# Vortex Roll Breakup in Turbulent Shear Flow

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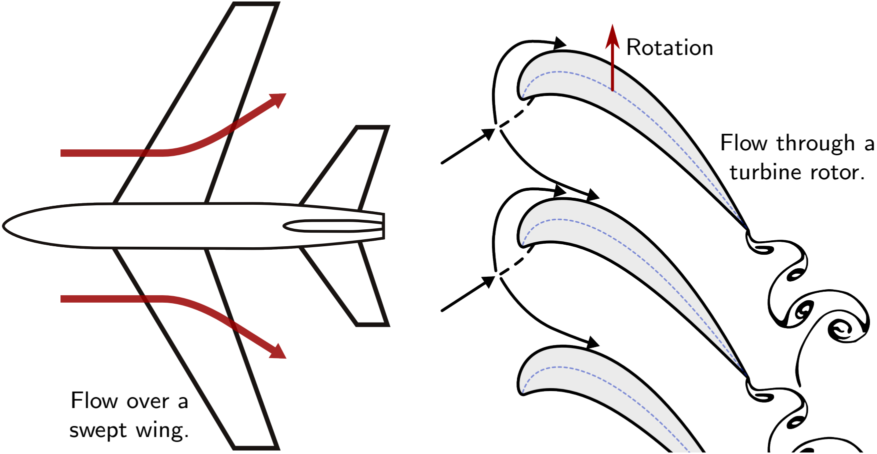
Supported By

# Motivation

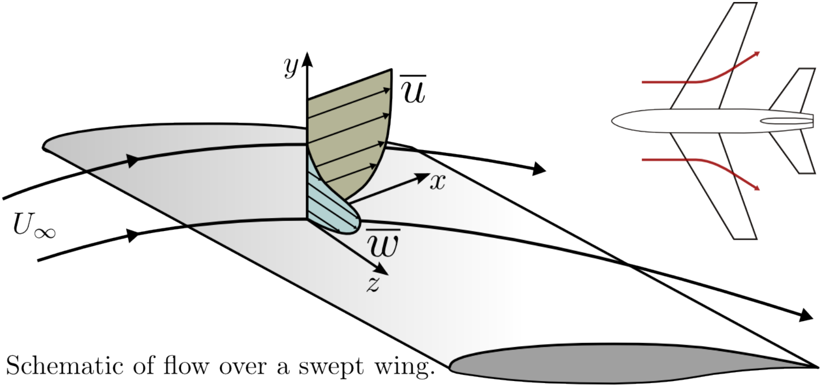
- We want to **predict complex turbulent flows**




- More "complex" than "textbook" thin shear layers:
  1. Extra **body forces** (buoyancy, rotation, . . .) $\rightarrow$ **vortex rolls**
  2. Extra **rates of strain** (streamline curvature) $\rightarrow$ **breakup**

# Effects of Transverse Strain: 3D Boundary Layers

- Mean flow speed *and direction* change with wall distance
- Turbulence “less efficient” at extracting energy from mean

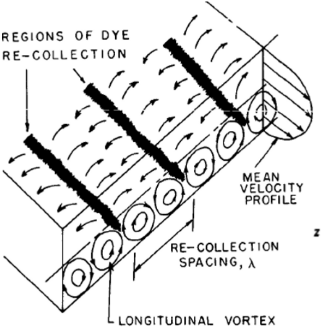



Schematic of flow over a swept wing.

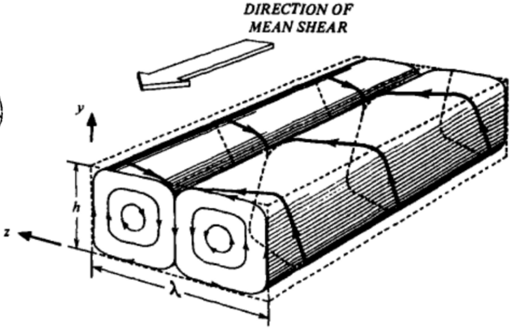
- Tends to reduce momentum and heat transfer rates
- Vortex generators used to prevent flow separation/stall

# Effects of Vertical Forcing: Vortex Rolls

- Streamwise-aligned vortices *ventilate* near-wall turbulence
- Large, organized vortex rolls embedded in a turbulent flow



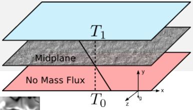

Rotating Shear Flow
(Johnston 1970)

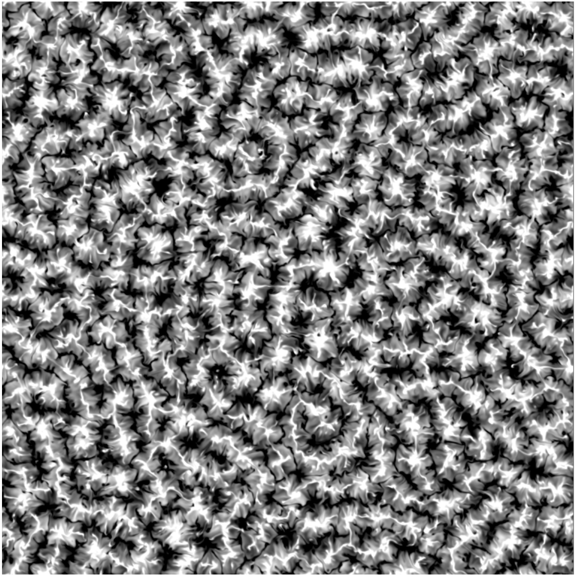



Heated Shear Flow
(Kelly 1994)

