THE EFFECT OF CHANGED MASS RATIO ON THE MOTION OF A TETHERED CYLINDER

K. RYAN, M. C. THOMPSON AND K. HOURIGAN
Fluids Laboratory for Aeronautical and Industrial Research (FLAIR),
Department of Mechanical Engineering,
Monash University, Melbourne, Victoria 3800, Australia

Abstract: The flow past a buoyant tethered cylinder was investigated for a variety of mass ratios. A critical mass ratio, $m^* = 0.2 - 0.3$ was found for the uniform flow past a tethered cylinder, below which sustained large amplitude oscillations were observed up to the highest reduced velocity simulated in this study. The critical mass ratio was found to coincide closely with that found in previous studies for a hydro-elastically mounted cylinder using two-dimensional simulations.

1. INTRODUCTION

To date, few studies on the uniform flow past a tethered body exist, most of these concentrating on the flow past a tethered sphere. This is despite tethered cylinders having practical applications in subsea pipelines, tethered lighter-than-air-craft, and tethered spars just to name a few examples.

A significant body of research exists in the related field of freely oscillating cylinders, both with high- and low- mass damping. For both cases, several parameter studies have been performed, including studies regarding the effect of mass ratio on the modes of oscillation observed. In particular, Govardhan and Williamson, 2000 observed that for low mass damped hydro-elastically mounted cylinders three modes of oscillation exist, namely the initial, upper and lower branch, and a critical mass ratio exists below which high amplitude oscillations continue up to an indefinite reduced velocity. Recent studies by Govardhan and Williamson, 2003 have confirmed that this phenomenon occurs up to an infinite reduced velocity.

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Three phenomena distinguish the tethered cylinder from the hydro-elastically mounted cylinder. The first is that the tethered cylinder has a component of motion in both the in-line and transverse directions, as such variations in both the drag and lift forces directly affect the cylinder motion.

Secondly, the natural frequency of the cylinder system (expressed in non-dimensional form as the reduced velocity) is now a function of the hydro-dynamic loading acting on the cylinder, and varies with lift and drag throughout the oscillation cycle through the equation:

$$U^* = \frac{U}{f_n D} = \sqrt{\frac{\pi(m^* + C_A)L^*}{2\sqrt{C_D^2 + \left[C_L + \frac{\pi}{2}\frac{(1-m^*)}{Fr^2}\right]^2}}} \quad (1)$$

Where C_D is the drag coefficient, C_L is the lift coefficient, m^* is the mass ratio (defined as the ratio of body density to fluid density), Fr is the Froude number, L^* is the tether length normalized by the cylinder diameter, and C_A is the added mass coefficient, equal to unity for a circular cylinder.

At very high Froude numbers (corresponding experimentally to high velocities) assuming a fixed mean drag and lift, the dependence on the fluid forces and Froude number impose an upper limit on the possible maximum value for the reduced velocity. From equation 1, in order to exceed this maximum value the absolute value of either the mean drag and/or the mean lift must decrease.

The third distinguishing feature is that there is no damping (it was assumed that the tether attachment point was frictionless) with the direct result that, assuming the forcing and resultant cylinder motion are well approximated by a sinusoidal function, there can be no 'upper' branch as described by Govardhan and Williamson, 2000. The phase angle between the total force and the cylinder motion, and the phase angle between the vortex force and the cylinder motion, must be 180^o for significant oscillation amplitudes.

There are two parameters of importance as the flow conditions are varied, namely the mean layover angle, θ, and the cylinder oscillations about this mean layover angle, θ^*_{std}.

To the authors knowledge, only the two-dimensional studies of Pregnalato et al., 2002, Ryan et al., 2002 and Ryan et al., 2003 have reported research on the flow past a tethered cylinder. In these related papers, only one cylinder mass ratio and tether length ratio were studied ($m^* = 0.833, l^* = 5.05$). However at large layover angles, θ (where the tethered cylinder experiences dominantly transverse oscillations), oscillations similar to that of a freely oscillating cylinder were reported. From