Drag reduction in gas export pipelines; a fundamental numerical approach

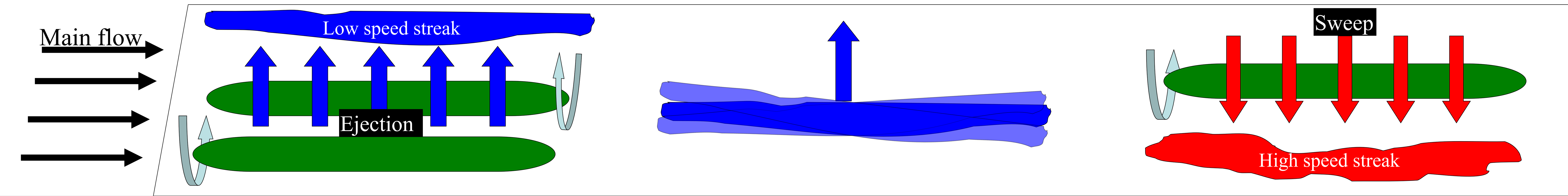
Scope

The present project has investigated the effects from swirl on the mechanics responsible for turbulent friction in a turbulent pipe flow.

Introduction

The mechanics responsible for turbulent friction are termed the *coherent turbulent cycle*:

1. Low-speed fluid is *ejected* from the wall by near-wall vortices. *Low-speed streaks* (low-speed fluid pockets) are created
2. The low-speed streaks start to oscillate while moving from the wall and eventually a violent break up occur, *burst*
3. The *burst* causes flow of high-speed fluid toward the wall. This inflow sustains the near-wall vortices and creates *high-speed streaks*