- Tends to enhance mixing and heat transfer rates
- May increase vibration, heat load, and fatigue

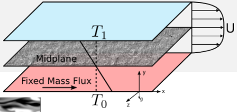
# Rayleigh-Bénard Convection (No Shear)

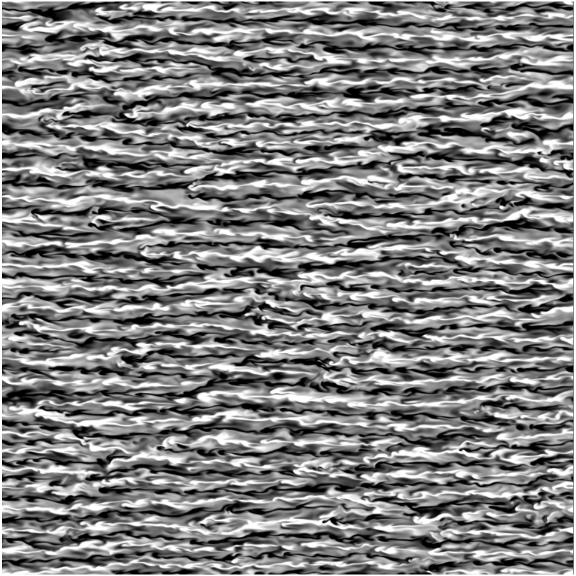


Temperature contours along midplane

# Rayleigh-Bénard Convection With Shear



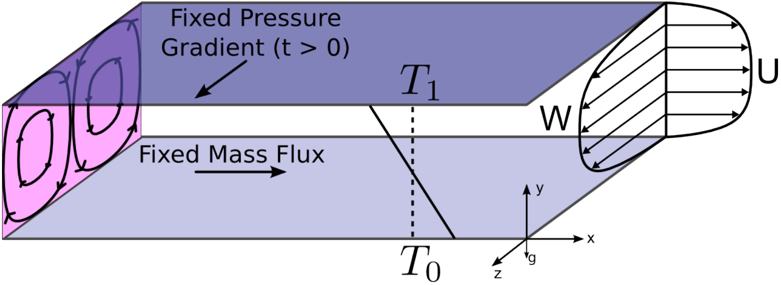



**Temperature contours along midplane**

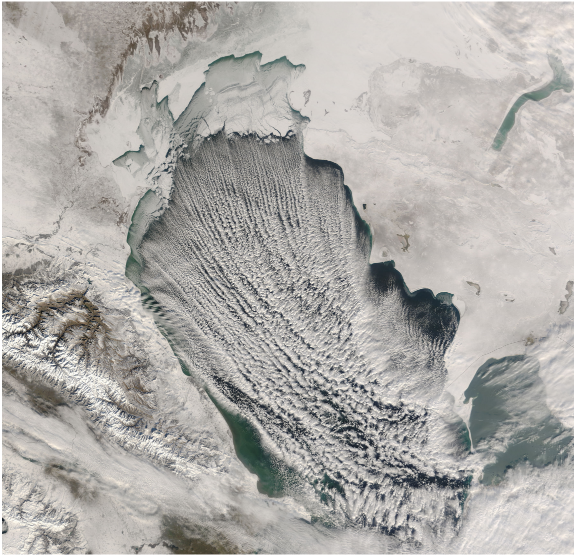
# Vertex Roll Breakup in 3D TBLs

1. 3D TBLs tend to **reduce** mixing and heat transfer
2. Vortex rolls tend to **enhance** mixing and heat transfer

