SOI: 1.1/TAS DOI: 10.15863/TAS
International Scientific Journal
Theoretical & Applied Science

p-ISSN: 2308-4944 (print) **e-ISSN:** 2409-0085 (online)

Year: 2023 **Issue:** 04 **Volume:** 120

Published: 26.04.2023 **http://T-Science.org**

Issue **Article**

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INVESTIGATION OF THE FORMATION OF KARMAN VORTEX STREETS IN HYDRODYNAMICS

***Abstract**: The analysis of the results of computer modeling of the process of fluid flow around the cylinder in order to determine the intensity of the action of Karman vortex streets at different Reynolds numbers was carried out in the article. It is determined that vortex streets are formed at the initial velocity of fluid flow from 1.0 m/s and higher. The greatest difference in the calculated frequencies of vortex formation of flows is observed in the range of initial fluid flow velocities from 0.1 to 1.0 m/s. The values of the drag coefficient decrease with an increase in the initial velocity of fluid flow and do not change further in the range from 1.0 to 10.0 m/s. The values of the lift coefficient increase with an increase in the initial velocity of fluid flow.*

***Key words**: cylinder, fluid, vortex street, flow velocity, drag coefficient, lift coefficient.*
***Language**: English*
***Citation**:* Chemezov, D., et al. (2023). Investigation of the formation of Karman vortex streets in hydrodynamics. *ISJ Theoretical & Applied Science, 04 (120),* 256-261.
***Soi**:* http://s-o-i.org/1.1/TAS-04-120-48 ***Doi**:* crossref https://dx.doi.org/10.15863/TAS.2023.04.120.48

***Scopus ASCC**: 1507.*

Introduction

Transient and turbulent flow modes of fluid or gas are characterized by active mixing of flows and the formation of vortices [1]. The formation of these flow modes is facilitated by various hydraulic resistances placed in the direction of fluid or gas movement.

Karman vortex street is a regular system of discrete swirling fluid or gas flows formed behind a streamlined solid. This phenomenon was discovered by Theodor von Karman in 1911, followed by a series of experiments to describe the formation of vortex streets when fluid flow around the circular cylinder and the flat plate [2]. The research topic has found great interest in the scientific community and has been reflected in a number of scientific papers [3-10].

The intensity of the formation of vortex streets depends on the Reynolds number. It is theoretically determined that when the Reynolds number is more than 30, the separated zone of fluid flows from the surface of the streamlined solid is destroyed. The flow process becomes unstable, fluid flows break away from the streamlined solid alternately from opposite sides in the form of vortices. The frequency of stall of vortex flows increases with increasing fluid flow velocity. This effect can lead to vibrations of the streamlined solid.

The purpose of this study was to determine the effect of the intensity of the formation of Karman vortex streets on the hydrodynamic characteristics of the streamlined solid.

Materials and methods

The process of fluid flow around the circular cylinder was studied.

The initial velocity of fluid flow was assumed to be 0.1, 1.0, 5.0 and 10.0 m/s to compare the experimental results. Water having properties under normal conditions was taken as a fluid.

The experiment was performed in a two-dimensional formulation to reduce the calculation time of the process in the Comsol Multiphysics program. On some area of the rectangle that imitated the water space, the area of the circle that imitated the circular cylinder was subtracted. The cylinder was assumed to be a solid with a boundary condition for the surface (no slip). The fluid model moved in two-dimensional space from left to right for 5 seconds.

The calculation area was transformed into a grid with small finite element sizes, which allowed to obtain more accurate results.

Results and discussion

The values of the Reynolds numbers for each calculation were determined in the following ranges:

a) 0.1 m/s – 0…0.422;
b) 1.0 m/s – 0…4.64;
c) 5.0 m/s – 0…24.3;
d) 10.0 m/s – 0…52.4.

The results of computer modeling are presented by the contours of the direction and vorticity of fluid flow during the flow around the cylinder in the Figs. 1 and 2.

Fig. 1 shows that for the given initial velocities of fluid flow, a vortex street is formed already at 1.0 m/s. The first phase has different amplitudes of vortex flows after flow around the cylinder. Further, the process of formation of vortex streets stabilizes and remains constant with a gradual decrease in intensity. At a fluid flow velocity of 0.1 m/s, vortex streets are not observed, but the fluid layers are mixed after flow around the cylinder. Stagnant zones are formed on the reverse side of the cylinder under conditions of the formation of vortex streets.

