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EXPERIMENTS ON VORTEX-EXCITED OSCILLATIONS OF AXIALLY-VARYING CYLINDRICAL STRUCTURES IN NON-UNIFORM APPROACH FLOW

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LONG-TERM GOALS

The long term goals of this experimental investigation are to identify and understand the important fluid-structure interaction mechanisms that occur during vortex-excited vibrations of axially-varying cylindrical structures in non-uniform flow fields.

OBJECTIVES

•To study the vortex-excited, aerodynamic response of pivoted and cantilevered axially-varying cylinders to uniform and linearly varying shear flows.

•To study the vortex-excited displacements and unsteady forces on pivoted and cantilevered axially-varying cylinders in non-uniform flow fields.

•To investigate the effects of body geometry and approach flow non-uniformity on the wake parameters such as: vortex formation length, base pressure and Strouhal number.

•To investigate the observed hystersis loops and phase jumps in the lock-in regime.

•To provide adequate data for van der Pol oscillator modeling of the vortex shedding process for self-excited cylindrical structures in non-uniform flow fields.

APPROACH

The experimental approach utilizes the low turbulence indraft wind tunnel and the water tunnel at the Hessert Center for Aerospace Research at the University of Notre Dame. Hot-wire measurements of mean and fluctuating velocity as well as power spectral densities of the near wake velocity fluctuations are made using constant temperature anemometers. Instantaneous displacements measurements of the vortex-excited cylinder amplitudes are made optically using a laser and a lateral effect detector. In addition, an accelerometer mounted on the model provides acceleration data. Flow visualization studies via smoke wire in the wind tunnel and lead precipitation in the water tunnel are integrated to reveal the three-dimensional character of the body and fluid oscillations in the near wake.

WORK COMPLETED

In the last year we completed several investigations of freely oscillating, straight and tapered, pivoted cylindrical models in uniform and linearly sheared velocity fields. The nine flow configurations investigated are shown in Figure 1. Each case consisted of a rigid cylinder pivoted at one end with a bearing and stiffened by two transverse springs at the other. The bearing and springs allowed for oscillatory movement only in the cross-flow direction. Measurements of the wake vortex shedding and body displacement during oscillations were made simultaneously to characterize the region of lock-in between the vortex shedding and body vibration frequency. A fully automated system for controlling the wind tunnel speed and measuring the mean velocity, wake velocity and body displacement was also implemented. This allowed for experiments to be conducted with a large number of velocity points—requiring a period of several hours—without operator assistance.

RESULTS

Freely oscillating cylinder experiments have been set up to investigate the lock-in of the wake with the cylinder motion in uniform and linearly-sheared flow fields. For a uniform cylinder a comparison between the results of the uniform and shear flow experiments reveals that the range of lock-in is larger in the shear flow case although the maximum amplitudes in the two case are comparable (Szewczyk, et al. 1997). The increase in the lock-in range is expected since in a shear flow some part of the cylinder will be under lock-in over a larger range of incident velocities, but the similarity in the maximum peak to peak amplitude is not as intuitive. Further experimental investigations with greater non-uniformity in approach flow are needed to enhance our understanding of this phenomenon.

If one examines the power spectral densities shown in Figure 2, a cellular structure was observed as the natural shedding frequency appeared at the pivoted end of the cylinder. As the cylinder wake was traversed from bottom to top a locked-in cell was observed up to a certain spanwise position where a natural shedding frequency cell began and extended to the top. This occurred because the wake failed to lock in due to the low amplitudes near the pivot.

For a uniform cylinder in a linear shear flow (maximum velocity at the pivoted end) the peak to peak amplitudes shown in Figure 3 provide excellent evidence of the body oscillations before, during and after lock-in. For small increments of the reduced velocity, U_R, $\Delta U_R \approx 0.05$ (shown as circles), the cylinder begins to oscillate at $U_R \approx 4.1$. As the velocity is incremented toward $U_R \approx 5.5$, the amplitude grows rapidly following the upper branch of the hysteresis loop. For $U_R \approx 5.5$ the maximum velocity of the upper branch, the amplitude is 0.45 and drops abruptly to 0.075 onto the lower branch of the hysteresis loop. This abrupt change occurs over a very small range reduced velocity, $\Delta U_R \approx 0.60$. Further increases in velocity result in a reduction of the amplitude until $U_R \approx 7.20$ where the vortex-induced vibrations disappear. For decreasing velocity (shown by x's) the lower branch of the hysteresis loop follows the upper branch up to $U_R \approx 5.8$ where the amplitude reaches its maximum. Further decreases in velocity reduce the amplitude until $U_R \approx 5.2$ where the lower branch again rejoins the upper branch of the loop. At $U_R \approx 5.1$ the amplitude changes abruptly from 0.21 to 0.1 where a second hysteresis loop is formed. Any further decreases in reduced velocity causes the amplitude to decrease and rejoin the upper branch until vortex-induced vibrations disappear. The reason for these abrupt changes are not entirely clear but the organization of the near wake structure coupled to the body amplitude plays an important role.

