Turbulence and Drag Reduction

Fluids Engineering Laboratory

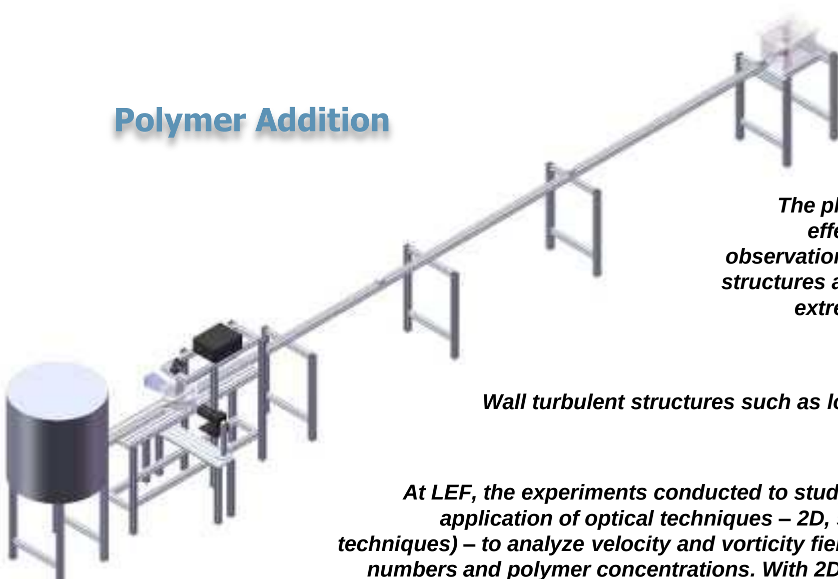
PUC RIO

There are countless systems in which it is desirable to reduce the friction caused by the flow of a fluid in contact with surfaces, as it is the case for airplanes, transport ducts, ships, among others. The potential efficiency increase in those systems makes the development of methods that can provide some reduction in drag fundamental.

The addition of polymers to the fluid and the use of modified surfaces are two of the methods employed in the industry which can achieve some degree of skin friction reduction in turbulent flows. The choice of mechanism depends on the restrictions and goals of each particular application. But, in any case, improving the physical understanding of the phenomenon is important not only for their application in a given practical situation or system, but can also help elucidate some academically interesting mechanisms concerning the turbulence itself.

At the Fluids Engineering Laboratory, these two methods for achieving reduction in drag for turbulent flows are experimentally addressed.

Polymer Addition

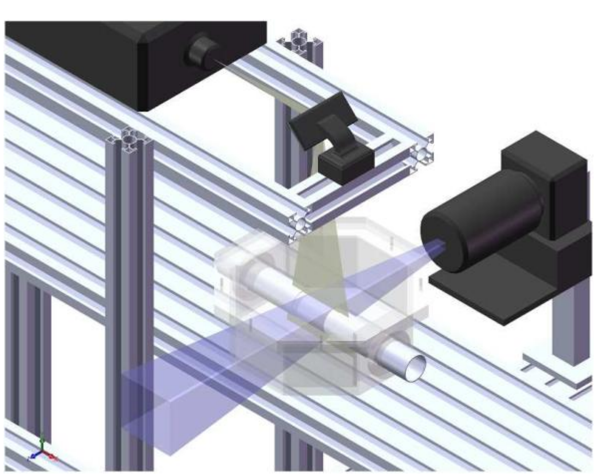


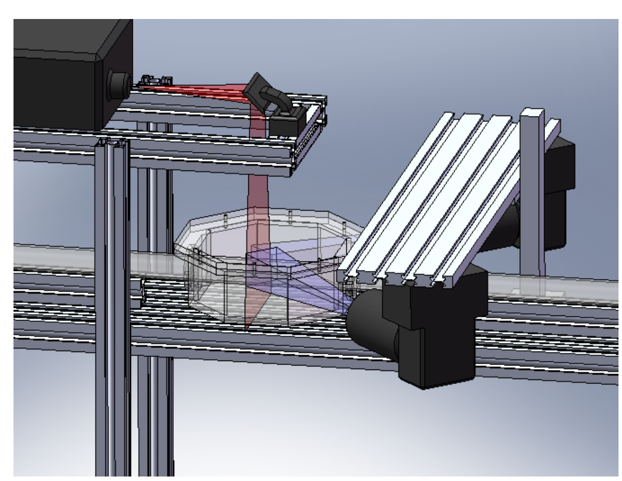
The addition of minimal amounts of long-chain polymers to turbulent flows can drastically (in some cases up to 80%) reduce pressure losses. This is, therefore, a powerful energy-saving resource in fluid transport applications.

