

ACOUSTICAL PRESSURE GENERATED BY AIRFLOW OVER A COMPLEX CAVITY: IDENTIFICATION OF PHENOMENA CONNECTED WITH HIGHEST PRESSURE LEVELS

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1. INTRODUCTION

Acoustic oscillations induced by flow over complex cavities (Fig. 1) concern a wide range of industrial structures such as aircraft, automobiles or high speed trains. As wind speed is increased, discrete frequency tones develop which go through cycles of growth and decay [1]. This study focuses on the higher sound pressure levels (SPL) generated. Our aim is to answer the question : Given a cavity and a flow, which are the mean flow velocity (U_{∞}) and frequency (f) leading to the maximum SPL ? and what is the SPL ?

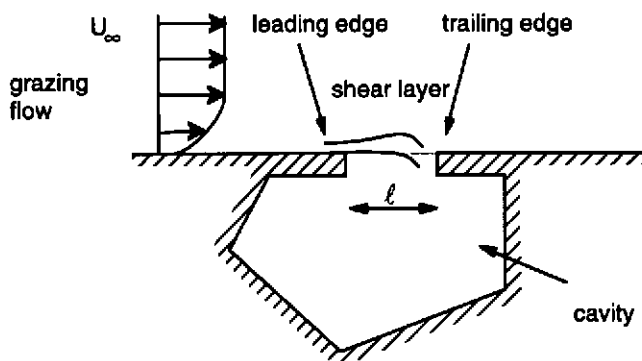


Fig. 1 : simplified geometry

The generation mechanism is generally explained as a coupling between shear layer instabilities and an *acoustic feedback* induced by the trailing edge and/or the cavity [2]. Yet, most authors consider no flow

parameters but the velocity in their feedback model, which prevents them from extrapolating their results for different length scales or Mach numbers [3]. Tam & Block [4] introduce the effect of finite shear layer thickness in their mathematical model by mean of the momentum thickness (θ). So far, it is the most advanced feedback model. though, results meet poor agreements with experimental measurements for Mach numbers below 0,2.

In this paper, we propose an original model which provides answers to the former question. It follows the phenomena connected with high SPL and gives prominence to the leading parameters. It is consistent with the feedback model but intrinsically more general. It is based on *spatial and frequency coincidence*. Comparisons with experimental data are provided, for Mach number below 0,25 and rather large cavities.

2. THE SPATIAL AND FREQUENCY COINCIDENCE MODEL

We consider that strong pressure levels are due both to :

- A spatial coincidence between the shear layer instabilities wave length (λ_{sl}) and a specific dimension of the cavity.
- A frequency coincidence between shear layer instabilities and eigen frequencies of the open cavity ; the first one being the Helmholtz frequency.

In order to get the shear layer wave length, we take an interest in the associated phase velocity (U_ϕ) ; which is different from the stream velocity (U_∞). We then make use of results from Michalke [5] who computes the phase velocity by mean of the inviscid linearized stability theory of spatially growing disturbances in the case of a free turbulent boundary layer (shear layer). The model takes into account : U_∞ , θ and f . The dispersion curve (phase velocity versus frequency) is shown on Fig 2 with :

$$\beta = f \cdot \frac{2 \cdot \theta}{U_\infty} \qquad C_r = \frac{U_\phi}{U_\infty}$$

The specific dimension of the cavity is the length of cavity mouth (noted ℓ on Fig. 1) as it is along the shear layer direction.

The first coincidence frequency is supposed to be the Helmholtz frequency of the cavity with no flow condition (f_0). At first, we can assume that the shift produced by flow is negligible.