The shape of vortex streets at the initial fluid flow velocities of 5.0...10.0 m/s is the same. With an increase in the initial velocity of fluid flow, the frequency of vortex formation increases in accordance with the calculated values on the scale. At the same time, low velocities of fluid flow around the cylinder create a high intensity of vortex formation on the frontal part of the cylinder. The greatest frequency of vortex formation at high fluid flow velocities is observed in the separated zone of flow from the cylinder surface.

Changes in the drag coefficient and the lift coefficient from the time of the process are presented in the Figs. 3 and 4.

The dependencies of the drag coefficient of the cylinder when flowing around it with fluid confirm the conclusions presented above. At low fluid flow velocities, the drag coefficient reaches a maximum value of 12.5 ($m^2 \times s^2/kg$) at the first second of the process and subsequently decreases to 8.0...9.0 ($m^2 \times s^2/kg$). At high fluid flow velocities, the drag coefficient decreases to 3.0 ($m^2 \times s^2/kg$). The initial velocity of fluid flow over 5.0 m/s leads to pulsation of flows and subsequent fluctuation of the coefficient values within 3.0 ($m^2 \times s^2/kg$).

The values of the lift coefficient increase with an increase in the initial velocity of fluid flow. The largest amplitude of fluctuations of the coefficient values was determined at 3.5 seconds of the process for all cases. A significant change in the values of the lift coefficient occurs in the range of fluid flow velocities from 0.1 to 1.0 m/s. The minimum change occurs in the range from 5.0 to 10.0 m/s. The lift coefficient in conditions of the formation of vortex streets has both positive and negative alternating values. The coefficient has negative values for conditionally laminar fluid flow.

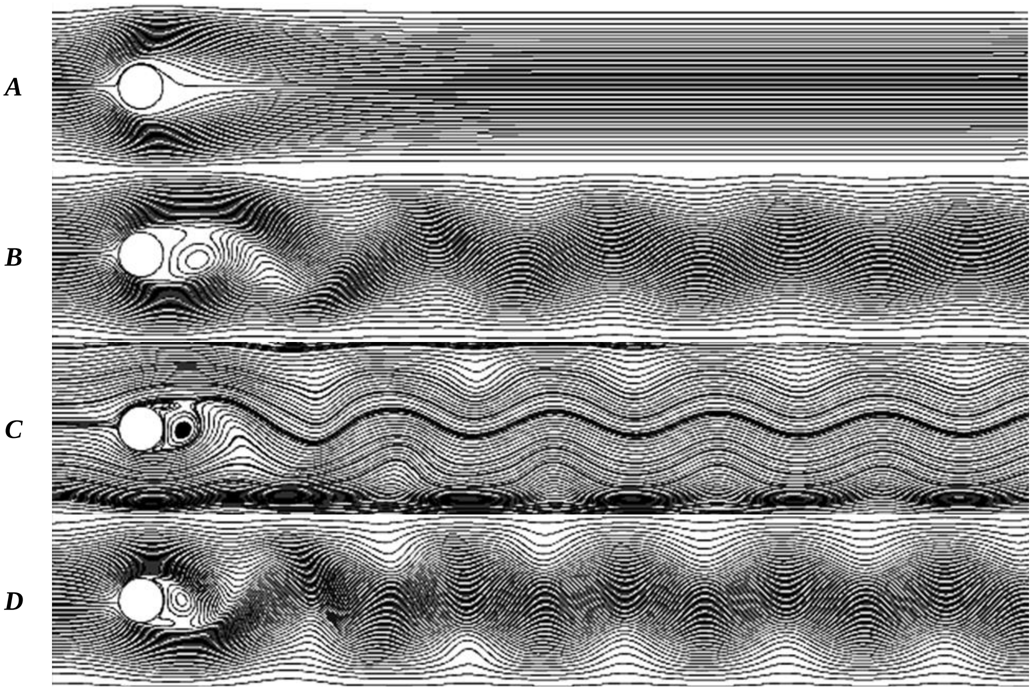

Figure 1 – The direction of fluid flows when fluid flow around the cylinder: (*A*) the initial velocity is 0.1 m/s; (*B*) the initial velocity is 1.0 m/s; (*C*) the initial velocity is 5.0 m/s; (*D*) the initial velocity is 10.0 m/s.