The physical understanding of this phenomenon is crucial to ensure its effective and adequate application. From the academical standpoint, observation of how the interaction of polymeric molecules with the turbulent structures at the local level results in a global average reduction in drag is of extreme interest, and considerable scientific value for wall turbulence research.

Wall turbulent structures such as longitudinal vortices and velocity streaks are visibly modified, and so are the distributions of statistical flow quantities.

At LEF, the experiments conducted to study this phenomenon involve pressure drop measurements and the application of optical techniques – 2D, stereoscopic, and holographic PIV (see more about measurement techniques) – to analyze velocity and vorticity fields. Series of measurements are performed for different Reynolds numbers and polymer concentrations. With 2D and stereoscopic PIV, velocity fields in both the longitudinal and cross section planes of a tube can be obtained. As for the holographic technique, an experimental test section is mounted with the goal of investigating the dynamics strictly in the region very close to the wall, studying a small (2 x 2 x 2 mm^3) volume in the vicinity of the wall in a square channel flow.





Above: schematic drawings of PIV measurement stations. Left: 2D PIV for obtaining velocity fields in longitudinal tube plane; right, stereoscopic PIV measurements for three-component velocity field evaluation at a cross-section tube plane.

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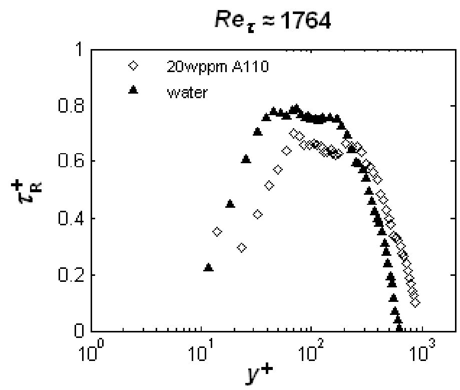
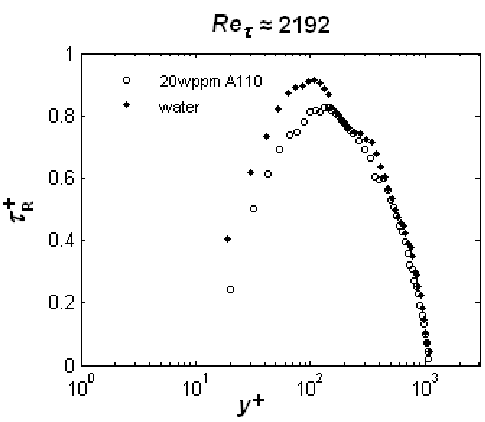
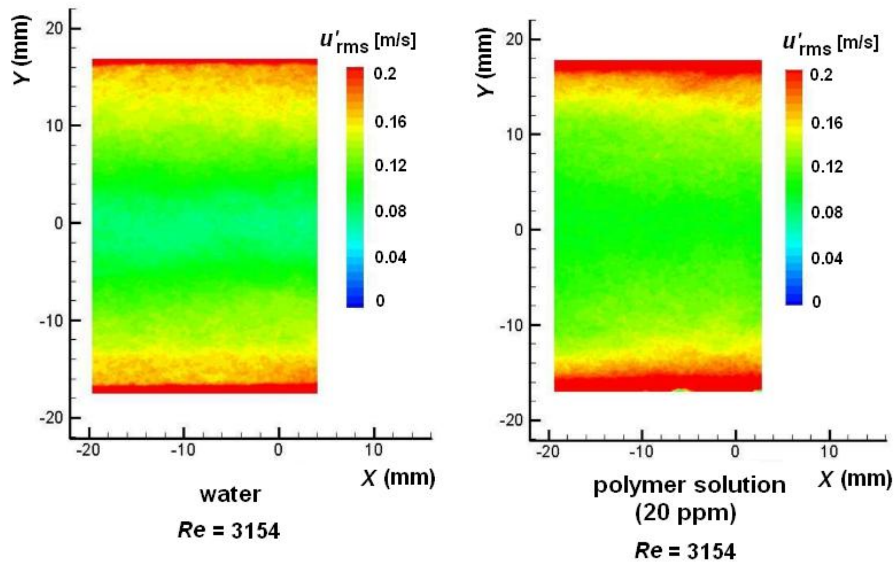
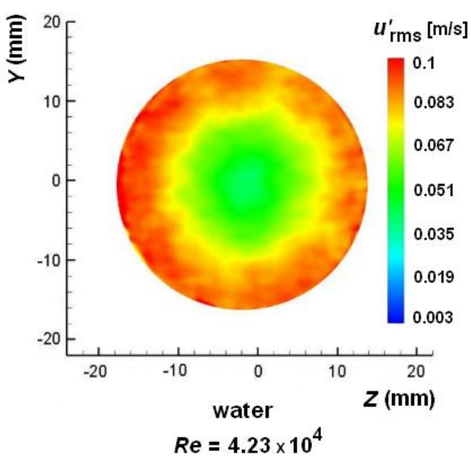


