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Dynamics and Vibroacoustics of Machines

Reducing friction drag on flat plates

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Abstract

There are in existence several methods of boundary layer control which have been developed for the purpose of reducing friction drag of streamlined bodies. These include such elements as acceleration of the boundary layer (blowing), injection of a different gas, cooling of the wall, etc. All of them are described in some detail in scientific literature. In this paper, a new method for the reduction of friction drag, which has been insufficiently studied. The proposed method is based on the use of a liquid film on the surface of the streamlined body. One solution to the problem of the flow over a flat semi-infinite plate set at an angle of deflection to the horizon, and having a thin liquid film on its surface by external airflow is presented. The film is formed at the plate in the form of raindrops. Liquid moves by gravity and friction on the outer surface of the film. Influence on the boundary layer raindrops and thermal effects are ignored. In general, the problem is conjugate, including the problem of a film flow (internal problem) and the problem of the boundary layer of incoming air (external problem). For the solution of the dual problem, a method of successive approximations was used. This method assumes the fact that the external and internal problems can be solved separately, either logically or iteratively. At each new approximation, the inner problem is solved with regard to the friction resulting from the external problem; the solution of which, in turn, takes into account the speed at the boundary surface, obtained from the previous approximation of the interior problem. Thus, the iterative process continues until the speed and, consequently, the friction at the phase interface change little from iteration to iteration. For the interior problem, the method of asymptotic expansion in a small parameter was used. This paper gives null and first approximation. The external problem was solved using the numerical method of finite differences. In this paper we present some results showing the reduction of friction drag on the flat plate.

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Keywords: flat plate; boundary layer; liquid film; friction drag; conjugate problem

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1. Introduction

It is known that a liquid film on the surface of a body blown over by an airflow changes characteristics of the boundary layer. The works [1, 2] and [3] present two-media boundary layers, when a fluid of one type is present or added in a wall-adjacent region and the whole system is placed in an incoming flow of a liquid of another type. In [3] the question regarding assessment of a possible gain in resistance due to introduction of a liquid to the boundary layer, (mixing with the surrounding liquid due to diffusion and convection), counting of the required consumption of the liquid is considered.

However, this phenomenon remains insufficiently studied to date. Note: several publications exist on this issue recently. In [4] and [5] two-media boundary layer when the media don't mix are considered. It is assumed that applied through a streamlined surface, the medium is enclosed in a thin region where of the longitudinal velocity distribution can be considered linear. In [4] the method of integral relations in the case of flow over a flat plate is used, whereas in [5] a method of finite differences for an arbitrary body is developed.

This paper [6] provides a solution to the problem of a flow over a flat semi-infinite plate set at an angle to the horizon, and having a thin liquid film spread on its surface by external airflow. The film is formed by extrusion of liquid from the porous wall. In [7] the film is formed from the external environment (e.g. raindrops. Influence on the boundary layer of raindrops and thermal effects are ignored). The mathematical model for zero-order approximation is obtained. This paper gives null and first approximation.

We consider a steady-state flow of a non-Newtonian liquid film with a variable thickness on a flat plate under the influence of an incoming air flow, velocity vector of which coincides with the plate plane (Fig. 1). Let us suppose that the plate is at α angle to the horizon. Then a liquid flows due to gravity and friction on the outer surface of the film.

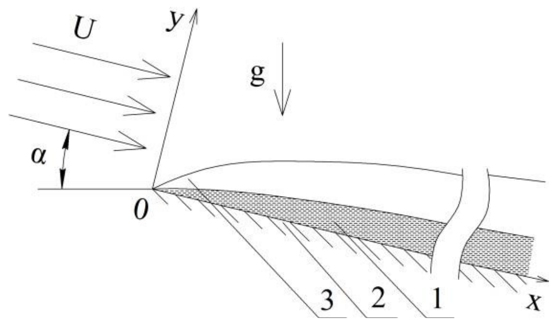

Fig. 1. Flow diagram: 1 – film; 2 – plate; 3 - boundary layer; U – incident flow velocity; g – free fall acceleration; α - angle of inclination of the plate to the horizontal; x and y - Cartesian axis

Let's define the influence of the film on the friction value in the boundary layer. In general, the problem is conjugate, including the problem of a film flow (internal problem) and the problem of the boundary layer of incoming air (external problem). To solve the dual problem, a method of successive approximations is used. The method consists of the fact that the external and internal problems can be solved separately, either logically or iteratively.

At each new approximation, the inner problem is solved with regard to the friction resulting from the external problem; the solution of which, in turn, takes into account speed at boundary surface, obtained in the previous approximation from the interior problem. Thus, the iterative process continues until the speed and, consequently, the friction at the phase interface change little from iteration to iteration. Let the film thickness $\delta_1 \approx 10^{-4}$ *m*, and imposition of the film change the geometry of the plate slightly. Therefore, to solve the external problem the film surface curvature can be neglected.

2. Task of boundary layer

A mathematical formulation of the external problem includes motion, continuity and thickness equations in the approximation of the boundary layer (index "3" corresponds to the boundary layer, index "1" - to the film) [7]