# Standing Waves Modelling of Transonic Shallow Cavity Flows

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Modern military aircraft and Unmanned Combat Air Vehicles (UCAVs) use internal weapon bays for stealth. During flight, the flow inside the bay is very unsteady, and generate strong acoustics comprising broadband noise, and tones, called Rossiter modes [1]. This noise is generated by complex interactions between the shear layer, and upstream travelling pressure waves produced at the aft wall. The acoustic field around ideal cavity flow is well studied, however, the accurate prediction of the cavity modes both in amplitude, frequency and number, can only be achieved by experiments or CFD which are expensive and time consuming.

Numerous studies tried to investigate the generation mechanism of the tones in cavity flows. Rossiter [1] and Heller *et al.*[2] proposed a formula predicting the tones of shallow cavities. Tam *et al.*[3] proposed an other model taking into account more flow characteristics including the shear layer thickness, and the acoustics reflections, agreeing well with the experiments. Handa *et al.*[4] developed a feedback mechanism model for deep cavity flow based on the superposition of reflected waves, agreeing better than Rossiter formula for this type of cavity. However, the previous models for cavity do not predict the relative amplitude of the tones, and not accurately predict the number of modes, while experiments and CFD show a finite number of modes, and large tone variations depending on the conditions, and the geometry. The lack of further explanations on the cavity flow tones generation shows that analysis of cavity flows is still needed to develop an unified cavity flow theory.

This paper will analyse the spatio-temporal behaviour of transonic shallow cavity flow, using the wavelet transform, and will present a one dimensional model of the resonance in cavity flow.

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The cavity flow is very unsteady, and its dynamics must be understood to gain insight in its acoustics, and fluctuations. The continuous Morlet wavelet transform is a method for time-frequency analysis [5], that reveals the temporal fluctuations of the different frequencies present in the flow. Integrating the Wavelet transform in a frequency band over spatial domain, it is possible to reveals the spatio-temporal fluctuations of the flow, this is called the Banded Integrated Wavelet (BIW). This method is applied to a cavity, where the length to depth ratio is 7, the length is 3.59m, the Reynolds Number based on the cavity length $R_{eL}$ is 6.5 million, and the Mach Number is 0.85. Two doors are hold at 110 degrees. The flow was computed with the Scale-Adaptive Simulation k-$\omega$ method on a Mesh of 38.6 million points (Figure 1).

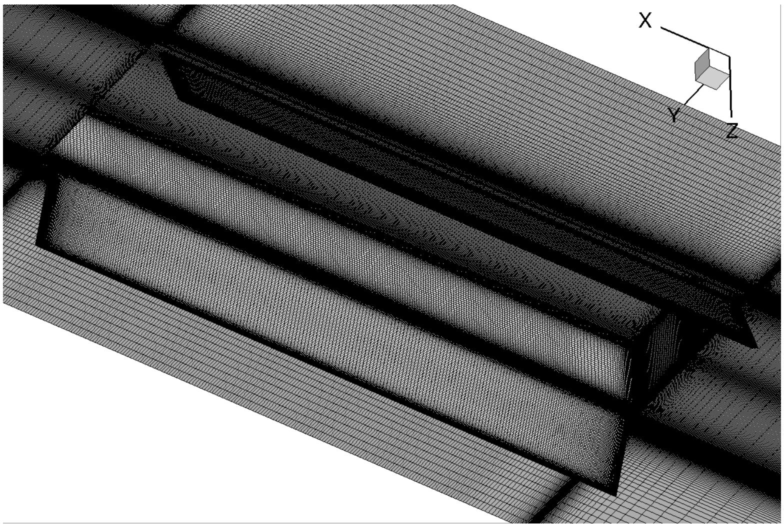
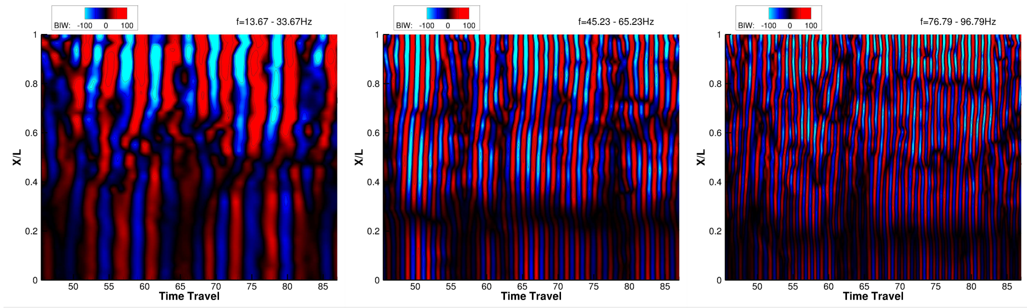


