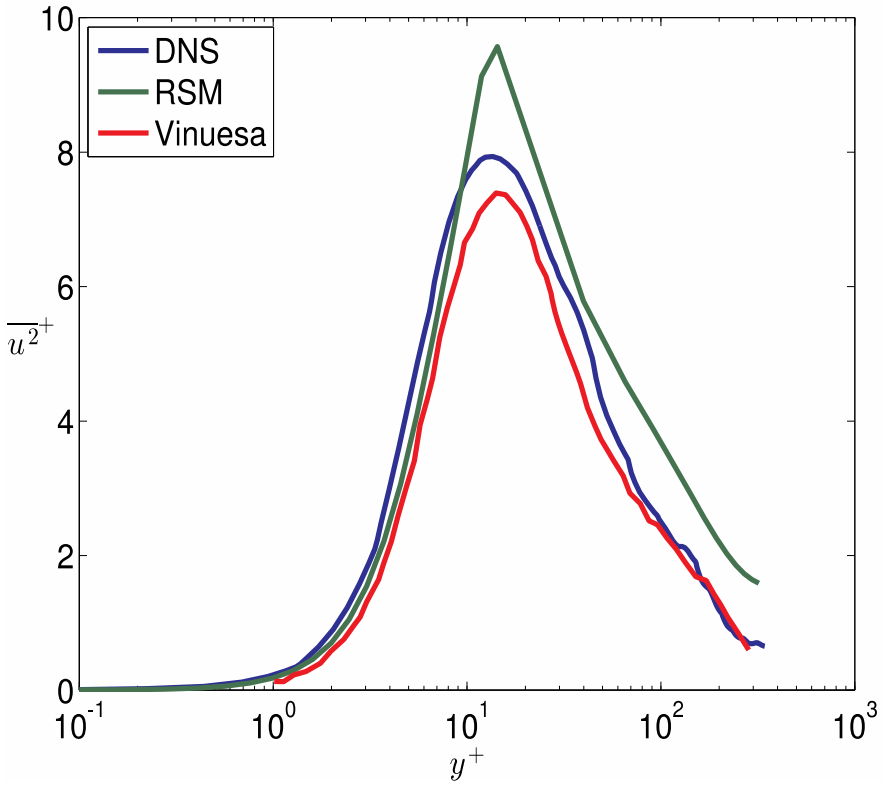
DNS Duct

Mean Flow



Streamwise turbulent intensities



