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Addendum

Addendum to "An experimental study of the nonlinear dynamics of cylindrical shells with clamped ends subjected to axial flow"

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The rationale for writing this addendum is to provide visual experimental evidence of the static and dynamic divergence observed in experiments with clamped shells subjected to axial flow. This addendum supplements the experimental results presented in the paper by Karagiozis et al. (2005), in which the nonlinear dynamics and stability of thin circular cylindrical shells clamped at both ends subjected to axial internal or annular fluid flow was investigated. Three different apparatuses were used to examine the nonlinear behaviour of clamped shells subjected to internal or external flow.

The first apparatus, shown in Figs. 1 and 2 in Karagiozis et al. (2005), employed an elastomer shell with material properties and dimensions listed in Tables 1 and 2 of the same paper. The AnnularAir_JFS file is a video clip showing the response of the clamped elastomer shell subjected to annular air-flow. When the air-flow velocity reached $U_C = 40.4\,\mathrm{m/s}$, the shell buckled inwards with a circumferential wavenumber $n = 4$. The shell amplitude at this air-flow velocity was 5 mm, which corresponds to about 3 times the shell thickness. After buckling had occurred, the air-flow velocity was gradually reduced until the shell returned to its original circular shape at $U = 35.8\,\mathrm{m/s}$ with $n = 0$. The video clip clearly shows that the shell has lost stability by divergence (buckling) without any type of shell oscillation. The shell exhibited a subcritical nonlinearity with large hysteresis. For this experiment the set-up shown in Fig. 2(b) was used, with a transmural pressure $\Delta P_{tm} = P_{\mathrm{ann}}(x) - P_{\mathrm{inn}} = P_{\mathrm{ann}}(x) - P_{\mathrm{ann}}(L)$.

The second apparatus, shown in Figs. 3 and 4 in Karagiozis et al. (2005), was used to examine the stability of an elastomer shell clamped at both ends and subjected to internal air-flow. The material properties and dimensions are listed in Tables 1 and 2 in the aforementioned paper. The InternalAir_JFS file is a video clip showing the response of an elastomer shell subjected to internal air-flow. The shell lost stability by *dynamic* divergence with a very large shell amplitude, whereas theory predicts a static divergence. This was explained as follows. Because the shell was very pliable, the amplitude of divergence was so large that it constricted the flow in the shell; the alternating pressure build up and release upstream of the shell gave rise to the dynamic divergence phenomenon shown in the video clip. Snapshots of this kind of dynamic buckling are shown also in Fig. 11 of the original paper with shell amplitudes of about 6.0 mm (4 times the shell thickness). In this experiment the set-up shown in Fig. 4(a) was used.

The third apparatus investigated the response of a clamped aluminium shell subjected to internal water-flow. The set-up of the experiment is shown in Fig. 6 in Karagiozis et al. (2005). The material properties and dimensions of the shell

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used in the experiments are listed in Tables 1 and 6, respectively. In this experiment, the transmural pressure was set to $P_{\mathrm{ann}} - P_{\mathrm{inn}}(L/2) = 5.7\,\mathrm{kPa}$. The InternalWater_JFS file is a video clip showing the response of the shell for different values of the water-flow velocity. At $U_{\mathrm{C}} = 16.4\,\mathrm{m/s}$ the shell lost stability by static divergence with a circumferential wavenumber of $n = 6$. The radial deformation of the shell at the first point of buckling was 2.45 mm (18 times the shell thickness). Upon reducing the flow, the original circular cross-sectional shape was restored at $U = 9.3\,\mathrm{m/s}$. In contrast to the elastomer shells, the flexural rigidity here is sufficiently large to result in relatively small amplitude at divergence (compared to the shell radius), hence incurring no appreciable constriction of the flow area. This is believed to be the reason for the nonoccurrence of dynamic divergence.

It is believed that the supplemental information (Supplementary Materials) provided by these three video clips would be of interest to the readers to better understand and visualize the difference between static and dynamic divergence and to emphasize the subcritical post-divergence response of clamped shells subjected to axial fluid flow.

Appendix A. Supplementary materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jfluidstructs.2006.01.005.

Reference

Karagiozis, K.N., Païdoussis, M.P., Misra, A.K., Grinevich, E., 2005. An experimental study of the nonlinear dynamics of cylindrical shells with clamped ends subjected to axial flow. Journal of Fluids and Structures 20, 801–816.