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ON THE EFFECT OF REYNOLDS NUMBER AND STRUCTURAL PARAMETERS ON VORTEX-INDUCED VIBRATIONS

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The article reports the effects of Reynolds number and structural parameters (mass, spring constant, damping coefficient, and diameter) on circular cylinders' two-dimensional vortex-induced vibrations (VIV). The Buckingham Π *theorem indicates six dimensionless groups of variables governing VIV. Accordingly, the dimensionless amplitude and frequency (*A^* *and* f^**) depend on Reynolds number, reduced velocity (*U^**), mass ratio (*m^**), and damping ratio (*ζ*). Every other primary dimensionless parameter remained constant to investigate the isolated effects of Re on response amplitude and frequency. There were two ways to achieve this: (1) adjusting the spring constant while keeping the cylinder's mass and diameter unchanged, and (2) adjusting the cylinder's mass and diameter while keeping the spring constant intact. The dimensionless amplitude decreased with Re within the studied range (i.e., Re = 100–500 and* $\zeta = 0.036$*). The dimensionless frequency appeared to increase with Re when mass and diameter were kept constant, but it did not follow a monotonic trend when the spring constant remained the same. This research also discovered that keeping Re,* U^**,* m^**, and* ζ *constant would not necessarily lead to the same dimensionless response amplitude and frequencies if structural parameters change. Note that this study was conducted at a very small mass ratio, preventing the frequency become equal to the natural frequency. This study's findings call for a follow-up investigation on the structural parameters' impact on VIV at large mass ratios.*

KEY WORDS: *vortex-induced vibrations, VIV, fluid–structure interactions, overset mesh*

1. INTRODUCTION

The concept of vortex-induced vibrations (VIV) has been studied in multitudes for a variety of applications (Anagnostopoulos, 1989; Ferguson and Parkinson, 1967; Griffin, 1971; Griffin et al., 1973; Mei and Currie, 1969; Moe and Wu, 1990; Williams et al., 2004). Like any other vibration, VIV is characterized by its frequency and amplitude. The frequency and amplitude of VIV are generally normalized via natural frequency ($f^* = f/f_N$) and cylinder's diameter ($A^* = A/D$). The normalized frequency and amplitude are called frequency ratio and amplitude ratio. According to the Buckingham Π theorem, if a problem depends on n dimensional variables, the dimensional analysis will reduce the problem to k dimensionless variables, where the reduction $(n - k)$ equals the number of different dimensions governing the problem. In the VIV problem, the impactful dimensional parameters are the fluid's properties (μ and ρ), freestream velocity U, cylinder's diameter as it affects both advection D/U and diffusion $\rho D2/\mu$ times, mass m, spring constant k, damping coefficient c, frequency f, and amplitude A. This sums up to nine dimensional variables. Three different dimensions govern this problem: the dimensions of mass, length, and time. Hence, the number of dimensionless variables that one can find for this problem is $9 - 3 = 6$. These dimensionless groups of variables are dimensionless amplitude (A^*), dimensionless frequency (f^*), Reynolds number, reduced velocity (U^*), damping coefficient (ζ), and mass ratio (m^*). According to the literature, frequency and amplitude ratios depend on Reynolds number, reduced velocity, mass ratio, and damping ratio. The literature also suggests considering a combination of

TABLE 5: Comparing response amplitudes and frequencies at Re = 200, $U^* = 22.12$, $m^* = 0.319$, $\zeta = 0.036$. All critical dimensionless numbers are equal between these cases. They have different structural parameters

Case	**Reynold's Number**	**Amplitude Ratio (A^*)**	**Frequency Ratio (f^*)**
3.1 (1.2)	200	0.257	4.09
3.2 (2.2)	200	0.271	4.53
3.3	200	0.271	3.17
3.4	200	0.234	3.80

they returned different amplitude ratios. So, for the conditions studied here, one can conclude that having all critical dimensionless parameters equal between different systems would not guarantee the same dimensionless response amplitude and frequency; they might be the same (such as Cases 3.2 and 3.3) or might be different (such as every other case). With all those dimensionless numbers being equal, the structural parameters still have a strong grasp over dimensionless VIV responses.

9. CONCLUSIONS

This research employed computational fluid dynamics to investigate the characteristics of a two-dimensional cylinder undergoing vortex-induced vibrations. VIV has been studied for decades; however, the impact of structural parameters on the characteristics of the vibrations has not been addressed yet. While keeping all other vital variables steady (i.e., mass ratio, reduced velocity, combined mass-damping parameter, damping ratio), the current research changed three parameters (cylinder mass, spring constant, diameter) to determine how they would affect the dimensionless amplitude and frequency. Results showed that knowing the Reynolds number, reduced velocity, mass ratio, damping ratio, and the mass-damping parameter is not enough to predict the amplitude and frequency ratios. Also, the Reynolds number appeared to affect the cylinder's response. Equations were found to formulate amplitude and frequency ratios in terms of Reynolds number for the studied conditions ($m^* = 0.319$, $\zeta = 0.036$, and Re = 100–500).

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APPENDIX A

Appendix A presents the user-defined function employed to implement free VIV. The numbers embedded in the code are associated with the case of $m = 0.0000843$ kg, $k = 10$, and $\zeta = 0.036$. This script communicates with the CFD code to solve the vibration equation at every timestep and update the location of the cylinder.

```
#include "udf.h"
#include "math.h"

#define zoneID 8 /* zone ID for the cylinder */
#define cyl_mass 0.0000843 /* mass of the cylinder (kg) */
#define spr_k 10 /* spring rate of system (N/m) */

real cg_o[3] = {0.0, 0.0, 0.0}; /* center location of the cylinder */
real vel_y = 0.0;
real ai = 0.0;
real vi = 0.0;
real yi = 0.0;

/* Damping */
real cr = 2*sqrt(spr_k*cyl_mass);
real zeta = 0.036;
real c = zeta*cr;

DEFINE_CG_MOTION(cyl_mot, dt, cg_vel,cg_omega, time, dtime)
{
real cts, yip1, vip1;
real aip1, fy;
real Vn, Fm;
real x_cg[3], f_glob[3], m_glob[3];
Domain *domain = Get_Domain(1);
/* Thread *tf = Lookup_Thread(domain,zoneID); */
Thread *tf = DT_THREAD(dt);

/* Get current timestep */
cts = CURRENT_TIMESTEP;

/* Intialize Values */
NV_S(cg_vel, =, 0.0);
NV_S(cg_omega, =, 0.0);
```