**What if transverse strain and wall-normal body forces act together?**

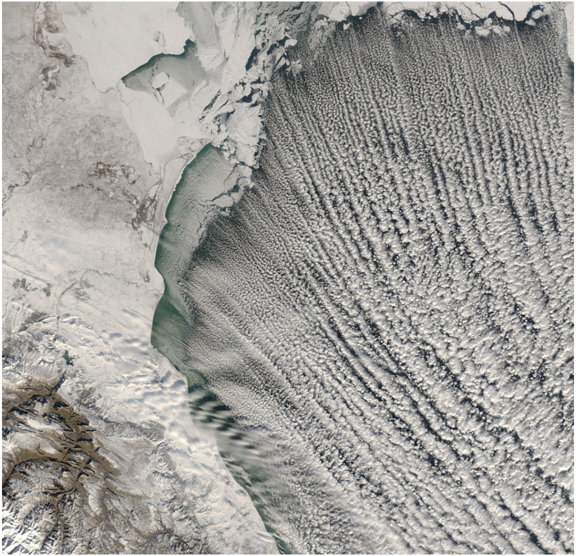


# Example 3D TBLs with Vortex Rolls



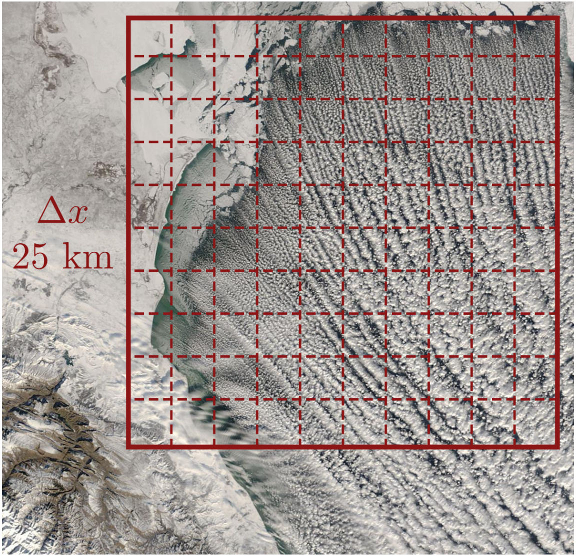
Vortex rolls over the Caspian Sea (NASA, 2008)

# Example 3D TBLs with Vortex Rolls



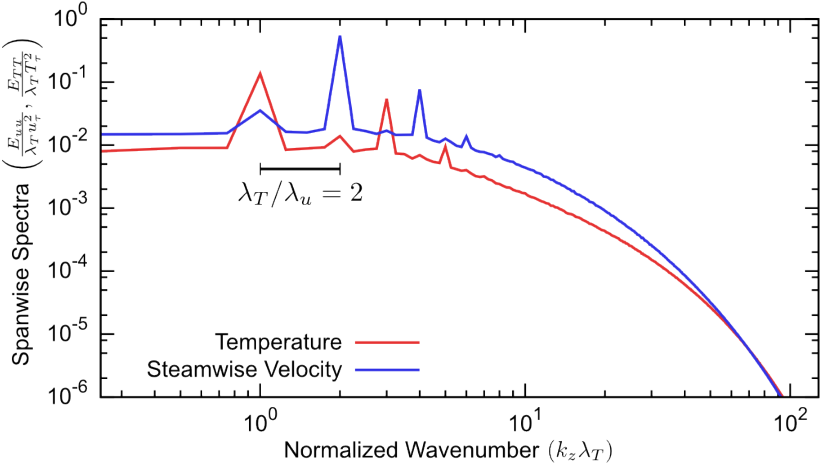
**Vortex rolls over the Caspian Sea (NASA, 2008)**