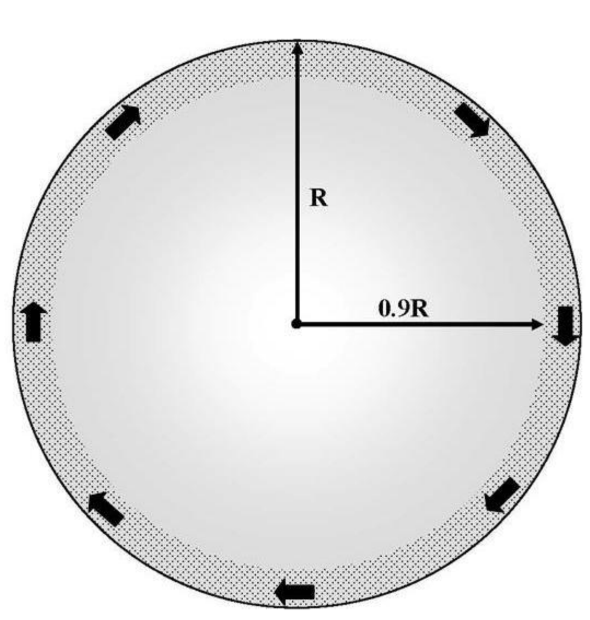
Simulation details

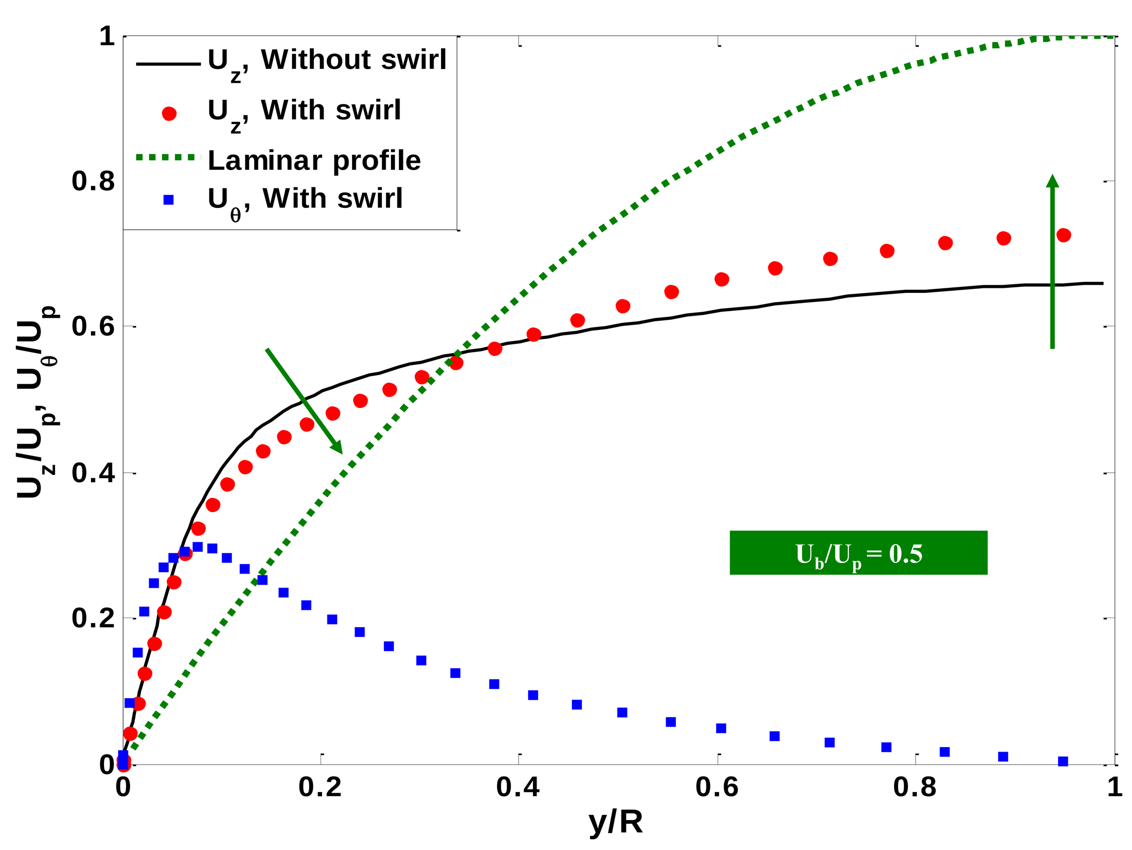
- Turbulent flow
- Direct numerical simulation
- Navier-Stokes equations
- Incompressible flow
- Cylindrical coordinates
- $Re_b = U_b D/\nu = 4900$