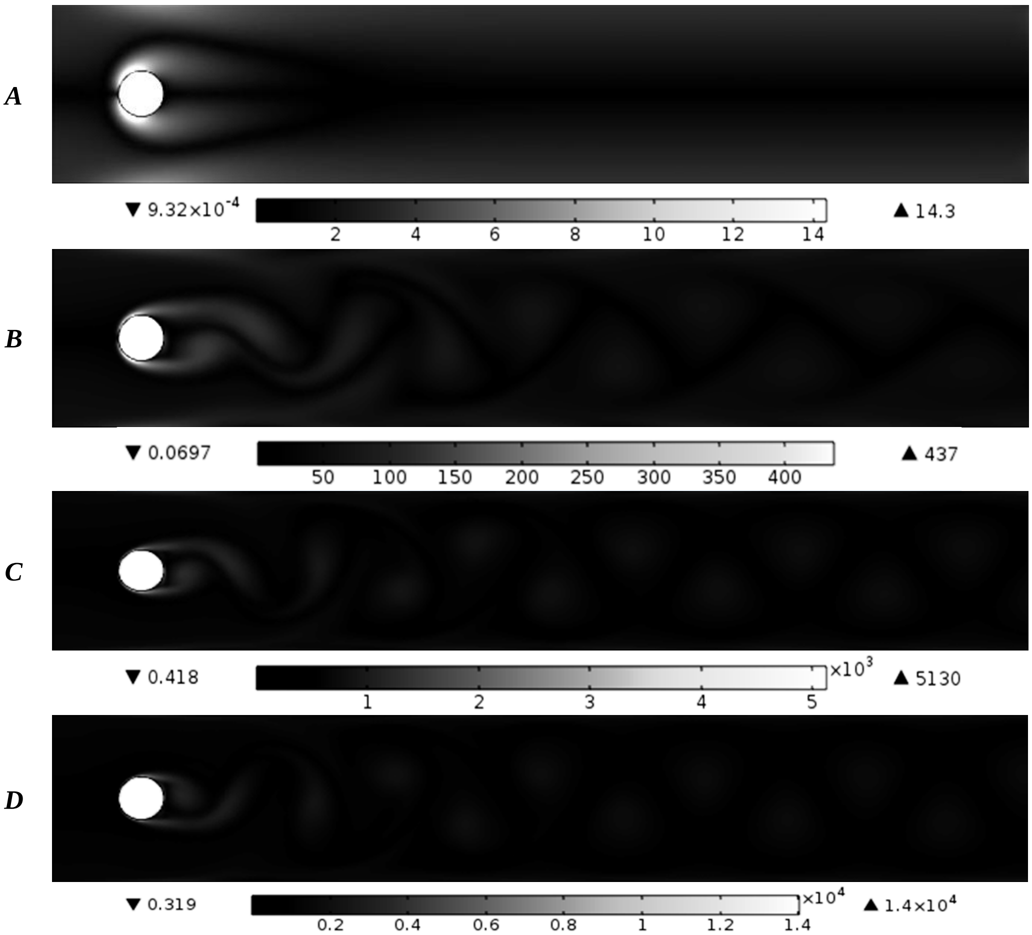

Figure 2 – Vorticity of fluid flow when fluid flow around the cylinder: (*A*) the initial velocity is 0.1 m/s; (*B*) the initial velocity is 1.0 m/s; (*C*) the initial velocity is 5.0 m/s; (*D*) the initial velocity is 10.0 m/s. The unit of measurement is 1/s.

