STUDY OF THIN WATER FILM EFFECT ON FLOW OVER CIRCULAR CYLINDER

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Abstract: In this work, the vortex shedding behind circular cylinder under heavy rain effects is simulated numerically; with the benchmark cases are first validated. The heavy rain effect is activated by using two-phase flow approach's Discrete Phase Model and surface roughness mechanism, which has been proved to be successful earlier in our airfoil cases. Then high Reynolds number grooved surface cable is further investigated and the explanation of physical processes for cable rain effects at different Reynolds number is fulfilled. The information gained here will be useful for the general aviation industrial application.

INTRODUCTION

The study of flow over circular cylinders has attracted great attention since early years. Since Roshko [1] carried out experimental study on the vortex shedding behind bluff bodies, many researchers have investigated and compared the vortex shedding frequency at low Reynolds number (50<Re<200). Then in 1977, Zdravkovich [2] reported that when more than one body was placed in the flow field, vortex shedding and resulting forces were totally different from those found on single body. A variety of flow patterns, characterized by behaviour of the wake region, may be observed as the spacing between two circular cylinders is changed. The results with side-by-side arrangement of two cylinders by Bearman and Wadcock [3], Williamson [4], Kim and Durbin [5] showed that only one wake was formed when the distance between the centers of cylinders (L) is below about 2.2 times of the cylinder diameter (D). For L>5D, the flow around of the cylinders is similar to that confronted for single circular cylinder. Meneghini et al. [6] investigated the flow past two circular cylinders in tandem and side-by-side arrangements. For the tandem arrangement, they observed a negative drag on the downstream cylinder and that the vortices were shed only from the downstream cylinder if the gap between the centers of the two cylinders is less than 3D, while for L/D>3, vortex shedding occurred from both cylinders and the drag force became positive for the downstream cylinder. On the other hand, there are numerous experimental works on low Reynolds number flow over circular cylinder. For instance, the Strouhal–Reynolds number relationship for the vortex shedding of a circular cylinder at low to medium Reynolds numbers (45 to 560) is investigated experimentally by Wen et al. [7]. It is found that the Strouhal–Reynolds number curve is in good agreement with other 2-D computations and the asymptote of 0.2417 of Strouhal number is also approached.

It is well known that vortex street will lead the structure to destroy, but few numerical works have been done on vortex street simulation under rain effects. In last decade the heavy rain effect on structure begins attract more attention, according to Wan et al. [8], the heavy rain will affect the performance of airfoil aerodynamics, the degradation trend agrees well with existing empirical data. Through proper modeling of discrete water droplets, shear flow between airfoil elements, detailed analysis of pressure distribution, viscous and pressure drags, and roughened cratering effects on airfoil surfaces, it is found that the airfoil lift-to-drag ratio degradation rate will increase with the rain rate. In 2003, Kikuchi et al. studied the drag of new electric power wire (LP-810) in heavy rain [9], they measured the drag in heavy rainfalls and the experimental results from the wind-tunnel unveil that the influence of heavy rainfall is not negligible on this wire. The new wire showed about 20% of increase in drag in raining cross-flow condition. It is the goal of current research to implement the same rain simulation procedure to achieve the similar drag increase for this wire.

NUMERICAL MODELING

To simulate the flow over a single circular cylinder at low Reynolds number, we choose pressure-based to be the flow solver. SIMPLE algorithm has been used as the numerical solution process. For grooved wire case the Reynolds number is about 10^{+5}, and the realizable κ-ε turbulence model is found to have the best results. In our work the hybrid grids is constructed for the best solution. The simulation time step size was elected as 0.00025 and 0.0001 at Re=100 and Re=200, and iteration process stops as long as the sum of absolute residuals in all equations is less than 10^{-4}.

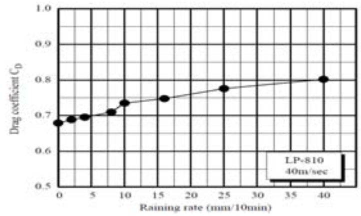
For heavy rain simulation, rainfall's intensity often measured in terms of Liquid Water Content (LWC) of air. According to Dunham [10], LWC (g/m^3) has relationship with rainfall rate R (mm/hr): $LWC = 0.062R^{0.913}$ The Γ-distribution [11] can be express as $N(D) = N_G D^{\alpha_C} e^{-\Lambda D}$ Where D is drop diameter (cm), $N(D)dD$ is the concentration of drops having diameters between D and $D+dD$, N_G is the concentration parameters (cm^{-5}), Λ is the slope parameter (cm^{-1}) and α is the curvature parameter. The concentration parameters N_G can be express as follow: $N_G = \frac{512.85(LWC)\times 10^{-6}}{D_0^4}(\frac{1}{D_0})^{2.160}$ The number of all rain drops ND (cm^{-3}) at specific rain rate can be calculated as integrating the modified Γ-distribution [12]. We can choose a diameter representing all size of rain drops. The volume averaged mean drop diameter D_m is chosen as the significant parameter. Also, the terminal velocity of a raindrop is a function of droplet size and altitude and has been established by Markowitz [13] as $V_T(m/s) = 9.85\left(1-\exp\left[-\frac{D_m(mm)^{1.147}}{1.77}\right]\right)$ Where V_T is the terminal velocity and the D_m is the rain droplet size. Thus we can execute these set of parameter onto the two-phase flow approach in our numerical scheme. Discrete second phase is simulated in Lagrangian frame which is called Discrete Phase Model (DPM), the droplet trajectories are computed individually at specified intervals during the fluid phase estimate. We can predict the trajectory of discrete phase particle by integrating the force balance on the particle in a Lagrangian frame. DPM particles are implemented here to model the wall-film of heavy rain, and the addition of surface roughness condition need also be included.

RESULTS AND DISCUSSION

Simulating the vortex shedding behind single and tandem circular cylinders can be used as basic problem. Our average drag coefficient and Strouhal number are close to other numerical and experimental results. Table 1 show the average drag coefficients and Strouhal number for a single circular cylinder at Re=100, similarly for Re=200.

Table 1

	Re=100	
	C_d	St
Present	1.364	0.169
Meneghini [6]	1.37	0.165
Mahir [14]	1.368	0.172
Saltara [15]	1.33	0.160
Williamson [16]	-	0.164



Where the Figure on the right is for the grooved wire drag coefficient vs. different rain date, similar to the experimental data [9], we are able to simulate the drag increase in the similar fashion. It is found that at 40m/sec wind speed (Re about 10^{+5}) and with the rain model, turbulence model we currently used, the addition of water layer will tend to smooth out the grooved surface for LP-810 wire, thus drastically increase the pressure drag but decrease the skin friction drag, but the total effect is still the net increase in drag. On the other hand, we observe that the rain water film will alter the flow behaviour and drag coefficient at Re=100 and 200, depends on the cylinder arrangement. We postulate that at these Reynolds numbers, rain droplets have more influence on shear stress and the skin friction, but this needs to be justified through further empirical works.

CONCLUSIONS

Our investigation of rainfall effects has extended to the cylindrical configuration in here, and several surface shape and Reynolds number are compared. The vortex shedding under heavy rain effects is simulated numerically; with the benchmark Re=100 and 200 cases are first validated. The heavy rain effect is activated by using two-phase flow approach's Discrete Phase Model and surface roughness mechanism, which has been proved to be successful earlier in our airfoil simulation. The high Reynolds number grooved surface LP-810 cable is further investigated and the explanation of physical processes for cable rain effects at different Reynolds number is fulfilled.

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