Results

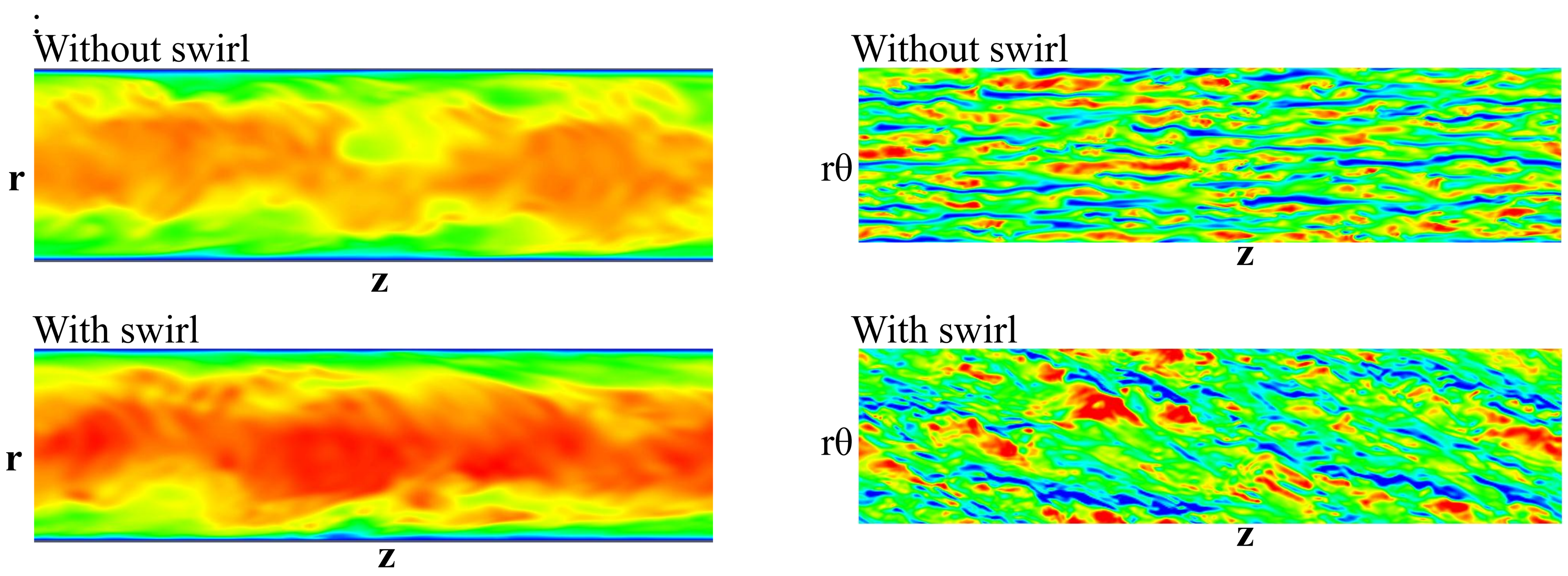
Academic approach: body force

A body force is inserted in the azimuthal momentum equation to induce a swirl. The force is designed to only be active in the near-wall region of the pipe as seen in the figure at the left below. Mean axial and azimuthal velocity profiles in pipe with and without a swirl are shown in the figure at the right. The turbulent mean axial velocity profile approaches the laminar profile compared to the case without swirl. The swirl induces a non-zero mean azimuthal velocity profile not present in a case without swirl :



