AIRCOAT

Drag reduction by air retaining surfaces

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In Short

- Drag reduction
- Air retaining surfaces
- Direct numerical simulation
- Turbulent channel flow

Figure 1: *Water drop on Salvina molesta.*

Transport of goods by ships or of liquids in pipes and channels are linked with energy demand. In case of ships, motors drive propellers, in the second example pumps maintain the flow of liquids. Both, motor and pump require energy, which can be of fossil/biological origin or come from renewable sources. A reduction of energy demand leads to lower CO_2 emissions or to lower installed power of wind turbines/photovoltaic plants.

Origin of the energy demand is the momentum transfer between the liquid and the ship hull, inner pipe/channel surface, which can be expressed in form of the wall shear stress. Due to the no-slip condition of the fluid at the wall, the fluid undergoes deformations with time in the near wall region. Depending on the viscosity of the fluid and the type of the flow (laminar/turbulent), this shear rate leads to a force tangential to the surface. Related to the surface one obtain the wall shear stress.

Several attempts have been undertaken to reduce the wall shear stress such as structured surfaces (riblets) or the injection of gas bubbles/polymers to reduce turbulent momentum transfer to the wall. A further approach, applicable to laminar and turbulent flows, is the installation of an air layer at the wall. Due to the different viscosities of the liquid and the gas, the wall shear stress is reduced and a drag reduction in comparison to the single phase flow appears. It can yield values of 10% and higher [1].

Such an air layer can be realised by permanent injection of air or by a surface structure to retain air. The latter case features lower operational energy demand and is considered in this proposal. The general ideas for a surface structure is taken from nature: The water fern *Salvinia molesta* realises air retention by a structure of pillars with hydrophobic shafts and hydrophilic tips. The former prevent water to penetrate into the structure, the latter the leaving of air, see Figure 1.

In comparison to a pure air layer the structure diminishes the drag reduction, which depends on the geometry, the size, and the ratio of air liquid interface to total surface of the structure. This proposal is part of the EU project AIRCOAT and focuses on the investigation of wall shear stress in turbulent channel flows for different structure geometries using Direct Numerical Simulation (DNS). The effect of the air is considered by modelling the liquid air interfaces at the channel walls by a slip condition, well established in literature [1–4]. Hence, the flow in the air layer is not calculated. Instead one phase flow simulations of the liquid in the channel are carried out. The surface of the liquid air interface and the tips of the structure are assumed to form a plane channel wall. This approach does not allow predictions of air retention but enables insight concerning the influence of shape and size of the structure on the wall on shear stress/drag reduction and the involved mechanisms in the turbulent flow.

In own numerical simulations with discretisation of second order in space and time, different geometrical structures, sizes of $79 \leq L^+ \leq 236$ at the friction Reynolds number $Re_\tau = 180$ and 300 an increase in drag reduction was found for structures in the order: no structure, grooves in spanwise direction, holes, pillars, grooves in streamwise direction. The averaged wall normal velocity profiles are shifted to higher velocities due to an increase in slip velocity at the wall and get flatter because of an increase in turbulent momentum transfer, see Figure 2. Right up into the logarithmic domain components of the Reynolds stress tensor and of terms of the transport equation for the Reynolds stress tensor deviate considerably from those of ordinary channel flow also reported by [1,4]. Furthermore, the latter terms partially show complex progressions down to wall normal distances of $y^+ < 0.1$. To the knowledge

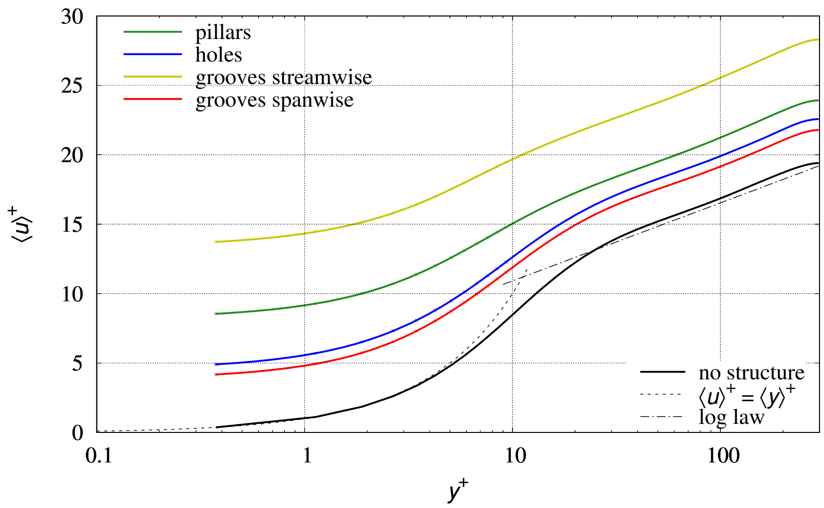

Figure 2: *Averaged velocity profiles for different surface structures, structure size $L^+ = 79$ and $Re_\tau = 300$ in wall units.*

of the authors this has not been reported in literature so far and enables the understanding of the mechanisms of turbulence production, distribution and dissipation in the very near wall region. It has to be assumed that the latter phenomena strongly influences the wall shear stress at the tips of the pillars and therefore the total drag of the surface. A grid study and the application of different codes indicates: For a proper resolution of these findings a minimum grid resolution at the wall in wall normal direction of $y^+ = 0.01$ and higher order discretisation in space are necessary in future investigations.

In this proposal we intend to investigate

- four shapes of structures (squared pillars, grooves in stream- and spanwise direction, holes) with sizes of $20 \leq L^+ \leq 80$ at uniform ratio of slip / total surface at $Re_\tau = 180$. Except $L^+ = 80$, the sizes of the structure are smaller compared to the previous investigations, due to a practical reason: In experiments smaller L^+ are applied to increase the ability of the structure to retain air. With $Re_\tau = 180$ the minimum possible value is chosen to restrict the computational costs. Own investigations show similar behaviour of the Reynolds stress tensor with y^+ for $Re_\tau = 180$ and 300, which is in accordance with literature [1].
- using a high order spectral finite element code ([7], 7th order in space (velocity), 3rd order in time) with a minimal spatial resolution at the wall of $y^+ = 0.01$.

From the results we

- receive for the first time precise and comparable data of different geometrical structures and sizes at a single surface ratio and Re_τ.
- deliver benchmark data for scientific use, to be stored in respective data bases.
- get insight to the impact of the surface orientations and distributions (slip/no-slip) on production, transport, redistribution and dissipation of turbulence in the wall region as well as on wall shear stress and drag reduction.
- intent to suggest new geometries of surface structures to lower the wall shear stress.

WWW

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More Information

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Funding

Horizon 2020 EU project AIRCOAT (grant agreement N° 764553)