The use of red blood cells to map wall shear and flow separation

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Abstract

Laminar flow boundary layer separation in channel flow has been experimentally and numerically investigated. An experimental method was developed incorporating the use of wall-attached and dispersed canine red blood cells to quantify the local wall shear stress, and to determine the presence and location of flow separation and attachment. A master curve relating wall shear stress to attached cell elongation was generated. Measurement of the cell elongation was accomplished via image analysis software, which lent to the accuracy and sensitivity of the method. Parallel plate flow experiments were performed using obstacle geometries that lead to both two- and three-dimensional flow separation. Using this experimental technique the existence of flow separation, location of flow separation and attachment, and magnitude and direction of the local wall shear stress were all accurately quantified as functions of the Reynolds number. Computational fluid dynamics simulations of the flow experiments were performed, the results of which exhibited close quantitative agreement with the experiments. Numerical and experimental results were used to examine unresolved issues in three-dimensional flow separation. The results support the hypothesis that, for three-dimensional separation, there is no explicit mathematical link between the location of the surface separation line and the magnitude of the local wall shear stress. It was observed that singular separation and attachment points were accompanied by vanishing normal components of the wall pressure gradient. It was verified by the experiments that ordinary flow separation lines originate from singular separation points.

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