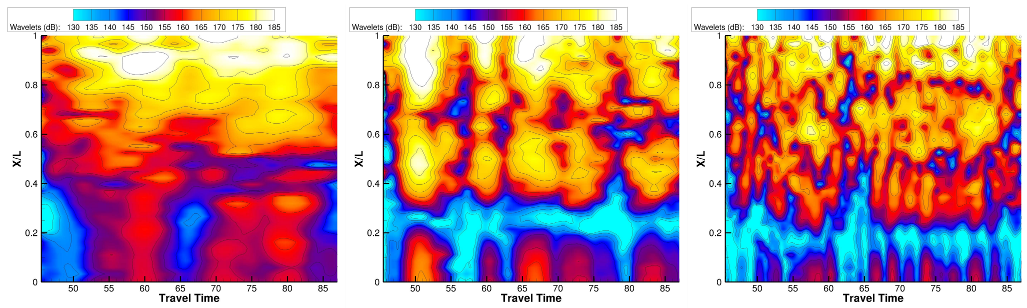

Figure 1: Cavity and doors configuration at 110 degrees.

Figure 2 shows the pressure BIW at the centre-line of the cavity. A standing waves oscillation is visible around the cavity modes with nodes and antinodes of fluctuation. Furthermore, the BIW envelope shows a complex pattern, with time modulation of the standing waves oscillations. The same analysis carried out on an experimental signal on the M219 cavity, shows the same pattern.

Based on this conclusion, a one dimensional standing wave model is built. A white noise is generated at the aft wall, and transported upstream using a 3rd order upwind scheme. Then, the signal is reflected alternatively at the




(a) Mode 1 (b) Mode 2 (c) Mode 3

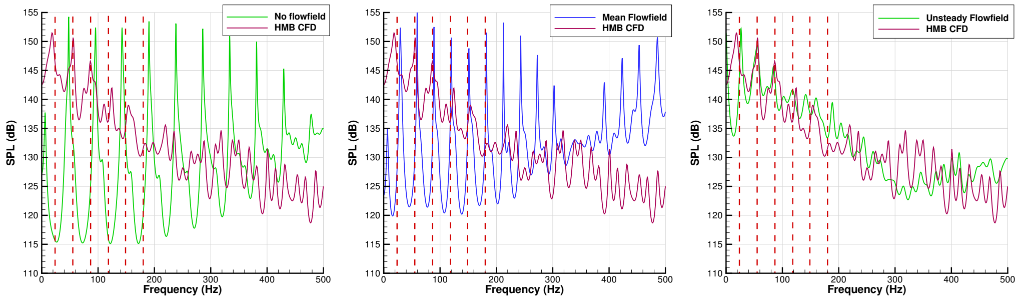



(d) Mode 1 (e) Mode 2 (f) Mode 3

Figure 2: BIW of modes 1 to 3 at the cavity ceiling of the cavity with doors at 110 degrees.

front, and that the aft walls, assuming an absorption of 1% by the walls. 29 reflections are taken into account, and the resulting signal along the cavity is the sum of all reflections.

Three hypothesis on the wave propagation are tested, the ideal, the steady flowfield, and the unsteady flowfield wave resonator. The ideal wave resonator models the pressure waves travelling in a pipe closed at both extremities. The obtained frequencies are much larger than the ones of the cavity flow (Figure 3a). Then, the steady flow resonator is introduced, where the wave speed is assumed to be the sum of the speed of the sound, and of the mean flowfield speed taken from the CFD results. This model gives better agreement (Figure 3b), giving the correct frequency. However, as the Rossiter theory, the mode existence, and their amplitude are not predicted. Finally, the unsteady flowfield resonator use at each timestep, the instantaneous flowfield given by the CFD computation. The result is in a good agreement with




(a) Ideal wave resonator (b) Steady flowfield wave resonator (c) Unsteady flowfield resonator

Figure 3: SPL of the cavity flow models compared to the CFD signal. Rossiter modes in dashed vertical lines.

the CFD, giving the tones frequency, their relative amplitude, and their existence (Figure 3c). Surprisingly, the model also predicts broadband noise, showing that this noise is not only produced by the turbulence of the shear layer, and that all frequencies resonate in the cavity.

This paper will also explain the origin of the store release variability using the wavelet transform, showing a large influence of the standing waves pressure oscillation.

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