The experimental results of the above experiments, uniform cylinders in uniform and shear flow, are in good agreement with van der Pol oscillator modeling (Balasubramanian, et al., 1997, and Balasubramanian and Skop, 1997). Of the nine configurations investigated, no lock-in of the shedding frequency to the natural frequency was observed for the pivoted tapered cylinder (max. diameter at top) in uniform flow

IMPACT/APPLICATIONS

The experimental results of the configurations tested are of a general nature and can be used to improve physical models that can predict unsteady lift and lock-in phenomena in many offshore systems.

TRANSITIONS

We expect the results obtained from the present experiments to provide the necessary data for modelers to formulate more sophisticated wake-oscillator models.

RELATED PROJECTS

We are in close collaboration with the Division of Applied Marine Physics, University of Miami on their project "Modeling vortex-excited vibrations of axially varying cylindrical structures in non-uniform flow fields," Principle Investigator: Richard A. Skop. We have also been in contact with Professor Pratap Vanka of the University of Illinois who is presently doing direct numerical simulations of low Reynolds number vortex shedding from tapered cylinders. Our water tunnel studies complement this study.

REFERENCES

Balasubramanian, S., F. L. Haan Jr., A. A. Szewczyk and R. A. Skop, On the Existence of a Critical Shear Parameter for Cellular Vortex Shedding from Cylinders in Nonuniform Flow. Journal of Fluids and Structures, in press, 1997.

Balasubramanian, S., and R. A. Skop, 1997, Modeling Vortex-Excited Vibrations of Uniform Cylinders in Uniform and Shear Flow. Proceedings of ASME 4th International Symposium on Fluid Structure Interactions, Aeroelasticity, Flow-Induced Vibration & Noise, Dallas, TX, 1997.

Szewczyk, A. A., S. Balasubramanian, F. L. Haan Jr. and R. A. Skop, Experiments on Vortex-Induced Vibrations of Pivoted Circular Cylinders. Proceedings of ASME 4th International Symposium on Fluid Structure Interactions, Aeroelasticity, Flow-Induced Vibration & Noise, Dallas, TX, 1997.

Flow Configurations Investigated

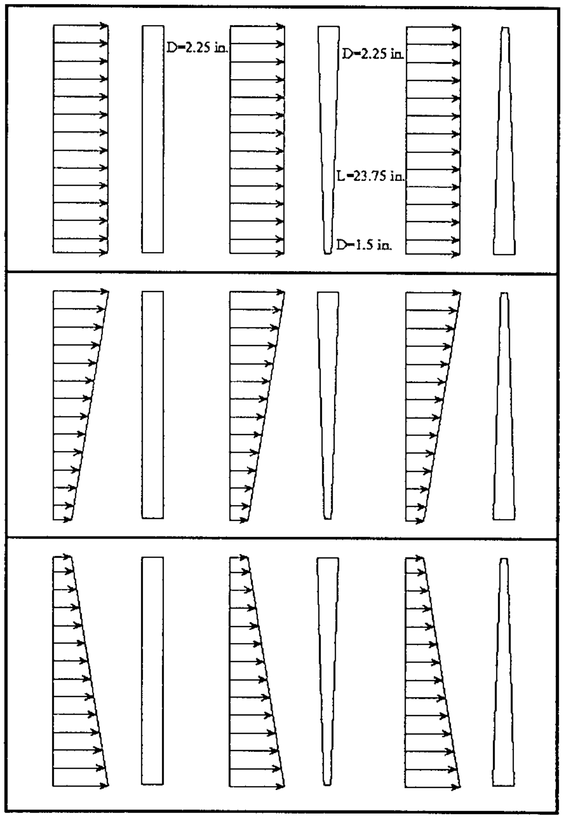
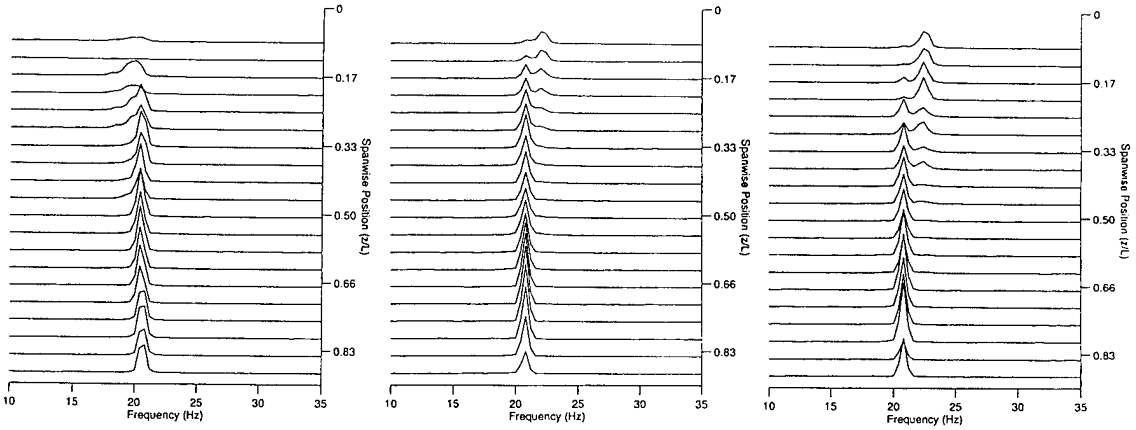