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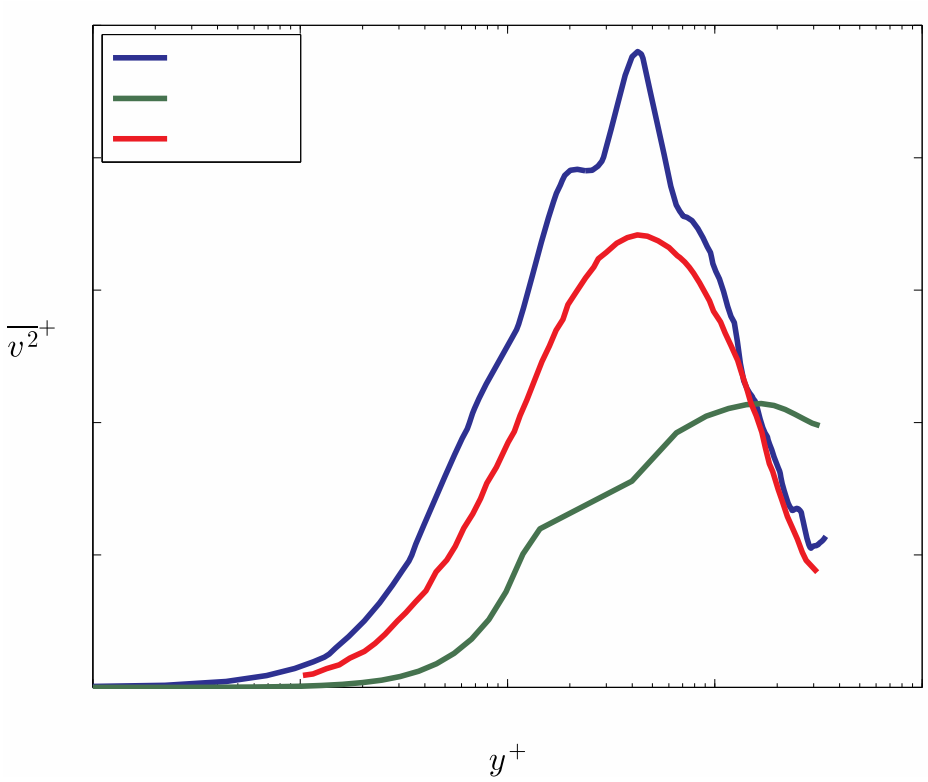
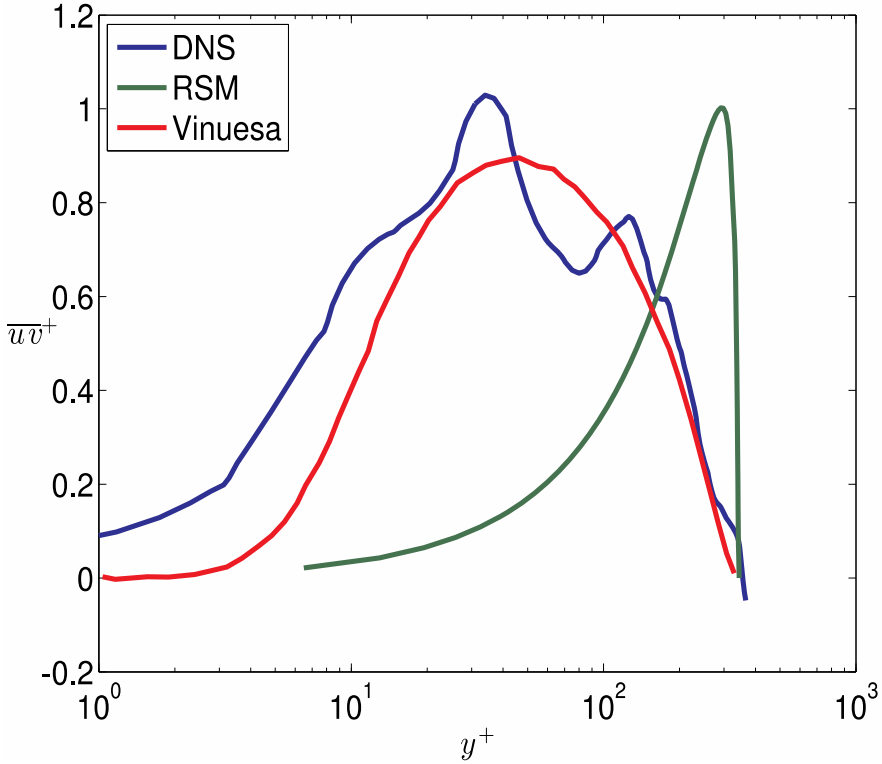
DNS Duct

