**Influence of vortex generators in a turbulent boundary layer on local friction and transport**

**Slide 2.** The concept of boundary layer was first used on August 12, 1904 by Ludwig Prandtl in an article at the third International Congress of Mathematicians in Heidelberg, Germany. **Boundary layer** - the area of the flow of a viscous fluid with a small transverse thickness compared to the longitudinal dimensions, which is formed near the surface of a streamlined solid body or at the interface between two fluid flows with different velocities or temperatures.

**Slide 3.** There are three types of flow in the boundary layer, each of which has its own characteristics and some of them are quite complex for numerical simulation:

* laminar – the movement of the fluid is ordered, the layers do not mix, the particles rotate within the same thin layer;
* turbulent – the motion is disordered; particles are mixed in the transverse direction and the entire boundary layer is randomly swirling;
* mixed – transitional state from laminar to turbulent motion.

The laminar flow is stable only under certain conditions determined by the value of the critical Reynolds number 𝑅e𝑐𝑟.

Usually, the transition from laminar to turbulent fluid flow in pipes is observed at 𝑅𝑒𝑐𝑟≈2300. The value of the critical number can be influenced by such factors as pressure gradient, channel shape, roughness of its walls, injection and pumping of boundary layer.

**Slide 4.** Ideas about the structure of the velocity profile gradually changed and were finally formed by the end of the 1950s. In a boundary layer there are two main regions. They differ from each other by different scales of vortex structures (inner (log-law, buffer, viscous) and outer). The inner region of the boundary layer occupies approximately 20% of the thickness of the entire layer and generates up to 80% of the turbulence energy in it.

**Slide 5.** Dimensionless quantities are usually used in order to work with the boundary layer. The thickness of the boundary layer is difficult to determine both in the calculation and in the experiment. The Reynolds number is characterized by distance from bottom wall The friction stress on the wall, Using the friction stress on the wall we can obtain the coefficient of friction, .

**Slide 6.** Despite the intensive development of computer technology and the impressive progress achieved in recent years, the problem of numerical simulation of turbulence remains one of the most complex problem. Among the main methods of numerical simulation of three-dimensional turbulent flows are: direct numerical simulation (DNS), simulation of large eddies (LES) and solution of Reynolds averaged Navier-Stokes equations (RANS). There are also various intermediate approaches that combine certain features of RANS, LES, and DNS, for example, the detached eddy modeling method (DES), and a number of others that do not have a proper physical justification and, therefore, are not widely used.

**Slide 7.** In computations Large Eddy Simulation method was used. LES method was proposed by Smagorinsky in 1963. The principal idea of LES is to reduce the computational cost by ignoring the smallest length scales, which are the most computationally expensive to resolve, via low-pass filtering of the Navier–Stokes equations. This filters called sub grid scale models. The LES solution contains richer information than the RANS. This advantages allowed to use this method in different tasks.

**Slide 8.** The channel is divided into two parts. The first part with curvature Its length is 396 mm. It contains barrier, with a radius of 2.1 mm and height of 1.98 mm. The second part is straight. Its height is 50 mm, width 124 mm and length 1100 mm. The general length of the channel is 1496 mm. The barrier creates turbulent state.

**Slide 9, 10.** The most important part of any numerical simulation is the creation of a sufficiently detailed grid model. A schematic plan for generating mesh was used. It helps to speed up mesh constructing and build high quality model. Also it was found, that disabling the multithreading mode (one physical core is divided into two virtual ones) for the processor increases performance, since all the power of the core is used, and not half of it. With information mentioned earlier, was created mesh model. It helps us to achieve optimal results of calculations. The model of the channel was divided into 4 parts. Its mesh consists of 51,397,337 nodes and 12,665,608 elements.

**Slide 20.** Q-criterion is one of the approaches to visualize vortex flow. It is defined as the second invariant of the velocity gradient tensor. where S – strain rate tensor and (omega) – rotation tensor.