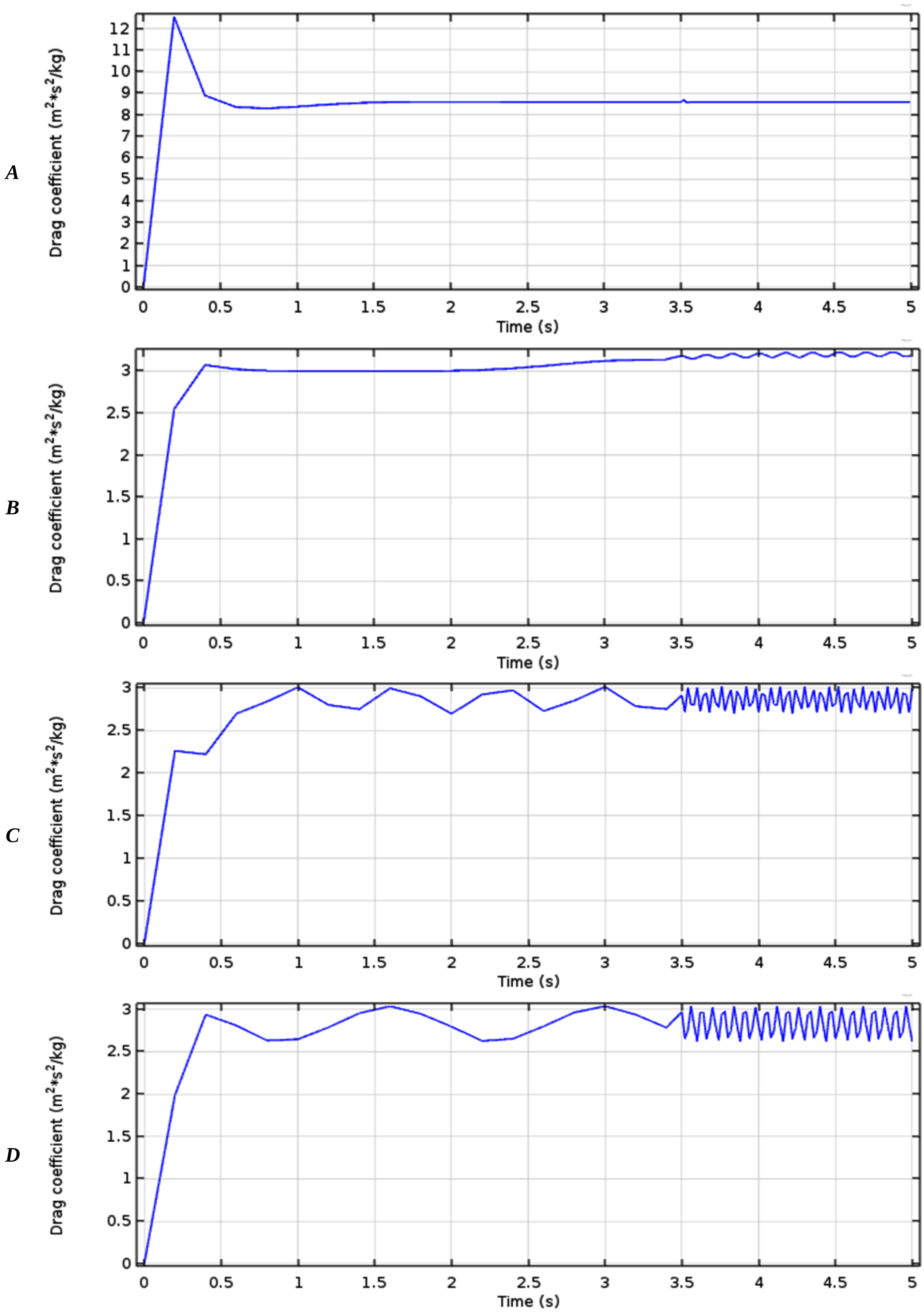

Figure 3 – The change in the drag coefficient from the time of fluid flow around the cylinder: (*A*) the initial velocity is 0.1 m/s; (*B*) the initial velocity is 1.0 m/s; (*C*) the initial velocity is 5.0 m/s; (*D*) the initial velocity is 10.0 m/s.