Spanwise turbulent intensities



Reynolds shear stress



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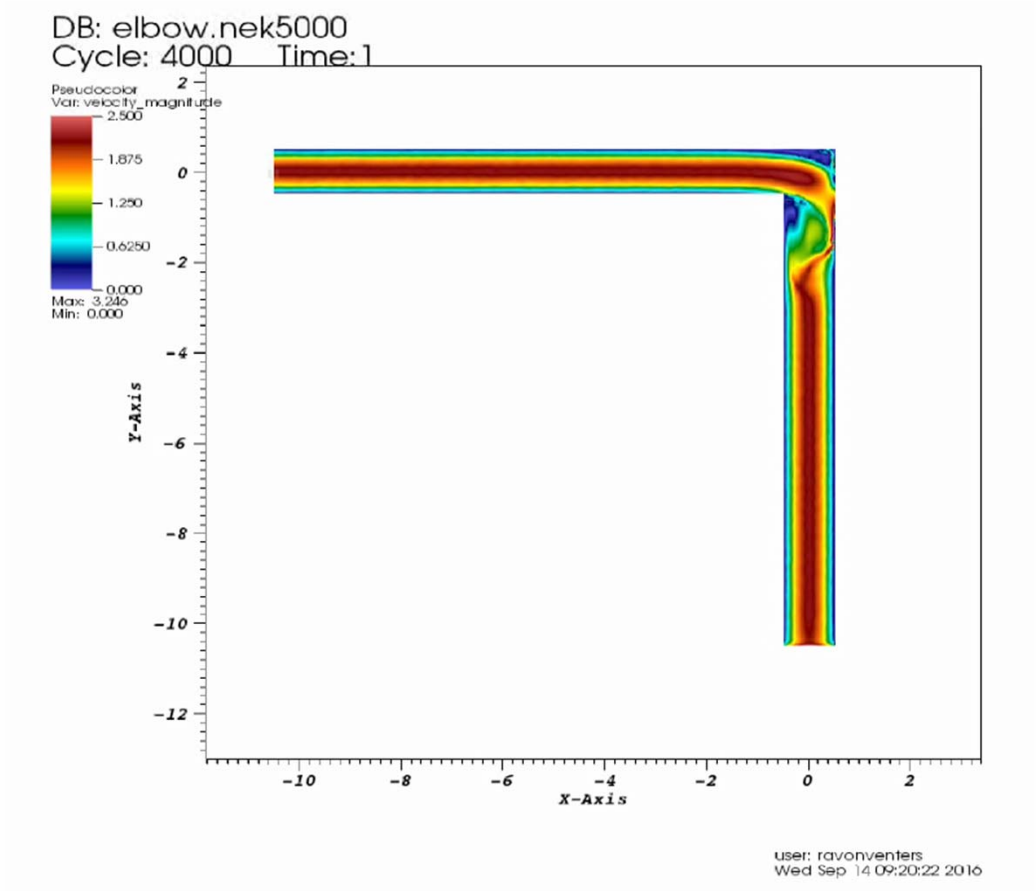
Coarse *DNS Elbow*

Reynolds Number (Re)	11,500
Entrance length (L/D)	10
Exit length (L/D)	10
# of elements	24,768
Polynomial number	8
Total grid points	12.68×10^6
Timestep ($\Delta t(U/D)$)	2.5×10^{-4}
Sample time(t(U/D))	185