Left: dimensionless turbulent stress curves for pure water flow and with addition of polymeric (Superfloc A110) solution at 20 ppm.

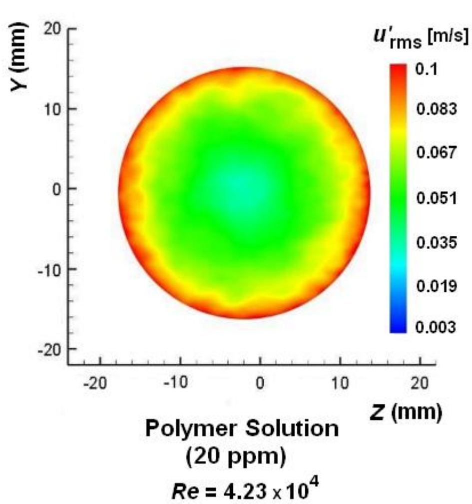


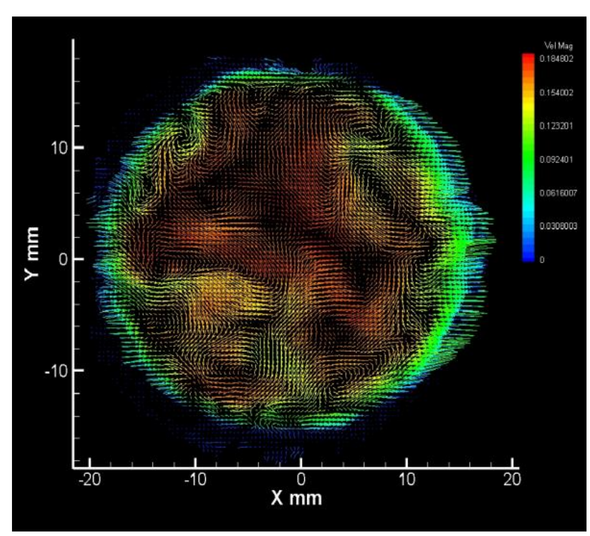
Below: contours of axial rms velocity fluctuation in longitudinal section of the tube.





Contours of axial rms velocity fluctuation in cross section of the tube (stereoscopic PIV).





Above: instantaneous, three-component velocity field obtained with stereoscopic PIV, coloured by velocity magnitude.

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Longitudinal Wall Riblets

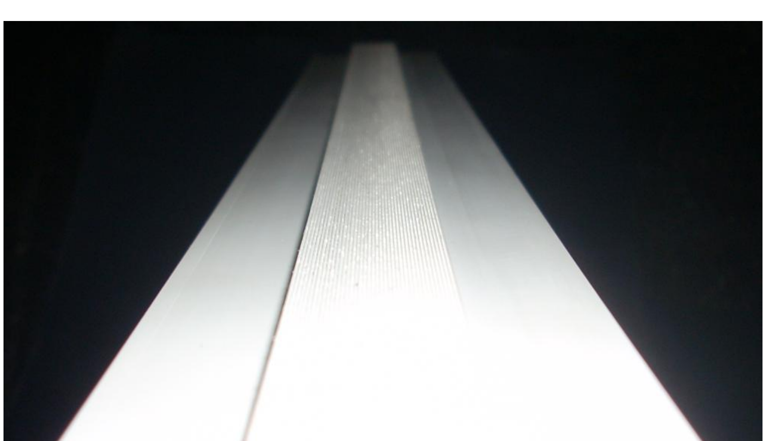
Left: closed flow circuit used for studying drag reduction by the use of longitudinal riblets. Channel cross-section is square, and riblets are machined in the top and bottom walls of the channel, only downstream of flow development region.