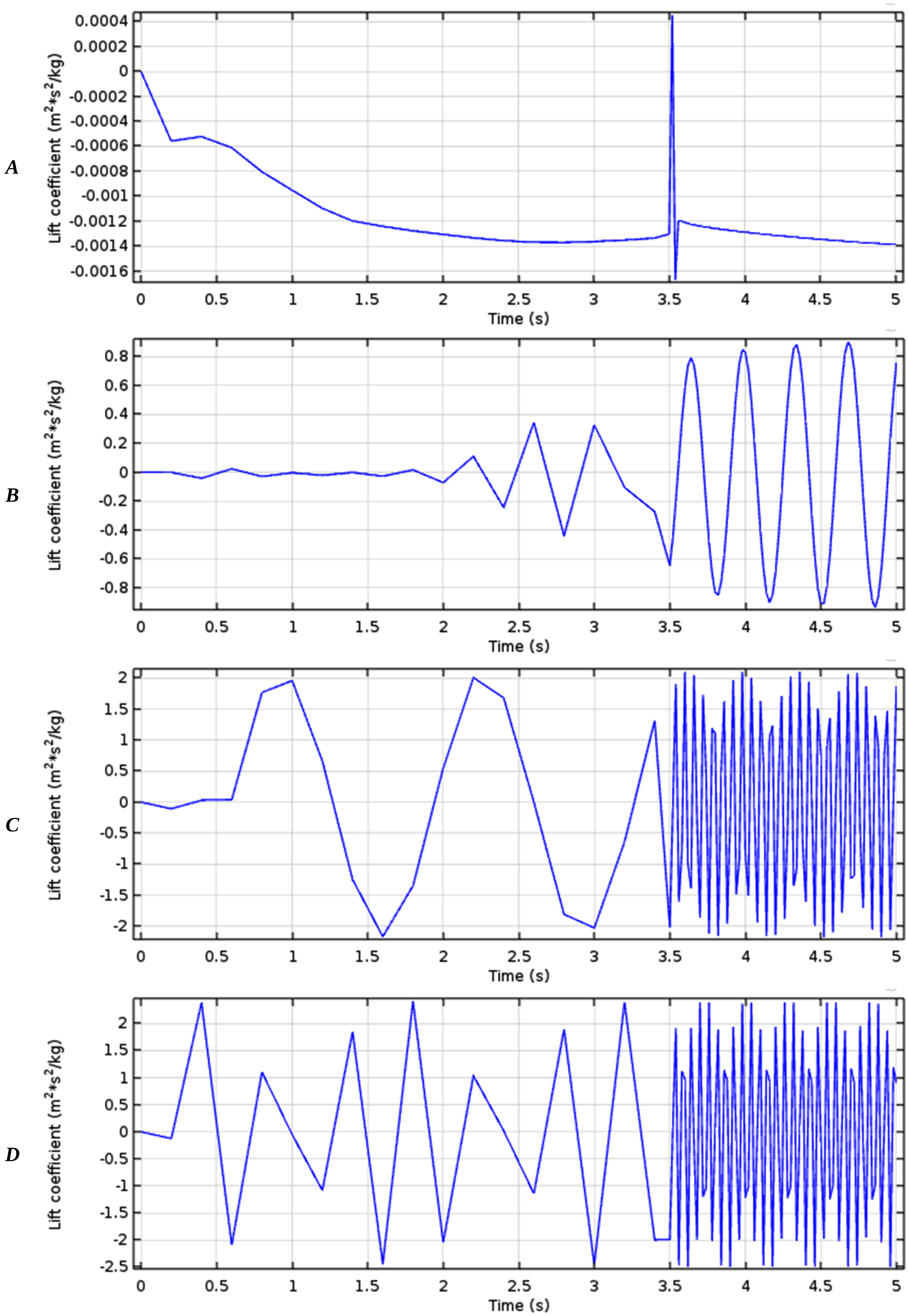

Figure 4 – The change in the lift coefficient from the time of fluid flow around the cylinder: (*A*) the initial velocity is 0.1 m/s; (*B*) the initial velocity is 1.0 m/s; (*C*) the initial velocity is 5.0 m/s; (*D*) the initial velocity is 10.0 m/s.

Conclusion

Thus, based on the analysis of the results obtained, the following conclusions can be drawn:

1. Karman vortex street is formed in the range of initial velocities of fluid flow around the cylinder from 0.1 to 1.0 m/s.

2. The intensity of vortex flows on the frontal surface of the cylinder decreases with an increase in the initial velocity of fluid flow.

3. At low velocities of fluid flow around the cylinder, the drag coefficient reaches its maximum value and maintains high values over the entire time range of the process. At the other considered fluid flow velocities, the drag coefficient has the same values, which vary in a small range.

4. The value of the lift coefficient increases with an increase in the initial velocity of fluid flow. The coefficient changes cyclically with the achievement of positive and negative maxima in a short time interval.

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