# Example 3D TBLs with Vortex Rolls



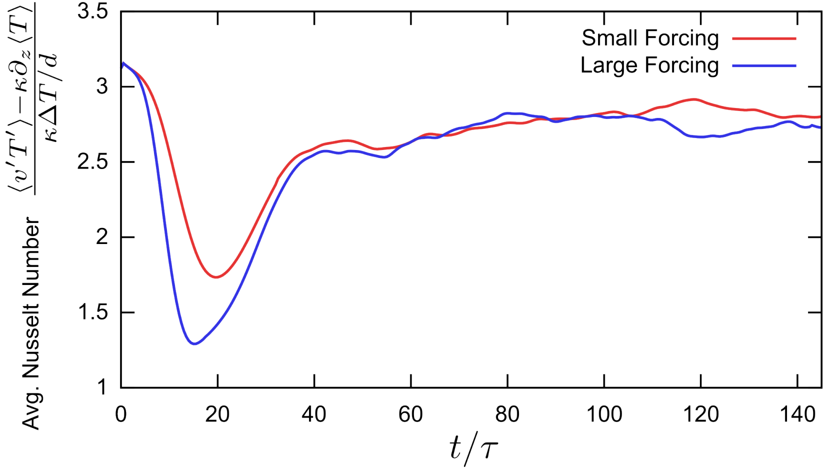

**Vortex rolls over the Caspian Sea (NASA, 2008)**

# Spanwise Spectra of Vortex Rolls (Centerline)



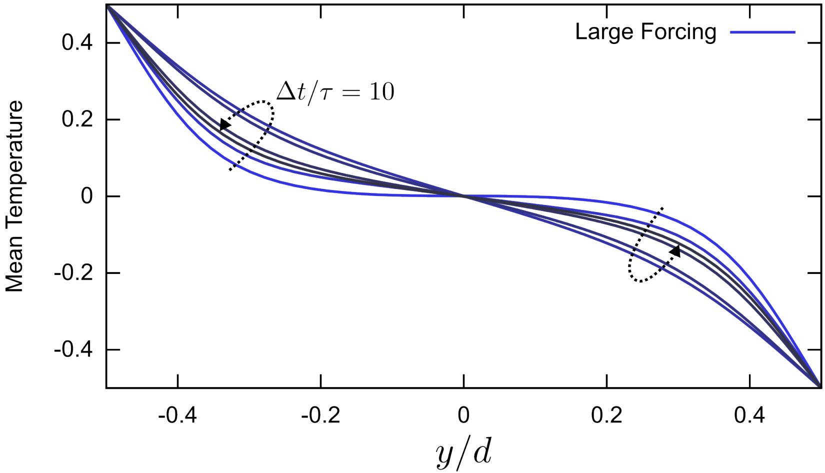
# Vertical Transport and Mixing

- Heat transfer, mixing suppressed in non-equilibrium flow

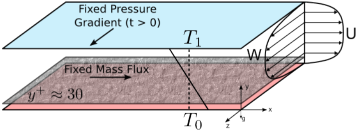


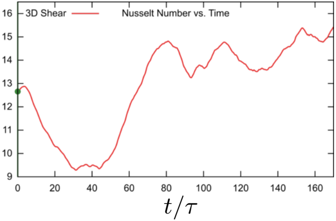
# Vertical Transport and Mixing

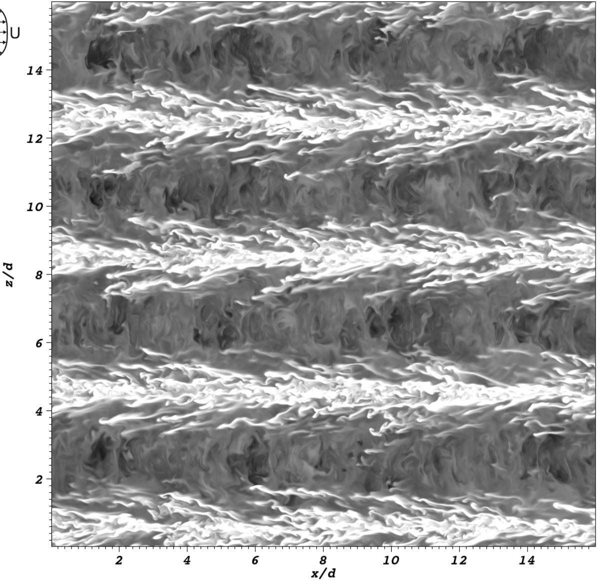
- Mean temp. and heat flux correlations readjust



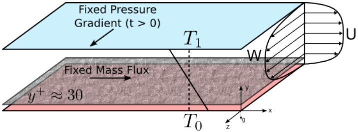
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 0$

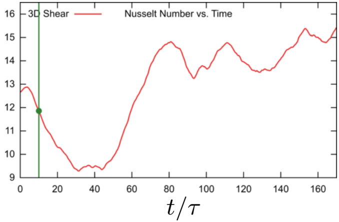


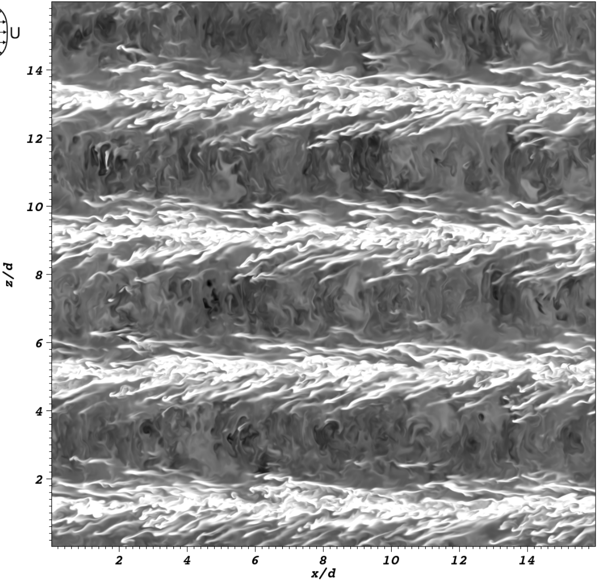



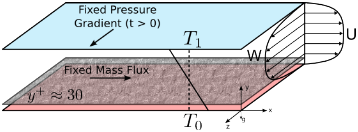
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 10$

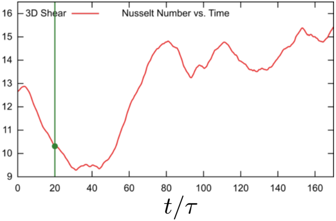


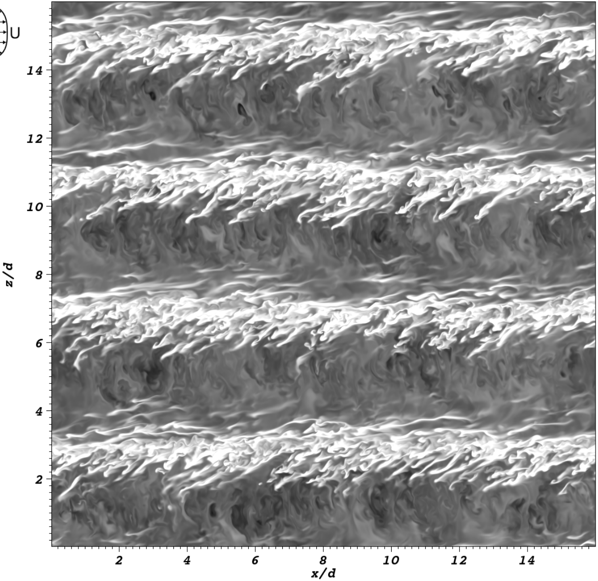



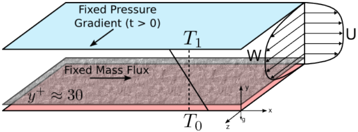
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 20$

