박 사 학 위 논 문

LCS 기법을 이용한 다중 실린더 주변의 유동장 분석

Analysis of Flow Around Multiple Cylinders Using Lagrangian Coherent Structures

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이 논문을 박사학위 논문으로 제출함.

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Nomenclature

B_w	the width of wake behind cylinder [m]
C_D	mean drag force coefficient
C_{Dp}	drag coefficient caused by pressure
C_{Df}	drag coefficient caused by friction
C_L	r.m.s lift force coefficient
C_p	pressure coefficient
D	cylinder diameter [m]
d_p	particle diameter [m]
f_s	frequency [Hz]
F_D	drag force [N]
F_L	lift force [N]
L	centre-to-centre longitudinal spacing between cylinders [m]
L_w	length of recirculation zone behind cylinder [m]
P	centre-to-center spacing between two cylinders [m]
$(P/D)_c$	critical spacing between two cylinders
Re	Reynolds number, based on cylinder diameter D
Str	the strouhal number
Stk	the Stokes number
T	integration time in calculating LCS
T_p	period of vortex shedding cycle
U_o	free stream velocity [m s^{-1}]
x	streamwise coordinate [m]
y	transverse coordinate [m]

Greek Symbols

α	stagger angle of two cylinders [degree]
θ	the angular displacement on cylinder's surface [degree]
ρ	fluid density [kgm^{-3}]
ρ_p	particle density [kgm^{-3}]
τ	stress tensor [Nm^{-2}]
μ	dynamic viscosity [Nsm^{-2}]
τ_w	local wall shear stress [Nm^{-2}]

Acronyms

CFD	Computational Fluid Dynamics
DPM	Discrete phase model (Fluent)
FFT	Fast Fourier Transform
FTLE	Finite-time Lyapunov exponent
LCS	Lagrangian Coherent Structure
SIMPLE	Semi-implicit pressure linked equation
SST	Shear Stress Transport (SST k-w)

Subscript or Superscript

D, L	referring drag and lift respectively
1,2	referring upstream and downstream cylinders respectively

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ABSTRACT

Analysis of Flow Around Multiple Cylinders Using Lagrangian Coherent Structures

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The flows around multiple circular cylinders were modeled in two dimensions by using Computational Fluid Dynamics, CFD. In which, the flow characteristics were investigated and analyzed based on Lagrangian Coherent Structure framework, LCS. These results were also supported by particle tracking simulations. It was found that wake and proximity interference effects, which are determined primarily by location of cylinders and Reynolds number, have a significant influence on the flow pattern, fluid forces, fluid transport mechanisms as well as particles movement behind cylinders. Results show that the transport process in wake flow was well described by the LCS. In case of single cylinder, the quantitative measurements of flow were performed to reveal the transport characteristics, the boundary of wake, fluid entrains and detrains the wake or the barrier for particle movement, with respect to Reynolds numbers. In cases of two cylinders, the relationship between flow pattern and drag coefficient was obtained. The drag coefficient suddenly changes when the flow pattern changes. For multiple cylinders, the author also found that LCS is an excellent tool for showing flow structure and fluid transport. The flow around vegetation (modeled by multiple circular cylinders) located at the sidewall of channel was tested. The coherent structure of flow calculated from LCS reveals four distinct zones. These zones show clearly where the flow entrains and detrains from the vegetation as well as the appearance of vortex shedding at the interface between vegetation and open channel regions.