

Window Buffeting Measurements of a Full Scale Vehicle and Simplified Small Scale Models

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ABSTRACT

Window buffeting is a major source of flow induced sound and vibration. This paper will describe window buffeting measurements acquired on a full scale vehicle as well as two different simplified small scale models. The experimental data sets included microphone and phase averaged Particle Image Velocimetry (PIV) measurements both of which show that the flow physics are qualitatively and quantitatively similar in all cases. The implication of this result is that simplified laboratory models of a vehicle are sufficient to study the various aspects of window buffeting in full scale vehicles.

INTRODUCTION

Side window and sunroof buffeting are a major source of flow induced noise and vibration in a vehicle. The pressure oscillations of buffeting can be very large and uncomfortable to drivers and other occupants. Experiments used to study this problem have often relied on scaled simplified models of vehicles that can be utilized for parametric studies.

A full scale vehicle in a free stream can be modeled as a flow excited Helmholtz resonator whose flow physics have been examined in many studies. Recently, Ma et al. (2008) thoroughly described the fluid mechanics of the flow excited Helmholtz resonator [1]. Other work on this topic has been completed by Kook and Mongeau [2], Mast and Pierce [3] and Nelson et al. [4]. These studies have led to theoretical models of buffeting that agreed well with many different types of experimental data.

Many studies have sought to control window buffeting through various means, both passive and active. Mongeau et al. [5] used a leading edge spoiler actuated by a loud speaker to control sunroof buffeting and was able to achieve sound reductions of approximately 10 dB. Hémon et al. [6] also used leading edge actuation to achieve sound reduction. The actuators in this case were piezo-electric bimorph elements and they achieved sound reduction of up to 10 dB as well.

Computational studies have been completed to try to understand and predict window buffeting. Crouse et al. [7], for example, used the lattice Boltzman method to study sunroof buffeting and were able to successfully match experimental data from a one fifth scale model. In a separate study, Crouse et al. [8] applied the same numerical scheme to the problem of side window buffeting. The computational model was in reasonable agreement with the experimental results from a 4.5:1 scale simplified model of a vehicle. The computations were able to capture the flow structures in the window.

Several studies have also acquired data in full scale vehicles during road tests. Rossi and Nicolini [9] acquired data on two different full scale vehicles during road tests. A simplified model for the resonant frequency of a vehicle was given and compared to the measured values with moderate success. Kook et al. [10] acquired sunroof buffeting data during a road test in a full scale vehicle. These data were compared to data acquired with a simplified one fifth scale model. While the dimensionless frequency of the flow oscillations was in

good agreement between the full scale vehicle and the model, the amplitude was not.

This paper will provide a description of the flow physics of window buffeting and a direct comparison between small scale simplified models and a full scale vehicle using both microphone and Particle Image Velocimetry (PIV) measurements.

EXPERIMENTAL SETUP

Two main sets of data were acquired for this study. The first was acquired in the Chrysler Aeroacoustic Wind Tunnel (AAWT) in Auburn Hills, MI. The second set of data was acquired at the Hessert Laboratory at the University of Notre Dame. This section will describe the experiments in detail for both sites.

CHRYSLER AAWT EXPERIMENTS – The Chrysler AAWT is a closed loop aeroacoustic tunnel with semi-anechoic treatment effective above 80 Hz. [11] The nozzle of the test section has an area of 27.9 m² and an aspect ratio of 1.7 which yields a nozzle width of 6.88 m and a height of 4.05 m. The tunnel has a maximum speed of ~160 mph (72 m/s). More details of the tunnel can be found in [11].

A production two-box compact size vehicle was placed in the test section with the passenger side rear window fully lowered. This window was open for all measurements. The vehicle cabin remained empty throughout the tests. The vehicle interior was known to have a resonance frequency of approximately 17 Hz and a quality factor, Q , of approximately 6-7. The quality factor is a non-dimensional damping coefficient.

A 1.27 cm B&K microphone was placed inside the cabin to record cabin pressure fluctuations. The acoustic wavelength that corresponds to the natural frequency of the vehicle was large compared to the dimensions of the interior. Specifically, $\lambda \gg \sqrt[3]{V}$, where λ is the acoustic wavelength and V is the volume of the vehicle, such that the unsteady pressure inside the cabin can be considered spatially uniform.