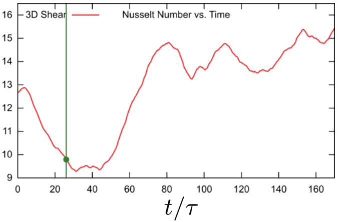


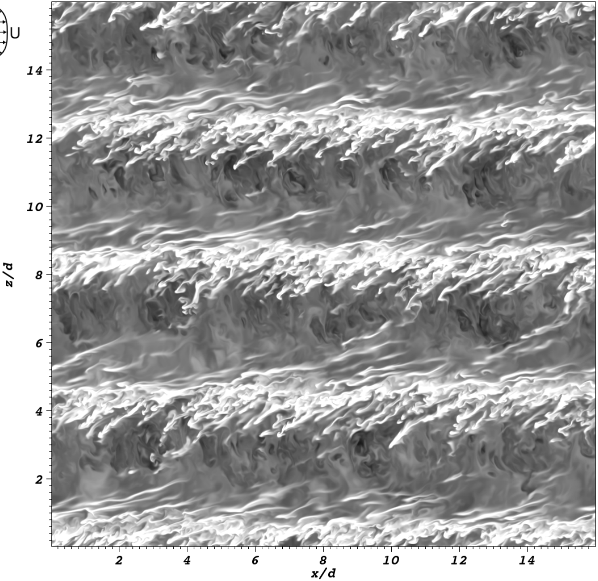



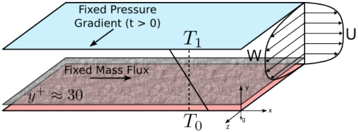
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 26$

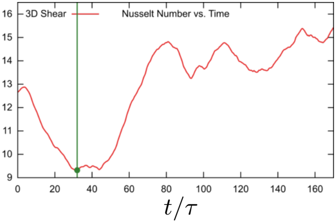


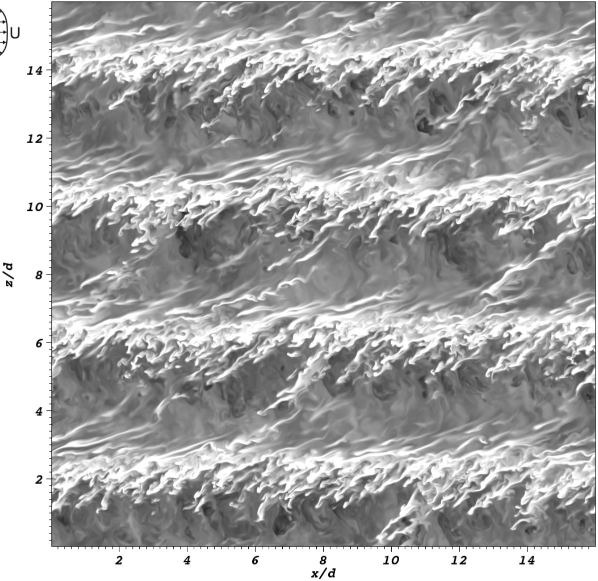



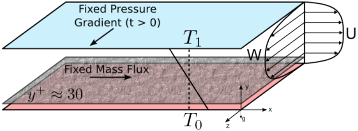
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 32$

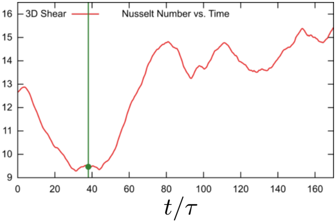


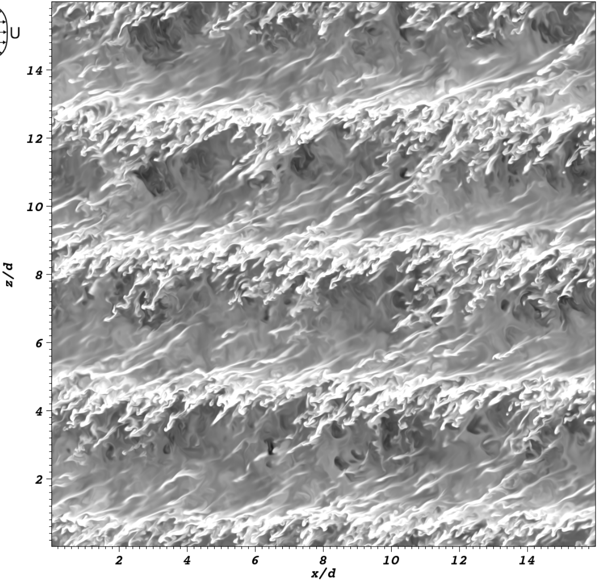



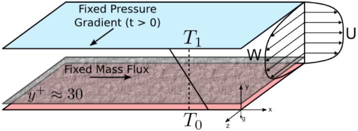
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 38$

