Sources of Flow Induced Vibration

by

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Introduction

The noise and structural vibration problems excited by flow are many and varied and can be divided into two main categories: (a) vibrations associated with "internal" flows such as heat exchangers, wind tunnels, fans and gas turbines, and (b) vibrations associated with "external" flows such as those around buildings, transmission towers and powerlines. The first category will be considered in this presentation although it is likely that the results will apply to the second category.

In an attempt to determine the source of a particular vibration, Engineers and Scientists often determine the spectral content of the flows around a body in the absence of vibration (e.g.Ziada et al. 1989). If the Strouhal number (St = frequency x dimension/flow velocity or the reduced velocity which = 1.0/St) of a particular peak in the spectrum coincides with the St of the flow induced vibration, then they assume that the source of the spectral peak without vibration is also responsible for sustaining the flow induced vibration.

The aim of this presentation is to show that the flow (source) which sustains a vibration cannot be determined in the absence of the vibration since the "feedback" effect of the vibration changes the flow to a new state. While sustaining the vibration, this new state is also dependent on the vibration.

Examples of Flow Being Influenced by an Externally Applied Vibration

There are many examples where researchers have subjected separated flows to sound fields using loud speakers (eg.Bhattacharjee et al.1986, Parker & Welsh 1983 and others). Bhattacharjee et al. (1986) found that the naturally occurring spectral peak in the signal from a hot wire located in the shearlayer separating from a two dimensional backward facing step, occurred at a St≈0.4. When they subjected the flow to a sound field, a sharp spectral peak occurred at the acoustic St.

Parker & Welsh (1983) subjected the flow around a plate, with a square leading edge and a chord-to-thickness ratio of 5, to sound generated by two speakers connected in anti-phase and located above and below the plate. Without sound applied, the signal from a hot wire located in the vortex street downstream of the plate showed a sharp spectral peak at a St≈0.104. With sound applied, the spectral peak at 0.104 was replaced by a peak at the acoustic St of 0.203.

In both of the these cases, the vortex dynamics of the shearlayers are altered significantly by the vibration. The merging of vortices is augmented and the shearlayers reattach earlier. For the plate, a vortex street is generated at the acoustic St which is approximately twice the St of the naturally occurring vortex street. These cases show the susceptibility of shearlayers, and consequently of the flow around a body, to an external vibration.

Both of these cases are examples of unstable flows resulting from *convective* instabilities since they depend on an external vibration to maintain their existence (Bechert 1986, Monkewitz et al. 1987). Consequently, any spectral peaks observed in a flow, without an external vibration, cannot be the product of *convective* instabilities in the flow.

Examples of Flow Induced Vibration Altering the Flow

When the plate described above was located in a hard walled duct and the flow increased from zero, Welsh & Gibson (1979) found that a loud resonant sound was excited when the natural vortex shedding frequency (St≈0.104) was approximately half the resonant sound frequency. Without loud sound, the vortex street was the product of an *absolute* instability in the flow since it existed without external vibration (Bechert 1986, Monkewitz at al.1987). As the sound level increased, it "fed back" on to the shearlayers separating from the leading edge and increased the vortex shedding frequency up to the resonant sound frequency. This modified vortex street was then responsible for maintaining a supply of energy to sustain the loud sound. It was the product of a *convective* instability since a spectral peak in the signal from a hot wire located in the modified vortex street was not present without the loud sound.

Recent experiments by Stoneman et al. (1988) described the excitation of loud sound by the flow around two plates located in tandem, when the plate spacing was greater than 2.5 plate thicknesses. A natural vortex street was shed from the upstream plate and loud sound was generated when the natural vortex shedding frequency was approximately equal to the sound frequency.

When the downstream plate is located within 2.5 plate thicknesses, the natural vortex shedding is suppressed and there is no dominant spectral peak in the hot wire signal. However, loud sound is still excited at approximately the same flow velocity as it was for the greater plate spacings and it is associated with a vortex street shed at the acoustic St. In this case, the instability in the flow leading to the modified vortex street and the loud sound must be the product of a *convective* instability since the modified vortex street depends on the loud sound for its existence.

This finding suggests that the excitation of the resonant sound for greater plate spacings, when the natural vortex shedding St approximates the acoustic St, is also due to a *convective* instability in the flow (i.e. it is dependent on the loud sound). Close examination of the flow with and without resonant sound (Welsh et al.1984) shows that the naturally occurring vortex street is changed significantly by the sound even though the St is unchanged. This evidence supports the suggestion that the flow instability which initiates the flow sustaining the resonant sound is not the instability producing the flow observed in the absence of sound even if the St's are the same.

In the literature (Ziada et al. 1989), it is often assumed that the natural vortex street, which is the product of an *absolute* instability in the flow and therefore does not require vibration for its existence, sustains the vibration. However, experimental evidence presented here suggests that even though the St of the vortex shedding without sound may approximate the St of the vortex street sustaining the loud sound, they result from different flow instabilities. It appears that the initial shearlayers shed from a bluff body are *convectively* unstable and are therefore influenced by vibration to form a new vortex street which sustains the vibration at the acoustic St.

In some cases, flows resulting from an *absolute* instability may be responsible for the **initial** excitation of sound at the resonant frequency prior to it 'feeding back' on to the *convectively* unstable shearlayers shed from the body. In these cases, the St of the unstable flow will be approximately equal to the vibration St. However, there are many cases where the initial excitation is due to background broad band vibration that includes the resonant frequency.

Conclusion

Flow sources which sustain a vibration cannot be detected without the vibration being present since they are the result of a *convective* instability in the flow.

Sometimes the St of a spectral peak, due to unstable flow without an external vibration, is equal to the flow induced vibration St. This occurs when the flow induced vibration is **initially** excited by a fluctuating flow which is the product of an *absolute* flow instability.

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