Figure 1



$V_r = 4.65$
PRE-LOCK-IN

$V_r = 5.90$
LOCK-IN

$V_r = 6.12$
LOCK-IN

POWER SPECTRAL DENSITY OF THE VELOCITY FLUCTUATIONS IN THE WAKE REGION OF A UNIFORM PIVOTED CYLINDER IN A UNIFORM FLOW.

Figure 2

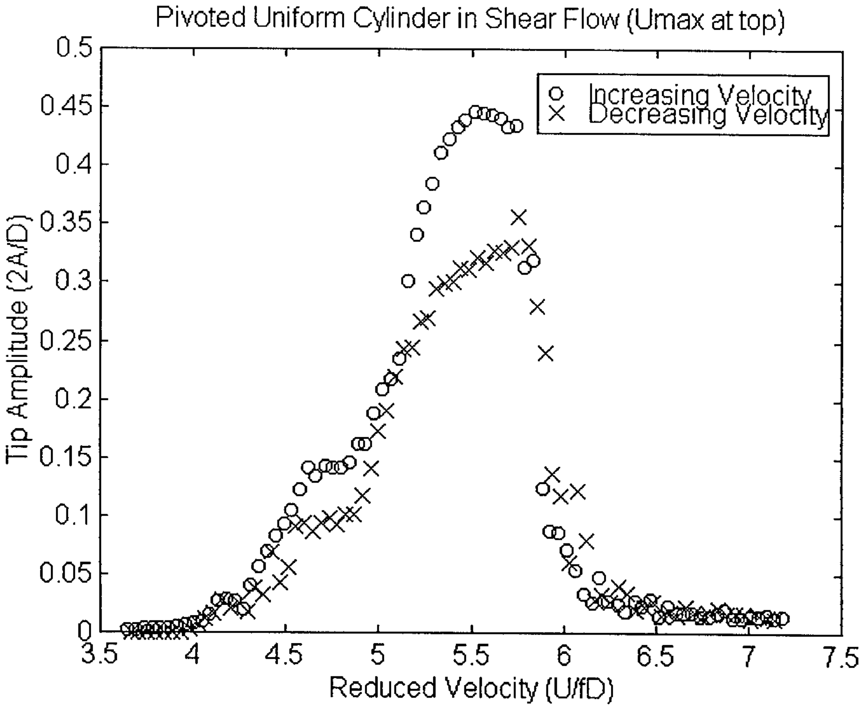


Figure 3

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Szewczyk, A. A., S. Balasubramanian, F. L. Haan Jr. and R. A. Skop. Experiments on Vortex-Induced Vibrations of Pivoted Circular Cylinders. Proceedings of ASME 4th International Symposium on Fluid Structure Interactions, Aeroelasticity, Flow-Induced Vibration & Noise, Dallas, TX, 1997.

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