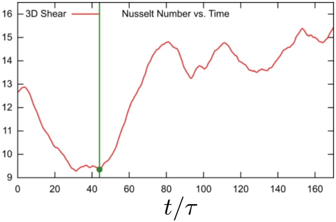


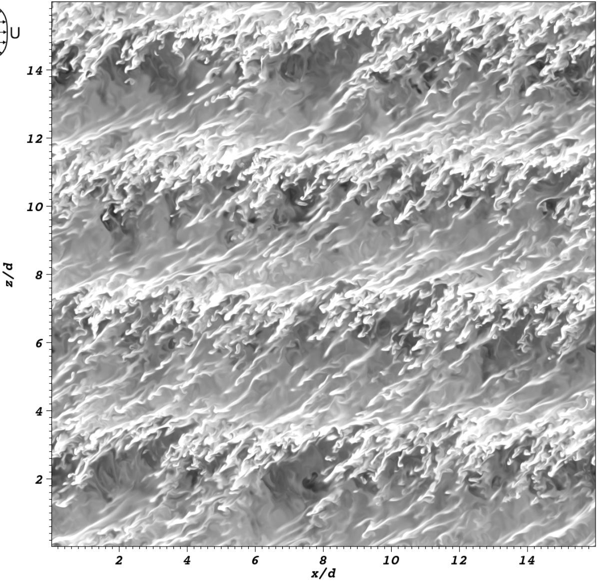



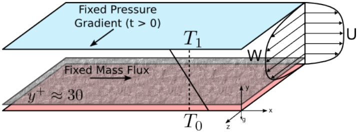
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 44$

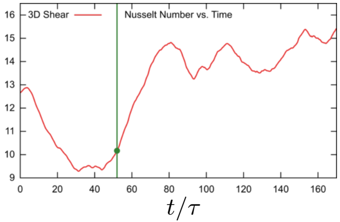


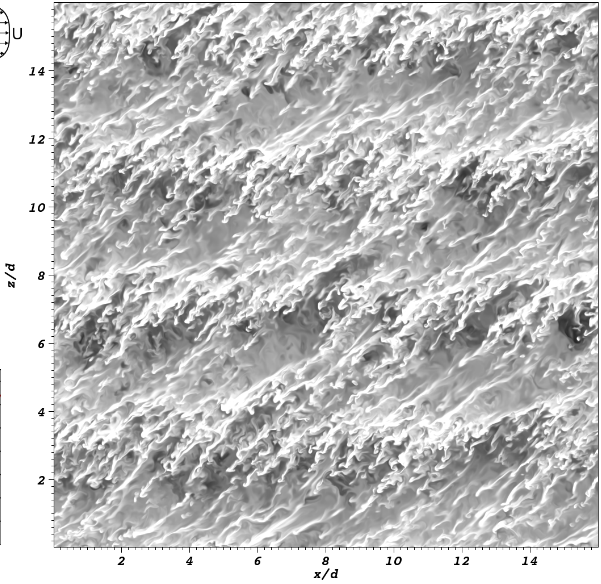



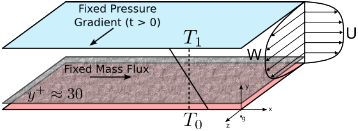
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 52$

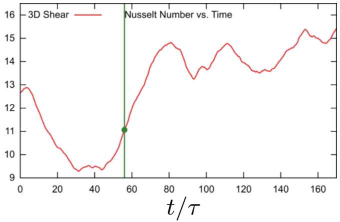


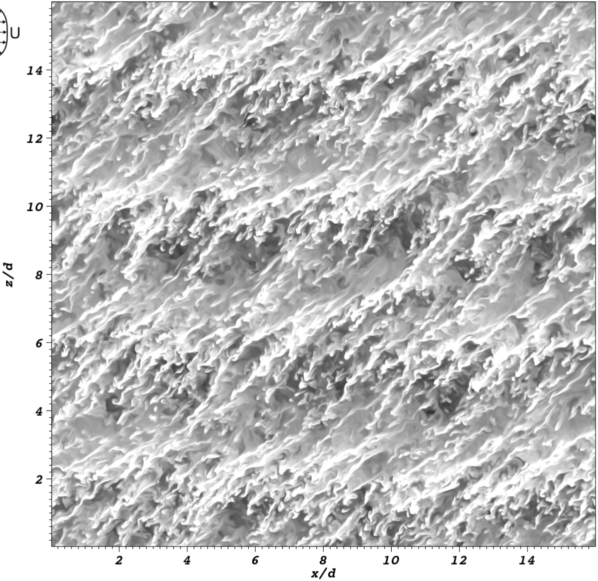



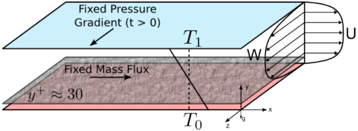
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 56$