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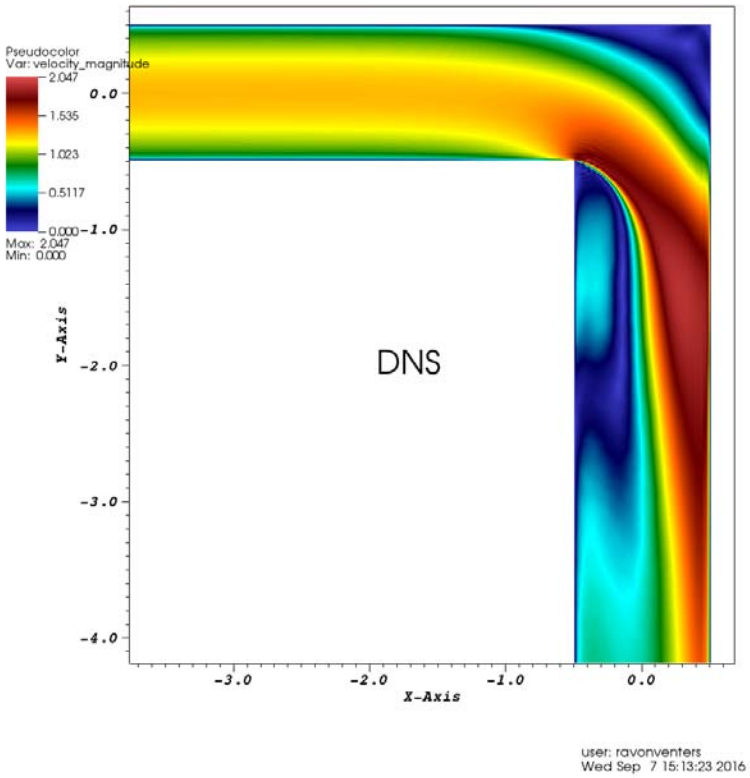
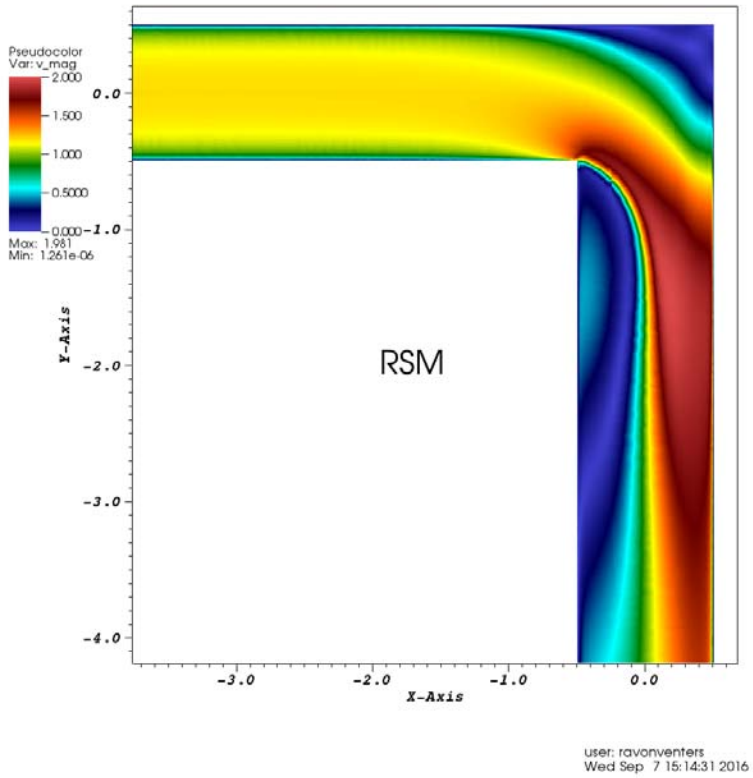
Coarse *DNS Elbow*

Velocity Contours Mid-plane





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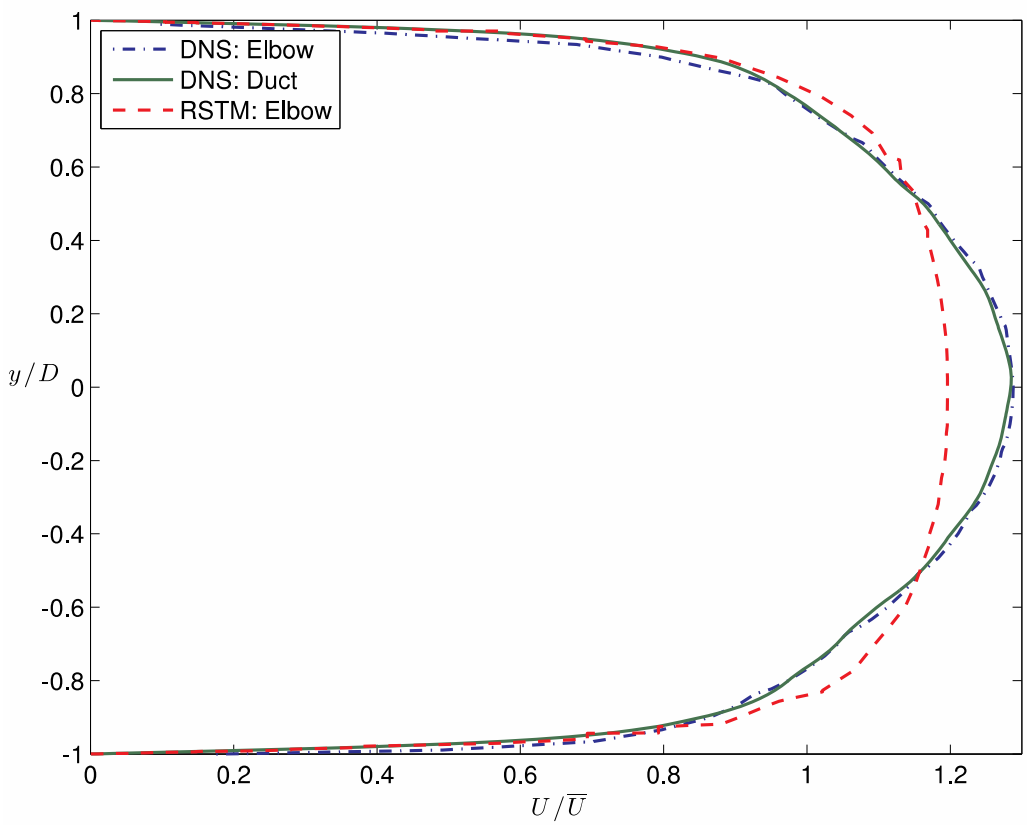
Coarse *DNS Elbow*