Finally, the model can be written :

$$\lambda_{sl}(U_\infty, \theta, f) = 2 \cdot \ell \qquad f = f_0$$

Hence, the required parameters for a prediction of the frequency and the critic velocity (U_∞^c) related to the strongest SPL are :

- The open cavity eigen frequency with no flow condition (f_0) and ℓ
- The flow characteristics : i.e. the law $\theta = \theta(U_\infty)$

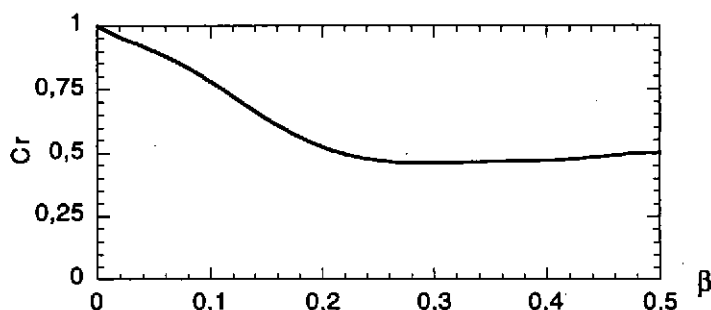


Fig. 2 : Nondimensional phase velocity versus nondimensional frequency from [5]

3. COMPARISON BETWEEN THEORY AND EXPERIMENT

Results from measurements in a wind tunnel

Each tested cavity is mounted on a plate (dimension order 0,1m - volume order 10^{-4} to 10^{-2} m³). Hence, the aerodynamic excitation is a turbulent boundary layer (TBL) flow over a smooth flat plate. Hot wire measurements are undertaken in order to characterise the stream [3]. The TBL has a 1/7,5 power velocity distribution ($n = 7,5$). The momentum thickness and the free stream velocity are related by :

$$\theta = \frac{n}{(n+1)(n+2)} \cdot 6,2 \cdot \frac{v^{1/5}}{U_\infty^{3/5}} \cdot (x')^{2,8/5} \quad \text{with : } v = 1,5 \cdot 10^{-5} \text{ m}^2/\text{s},$$

and x' : distance from flat plate leading edge to cavity leading edge.

As the cavity is mounted, both the power velocity distribution and momentum thickness laws remain valid upstream and downstream the cavity aperture.

Comparisons between theory and experiment are presented on Table 1 for different cavities. β ranges from 0,1 to 0,7.

Cavity	Theory				Experiment	
	ℓ (mm)	x' (m)	f_0 (Hz)	U_∞^c (m/s)	f (Hz)	U_∞^c (m/s)
1	8	0,882	533	17	531	20,9
2	16	0,893	253	17	258	16,1
3	16	0,893	265	18	267	17,6
4	52	0,930	208	29	195	27,6
5	52	0,930	196	29	197	31,4
6	57	0,885	216	31	210	29,7

Table 1 : Comparison between theory and experiment

Good agreement is found between the frequency and velocity predicted by the double coincidence model and experimental measurements over the range of Mach number allowed by the wind tunnel (0 - 0,1).

Note that cavity #2 is cavity #1 drawn to a scale of two. Results concerning the velocity for a maximum SPL enhance the fact that no simple similarity law can be extrapolated. This comes from the fact that the phase velocity is not directly proportional to the stream velocity. The phenomena are non-linear.

Results from measurements on high speed train

For a train velocity between 60 and 85 m/s, the average momentum thickness can be estimated at 0,15 m. The Helmholtz frequency of the complex cavity between two carriages is around 60 Hz (cavity dimension order is 1 m - volume order 1 m³). Hence the predicted train velocity for a maximum SPL is around 71 m/s. This yields well with first measurements on a full scale train.

4. CONCLUSIONS

The spatial and frequency coincidence model emphasises the leading parameters. We can underline that :

- no hypothesis is required for the cavity geometry. Only the eigen frequencies and length of mouth in streamwise direction are required
- and that flow characteristics must carefully be taken into account as the phase velocity strongly depends on it.

Good agreement is found between discrete tones frequency and velocity predicted by the model and experimental measurements for low Mach numbers (below 0,25).

Further developments are in progress :

- Influence of cavity on Michalke's model.
- Estimation of maximum SPL. Our approach is both experimental and numerical.
- Determination of the relations between frequency, velocity and SPL for velocities around the high acoustic pressure generation.

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