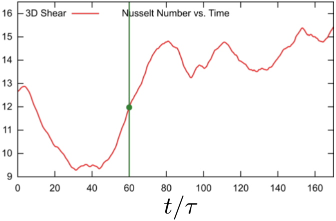


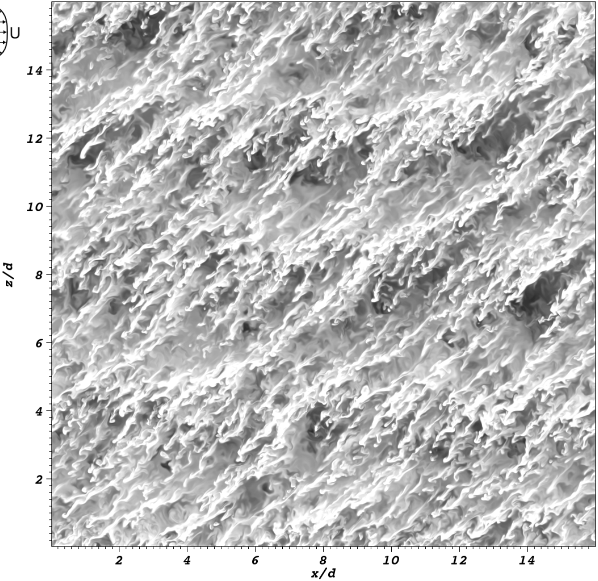



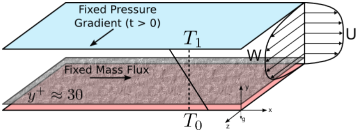
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 60$

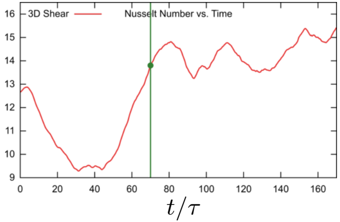


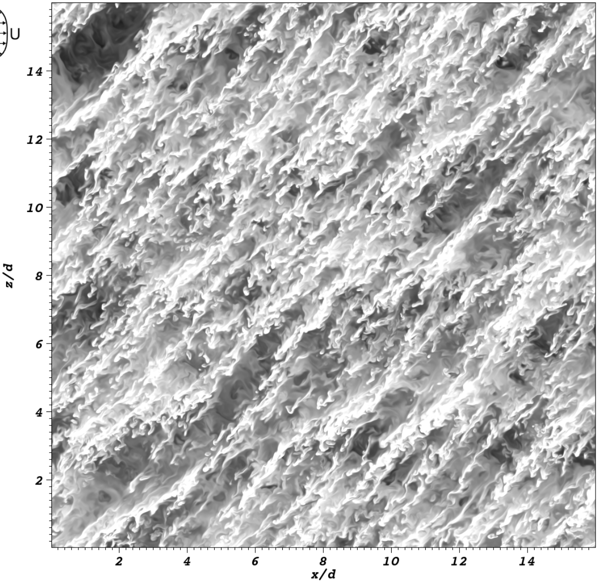



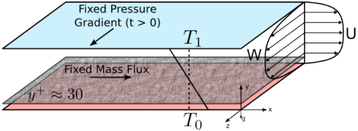
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 70$

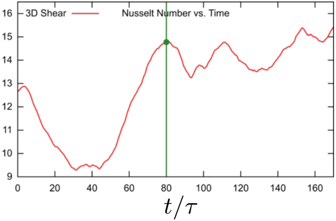


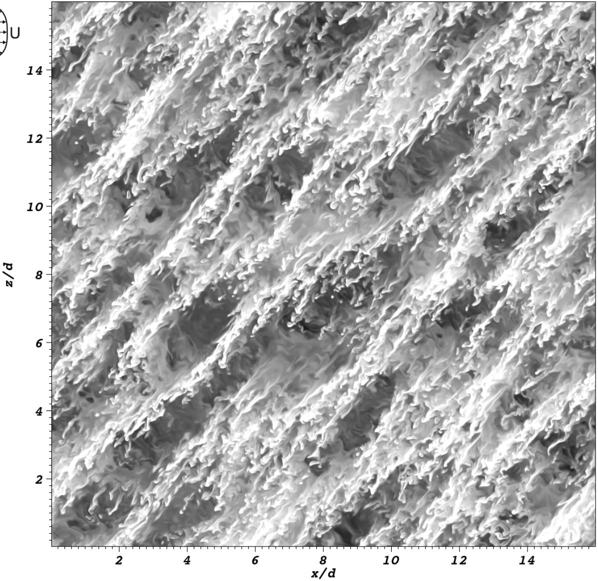



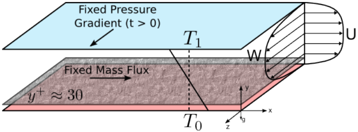
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 80$