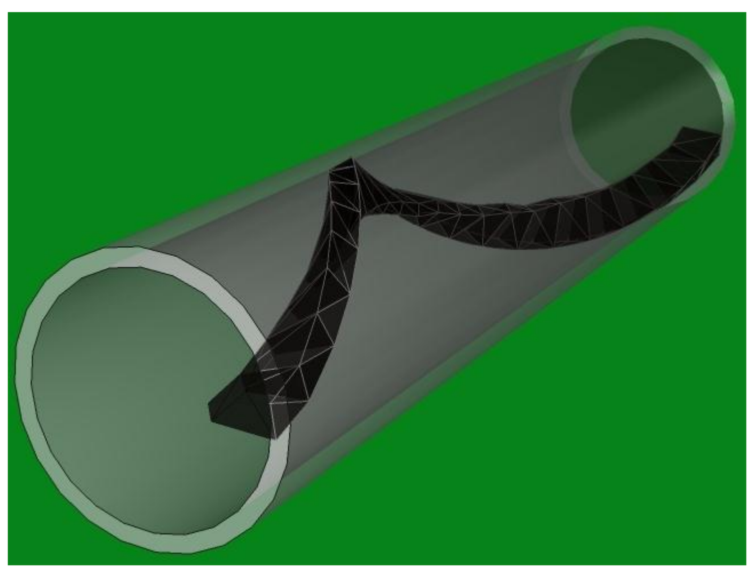


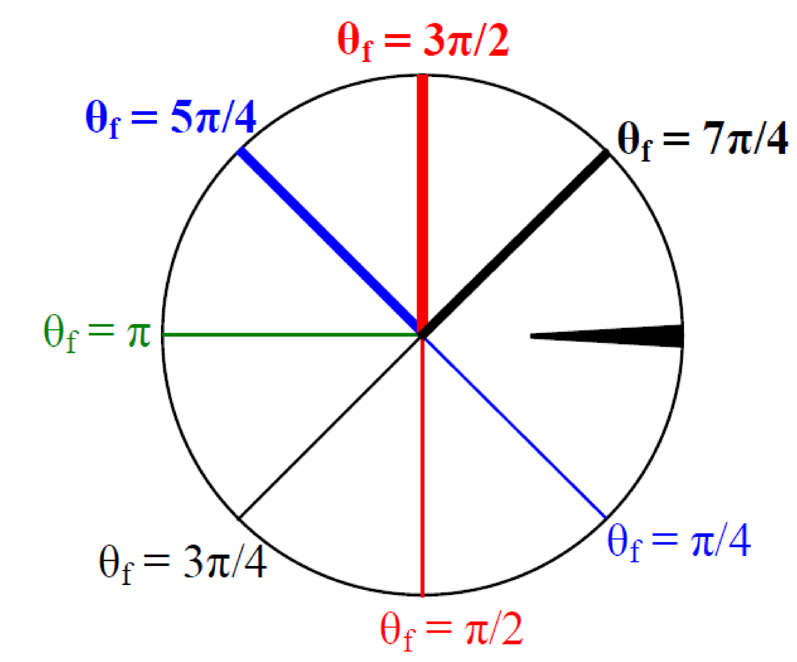
The velocity in the core region for the case with swirl is increased, here seen in the visualization of the instantaneous axial velocity in the figures at the left below. The high- and low- speed streaks are clearly seen as red and blue elongated structures in the case without swirl at the right figure. The swirl tilts the streaks, breaks the streaks into smaller parts, and increases the streak-width and the space between the streaks. This leads to an reduction in drag of about 6 %:



