Excitation Of Acoustic Resonance by Cross Fluid Flow over a Row of Multiple In-Line Cylinders.

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Introduction

- Flow excited acoustic resonance is a phenomena associated with high acoustic pressure levels.
- Flow perturbations due to interaction with obstacles can provide energy to the acoustic field.
- Severe acoustic resonance occurrence that can damage equipment.

- Flow excited acoustic resonance occurs in many applications, such as
  - Shell and tube heat exchangers
  - Air heaters
  - Power generation boilers
  - Marine boilers
  - Conventional power plants
Introduction

• Flow excited acoustic resonance occurs due to a feedback mechanism.

• The resonance occurs when the coincidence occurs between
  • Vortex shedding frequency
    \[ St_v = \frac{f_v \times D}{U} \]
    Acoustic mode frequency
    \[ f_a = \frac{c}{2H} \]

• At coincidence,
  • Frequency has a lock-in \((f_a \sim f_v)\)
  • Self excitation, Severe Sound Pressure
Introduction

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Introduction

- Extending the investigation to two tandem cylinders showed that in certain cases, acoustic resonance can be excited by perturbations in the gap between the cylinders.

- This abrupt excitation of resonance, observed by Mohany and Ziada (2005), resembled the behavior of in-line tube bundles, where downstream wakes cannot form, more closely.

Introduction

• Curle (1955) extended the theory of aerodynamic sound to solid rigid surfaces

• Fluctuating forces on surfaces act as sound dipoles.

• Fluctuating lift force can convert flow energy into acoustic energy.

\[ \rho - \rho_0 \sim \frac{1}{4\pi c_0^3} \frac{x_i}{x^2} \frac{\partial}{\partial t} F_i \]

Dipole Source
Generated by fluctuating forces

Figures from http://www.acs.psu.edu/drussell/demos/rad2/rdq.html
Introduction

• Mohany and Ziada (2009) conducted simultaneous measurements of acoustic pressure and fluctuating lift force on cylinders.

• Fluctuating lift coefficients were analyzed to investigate energy exchange between the acoustic and flow fields off and during resonance.

• Their results revealed that shear layer instabilities in the gap between the two cylinders are responsible for the excitation of pre-coincidence resonance.
Objective

• Extend the current knowledge of the energy exchange mechanism during flow-excited acoustic resonance to the case of multiple inline cylinders.

• Investigate the aeroacoustics behavior of the in-line row of cylinders by locating the dipole sources contributing to the acoustic field.

• Investigate the influence of acoustic resonance on the lift force coefficient during the pre-coincidence resonance.
Experimental Setup

- Open-loop wind tunnel, cross section is 5”x10”

- Flow speeds up to 150 m/s, capable of exciting the gap-shedding resonance

- 2, 3, or 4 Cylinders in a row
- D = 1”

- Spacing ratio L / D = 2.0

- Flush mounted microphones to measure pressure signal at the pressure antinode.
Experimental Setup

- Lift force is measured using piezoelectric force sensors.
- Simultaneous measurement of fluctuating lift on all cylinders.
- Cylinder passes through the test section side with a gap of 1/16 " , sealed with an oiled O-ring.
- Structural resonance frequency, ~1.2 kHz, to allow accurate measurements in the resonance frequency range.
Results

Aeroacoustics Response

- Pre-coincidence resonance occurred for 2, 3, and 4 inline cylinders.

- For a fixed spacing ratio and diameter, increasing the number of in-line cylinders from 2 to 3, increased the resonance pressure level.

- However, further increase to 4 cylinders did not increase the sound pressure level further.
Results

• The measurements of lift coefficient were verified against reported data for cylinders of the same aspect ratios.

• Results also agree with reported behavior of lift coefficients on single cylinders during resonance.
Results

Fluctuating Lift Coefficients

![Graphs showing fluctuating lift coefficients for different cylinders under varying flow velocities.](image)
Results

lift coefficient phase with acoustic field
Results

Phase between lift on successive cylinders

![Graph showing phase between lift on successive cylinders.](image)
Force decomposition

- For the closely related phenomena of flow-induced vibrations, Sarpkaya (1979) showed that energy conversion between flow to resonant field can be analyzed using force phasor components.

- Mohany and Ziada (2009) showed that $C_L$ components $C_{mh}$ and $C_{dh}$ indicate energy exchange between the flow and acoustic fields.

- $C_{mh}$ relates to resonance frequency change.

- $C_{dh}$ becomes negative when flow forces supply energy during resonance.

$$C_L = C_{mh} \sin \omega t - C_{dh} \cos \omega t$$

- In-phase with pressure
- Out-of-phase with pressure

$$C_{mh} = C_L \cos \phi$$

$$C_{dh} = -C_L \sin \phi$$
Results

Force decomposition

- Negative $C_{dh}$ means that the cylinder provides energy to the flow field during lock-in.

- For the pre-coincidence resonance, negative $C_{dh}$ is only observed for the downstream cylinder.

- The higher negative $C_{dh}$ explained the higher sound pressure level for this early resonance range.
Results

force decomposition

- Lift force decomposition shows that negative $C_{dh}$ is observed
  - for the downstream cylinder in the case of 2 inline cylinders.
  - for the middle and downstream cylinders in the case of 3 inline cylinders.
  - for the second and the downstream cylinders in the row of 4 in-line cylinders.
Conclusions

• Pre-coincidence resonance for the case of multiple inline cylinders is triggered by shear layer instabilities in the gaps between in-line cylinders.

• Lift coefficients on all cylinders in an in-line row increases significantly during lock-in. However, not all cylinders may be contributing energy to the acoustic field.

• During lock-in, high acoustic pressure and lift coefficients are observed when lift force leads the acoustic field, causing negative damping and supplying energy to the acoustic field.

• Flow structures in gaps within the in-line row can be different during resonance. This can limit the resonance SPL.
Thanks for your attention
Results

- The measurements of lift coefficient were verified against reported data for cylinders of the same aspect ratios.

- Strouhal no. for wake shedding agreed with reported data.