

## Accepted Manuscript

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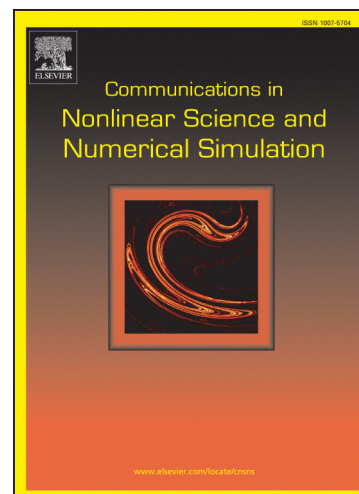
PII: S1007-5704(14)00361-X  
DOI: <http://dx.doi.org/10.1016/j.cnsns.2014.07.028>  
Reference: CNSNS 3295

To appear in: *Communications in Nonlinear Science and Numerical Simulation*

Received Date: 4 December 2013  
Revised Date: 22 July 2014  
Accepted Date: 28 July 2014

Please cite this article as: Lei, P., Zhang, J., Li, K., Wei, D., Study on the Transports in Transient Flow over Impulsively Started Circular Cylinder using Lagrangian Coherent Structures, *Communications in Nonlinear Science and Numerical Simulation* (2014), doi: <http://dx.doi.org/10.1016/j.cnsns.2014.07.028>

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## Study on the Transports in Transient Flow over Impulsively Started Circular Cylinder using Lagrangian Coherent Structures

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**Abstract:** The material transport in transient flow over impulsively started circular cylinder is studied from Lagrangian point of view, in order to understand the nature of some complex transient phenomena. The transient flow is simulated numerically by CBS scheme with dual time stepping. Then, the transport processes during the development of separation bubbles and vortices are analyzed in terms of Lagrangian coherent structures (LCSs), in order to understand the transport and mixture in the transient phenomena and their contributions to the aerodynamic performance of circular cylinder. Results show that the transport processes in the transition flow are well described by the LCSs. In particular, at the beginning stage of formations of flow separation and vortex, the transports between main flow and separated flow are strong, and the aerodynamic performance of circular cylinder can be affected significantly. During the transition of flow states from symmetric flow to periodic vortex shedding, the dynamical behaviors of flow are different from that of periodic flow. Compared with Eulerian description, it can be seen that the Lagrangian description is much more available for the analysis of transient flow. More, the results are also instructive to the flow control from the viewpoint of nonlinear dynamics.

**Keywords:** transient flow; Lagrangian coherent structures; material transport; nonlinear dynamics

### 1. Introduction

Transient phenomena are common in unsteady flows over cylindrical structure, airfoil or blade, especially in the flows with unsteady control techniques. It has been verified by both experiments and numerical simulations that the airfoil or blade can gain higher aerodynamic performance under some unsteady flow control technique [1-3]. The results show that some of the transient phenomena near the wall, such as flow separation or vortex formation, are the key factors for the improvement of performance of airfoil or blade. However, most of the controlled flows are complicated unsteady flow, and the mechanisms of the flow control still need to be fully understood.

In transient flow, there are strong material transport and mixture of fluids between different flow regions. Along with the material transport, energy can be transferred and exchanged between main flow and boundary layer, resulting in the change of aerodynamic performance of object. In the flow past impulsively started circular cylinder, flow will separate from the boundary and form two symmetric separation bubbles shortly after starting, and then, bubbles become unstable, and vortex shedding takes place. These phenomena are fundamental and key flow structure in many complicated unsteady flow, thus the studies of them can give a deep understanding of the unsteady flow and their control.

As a typical model problem for the studies of flow separation and vortex, flow over impulsively started circular cylinder has been well investigated numerically and experimentally [4, 5]. The unsteady flows in the wake of circular cylinder have been studied in detail in terms of

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