Mean velocity profile



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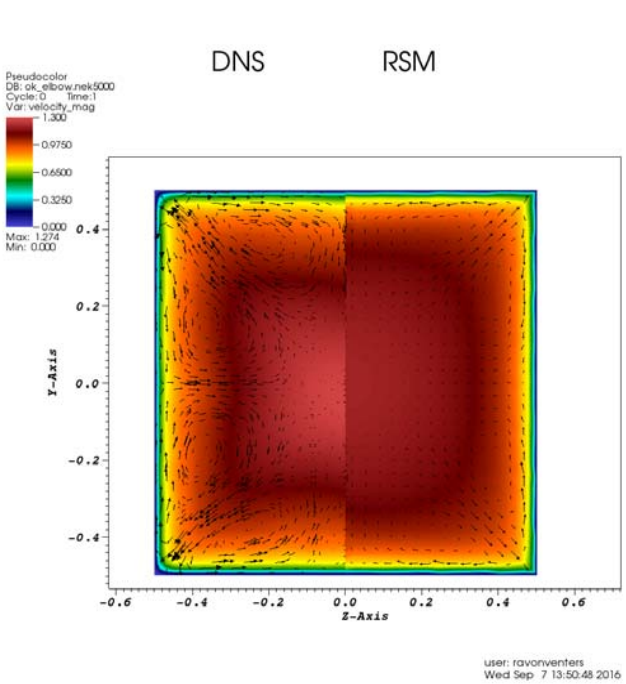
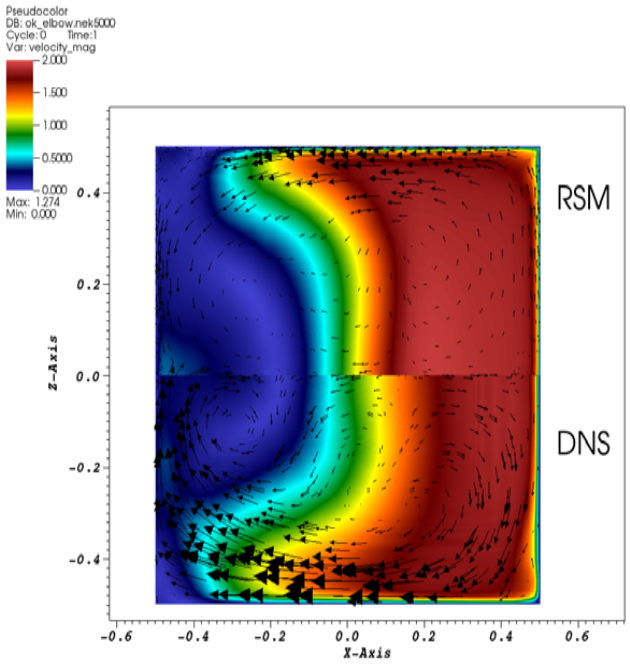
Coarse *DNS Elbow*

Streamwise velocity overlaid with in-plane velocity vectors

Upstream



Downstream



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Future Work

- In the process of performing one-way coupled DNS in an elbow
- Complete comparison of RANS, DNS, and experimental results
- Validation of the two-way coupled model

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