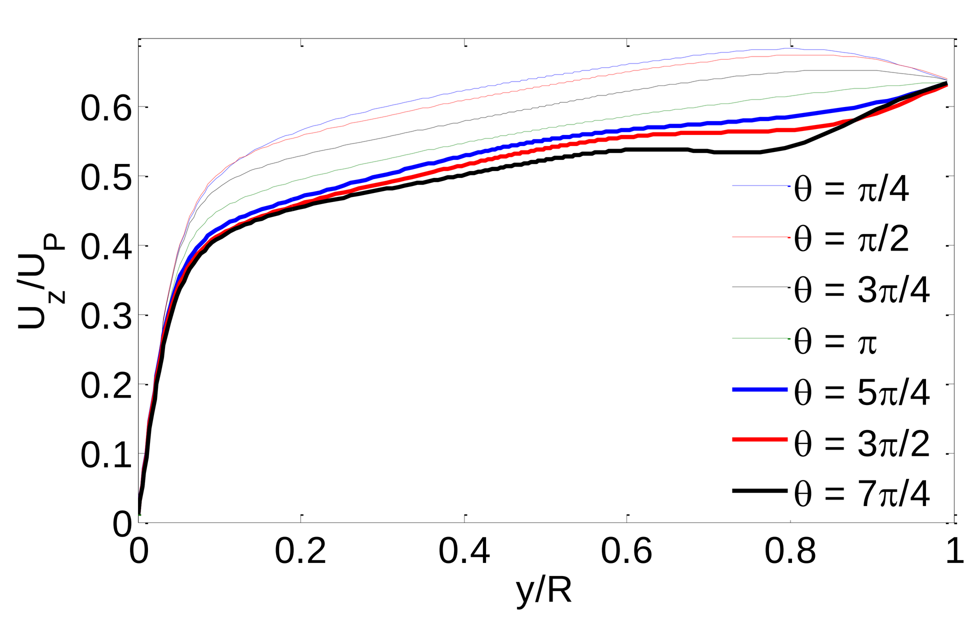
Practical approach: helical fin

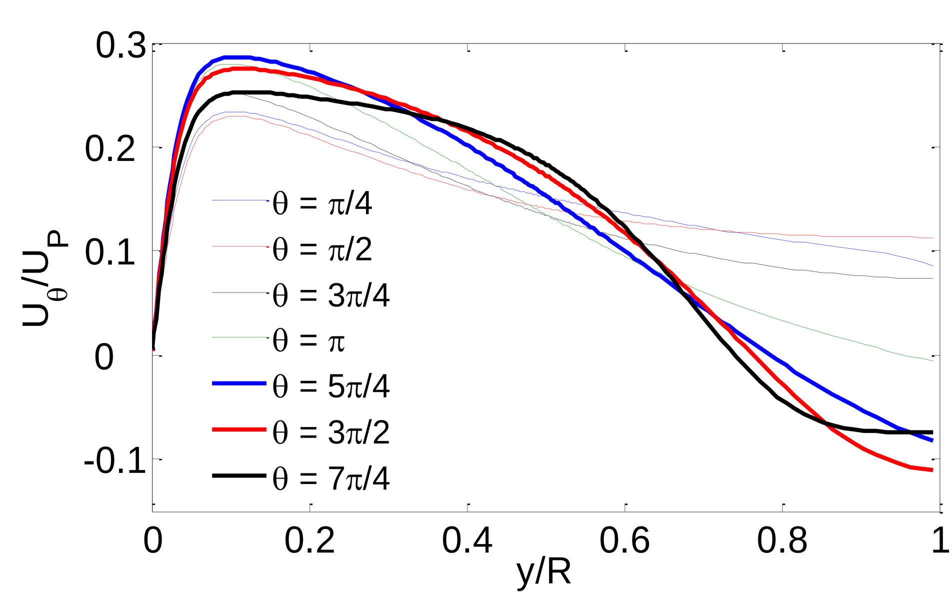
The swirl is induced by a helical fin at the pipe wall (see the left figure below) and the presence of the fin will result in a non-homogenous flow in the azimuthal direction. The positions in the r-θ cross section in the right figure below are correlated with the line formats in the figures showing the mean axial and the mean azimuthal velocities.



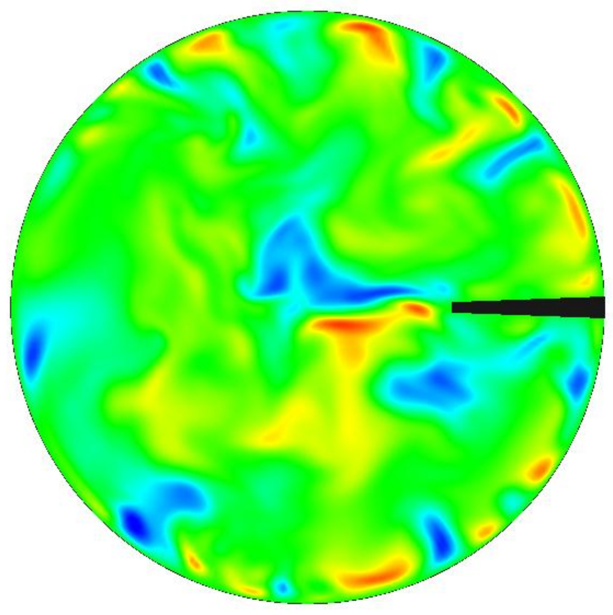


The presence of the helical fin breaks the symmetry around the centreline. The highest mean axial velocity is found to the right of the fin seen from the centre and the velocity is decreasing while moving clockwise. The highest azimuthal velocities are found in the near-wall region at the top left quarter of the r-θ cross section:





The streaks are seen as red and blue regions in the near-wall region in a r-θ cross section. Few streaks seen in the region $\pi/2 < \theta_f < 5\pi/4$ and this is found to correlate with the turbulent contribution to the friction coefficient. However no total drag reduction was achieved for this case due to the domination of the fin form drag:



Conclusions

- Two approaches to induce a swirl:
  1. Academic: Body force in the azimuthal equation
  2. Practical: Helical fin at the pipe wall

1. Academic approach: body force
   - The streaks are broken into smaller structures
   - Reduction of drag of about 6 %

2. Practical approach: helical fin
   - Streaks seem to be suppressed in certain azimuthal positions
   - However, no drag reduction achieved due to domination of the fin form drag

Frode Nygård, Statoil ASA, Norway

Helge I. Andersson, Fluids Engineering Division, Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU)

NTNU
Norwegian University of Science and Technology