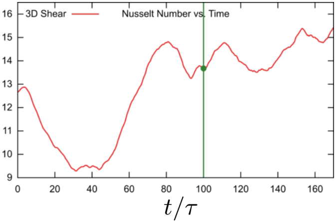


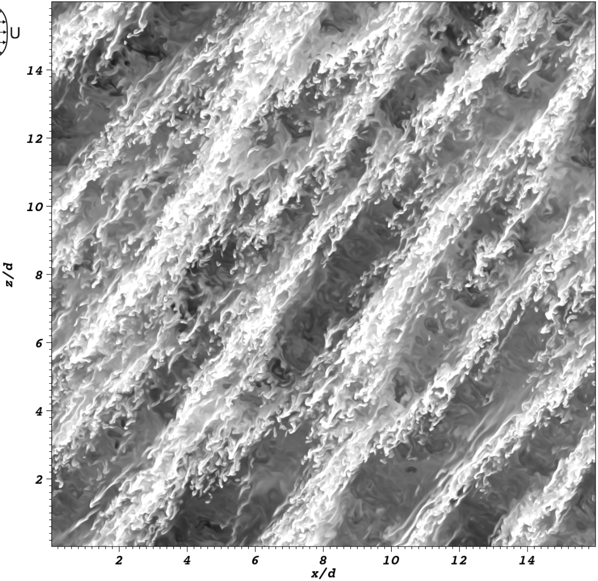



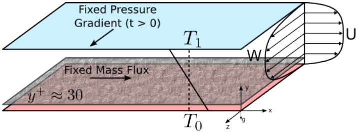
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 100$

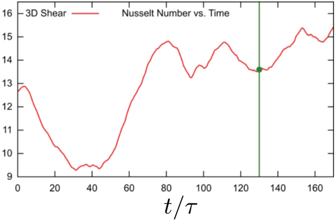


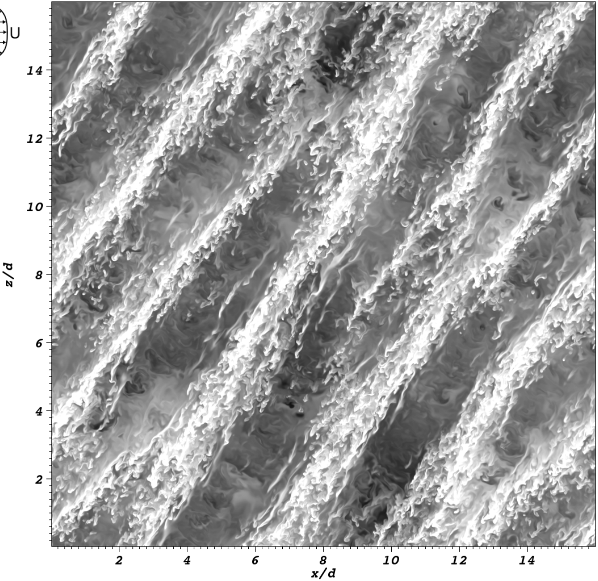



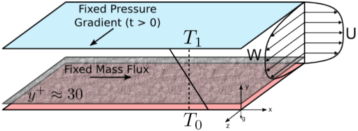
# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 130$

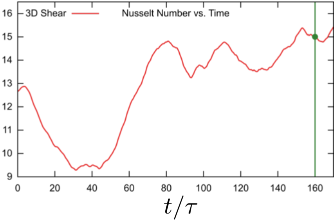


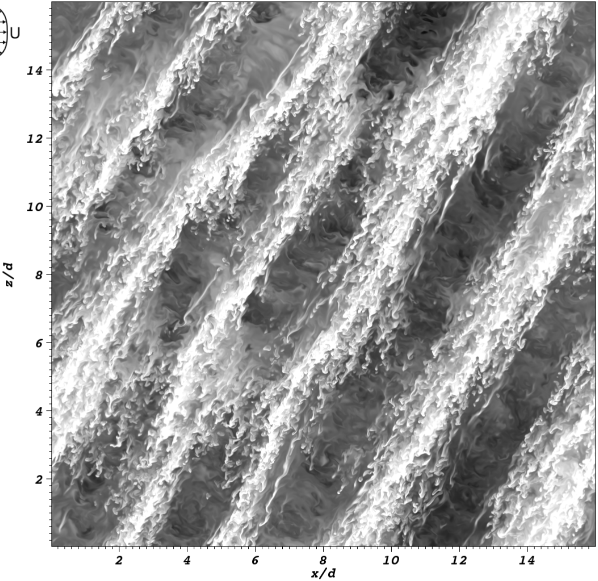



# Contours of Temperature at $y^+ \approx 30$ at $t/\tau = 160$



# Summary

1. 3D TBLs tend to **reduce** mixing and heat transfer
2. Vortex rolls tend to **enhance** mixing and heat transfer

**What if transverse strain and wall-normal body forces act together?**

- Impulsively applied transverse pressure gradients shown to breakup vortex rolls temporarily reducing vertical transport of momentum and heat flux from equilibrium values.