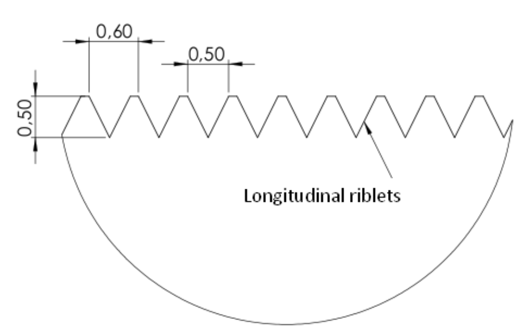
Among research works in turbulent drag reduction, the use of surfaces with longitudinal riblets is probably one of most investigated methods. These riblet patterns modify the near wall turbulent structures, specially longitudinal vortices , and if they have the adequate shape and size for the flow in question, they can generate an average drag reduction of 10% or even more. The use of riblets is interesting when the rheology of the fluid cannot be altered, but it is possible to modify the geometry of the surface (e.g., ships, airplanes, some transport lines, among others).

The experiments developed at LEF measure the pressure drop associated to the use of riblets in comparison to smooth walls, using whether micro-manometers or high precision thin membrane sensors. The channel has a square cross-section, and is designed for allowing 2D and 3D (holographic) PIV measurements in the interior of the riblets as well, using refraction index matching. Additionally, there is an interest in studying different kinds of surfaces, such as nano-posts and other supposedly hydrophobic surfaces.

Left: pressure taps distributed along the whole channel.

Right: micromanometer, specially designed for small pressure differential measurements in the riblets test section.





Left: photograph of the inferior channel wall, where small triangular-shaped longitudinal riblets (top) were machined.

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• Some of the equipment and infrastructure for turbulent drag reduction experiments at LEF:

✓Test section for three-dimensional velocity measurements in the very near-wall region of turbulent water flow: plexiglass, square cross-section (45 mm x 45 mm) channel, with length necessary for flow development before the measurement section. Designed to allow injection and mixing of polymeric solution with the main flow. It is instrumented with several pressure taps along the channel;

✓Plexiglass circular tube test section (D = 50 mm) designed for velocity field measurements in planar regions of the flow (longitudinal and transversal) by means of 2D and stereoscopic PIV, for developed turbulent (water) flows with and without the addition of polymers. Also instrumented with pressure taps for pressure loss measurements;

✓Plexiglass test section, with square cross-section (40 mm x 40 mm), and riblets in the bottom and top walls after development length. Designed for detailed pressure loss measurement, with closely spaced pressure taps along streamwise direction;

✓Centrifugal and volumetric pumps for several flow rate ranges, used for pumping main water flow and polymeric solution, respectively;

✓Motorized syringe for localized injection of particle solution;

✓2 TSI cameras with 4Mpx resolution and frame rate up to 15Hz;

✓2 High speed cameras IDT X3Pro with frame rate up to 3kHz;

✓Several data acquisition systems;

✓NdYAG lasers with 120 mJ per pulse;

✓High frequency laser with 10mJ/pulse @ 1kHz;

✓2-channel laser Doppler velocimetry system;

✓TSI hot wire anemometer;

✓Vibration-free optical table;

✓Optical components for laser sheet formation in 2D ou stereoscopic PIV, and for generation of good quality holographic images in the case of HoloPIV: mirrors, filters, spherical and cylindrical lenses, beam splitters, polarizers, among others;

✓Equipment for pressure (Validyne membrane sensors, manometers and micro-manometers, other high precision transducers), flow rate (rotameters, magnetic and turbine meters) and temperature measurements;

✓Tanks of all sizes;

Partnerships

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