Two different types of data were acquired for this vehicle. The first type of data includes only cabin pressure fluctuation data. The tunnel free stream speed, U , was brought from 30 mph (13.4 m/s) to 82 mph (36.7 m/s) in varying increments of U and unsteady pressure data were recorded at each speed. The tunnel speed was controlled from a central command center. A pause of 15 s was introduced between each speed to allow the tunnel to adjust to the new speed. Data were acquired at 5 kHz for 105 s which provided sufficient independent samples for statistical convergence.

Second, velocity measurements were acquired of the rear passenger side window flow field using PIV. A schematic of the setup is shown in Fig. 1 which gives the location of the cameras and laser sheet as well as the seeding device.

Two cameras of 2048 x 2048 pixels each were used side by side in planar mode to extend the field of view without sacrificing resolution. The cameras were mounted to a solid frame on the floor of the wind tunnel. The frame was held down with ballast to avoid vibration due to the flow over the cameras. The cameras were set as low to the ground as possible to maximize the field of view as well as minimize flow induced vibration.

A dual-pulsed Nd:YAG laser with pulse energy of 120 mJ was used for all PIV measurements. The laser used a cylindrical lens to form the beam into a thin (~1 mm) sheet. The laser was placed as close to the vehicle as possible to minimize dispersion of the beam. A fairing was built to deflect any flow around the laser and to avoid vibration. The interrogation plane was horizontal and perpendicular to the plane of the window at a point halfway up from the bottom of the window. Care was taken to minimize the reflections of the laser into the cameras.

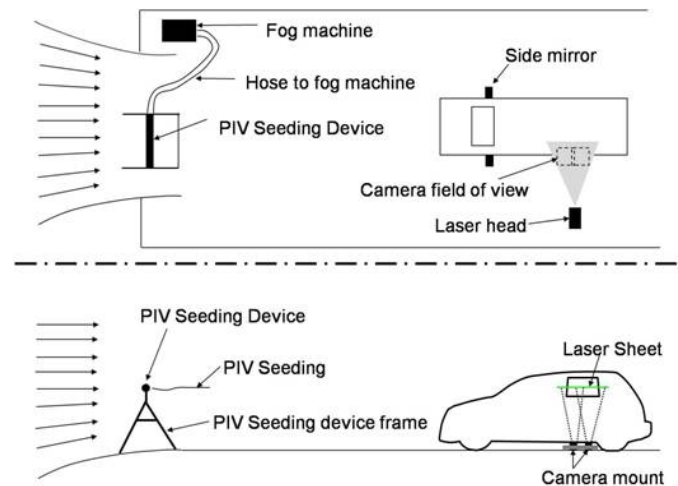


Figure 1. Schematic of PIV setup at Chrysler AAWT.

Calibration of the system was performed by adjusting the camera positions so that the field of view was as desired and the laser sheet was adjusted to be parallel to the free stream and perpendicular to the vehicle at the proper height. The vehicle was then rolled forward. A calibration plate with dimensions of 1 m x 0.5 m was tilted to be aligned with the laser sheet. Once the calibration plate was in place, the cameras were focused and the system was calibrated. The vehicle was then moved back into place by laser guidance marks placed on the vehicle and the camera fields of view were checked to insure that they covered the desired area.

The seeding system was comprised of a pressurized box that housed a Rosco Fog Machine attached by a 15 m, 5.1 cm diameter hose to an aerodynamically shaped section of aluminum ducting that was secured to a fully adjustable "A" frame. This frame was placed as far upstream as possible to allow the flow to recover from any wake left by the device while the pressurized box was kept out of the flow. A slot was cut along the downstream side of the ducting to allow the fog to travel

downstream in a thin sheet. A second, smaller tube was branched off of the main line to seed the cabin of the vehicle. The small (1.27 cm ID) line was fed in through the floor of the vehicle and was sufficient to seed the entire cabin.

The wind tunnel free stream was set to a pre-determined speed and 1000 realizations of the flow were acquired at each speed. The cabin microphone and laser trigger signal were acquired simultaneously at a rate of 1 MHz for 250 ms for each realization.

Both pressure and velocity measurements were acquired for two different vehicle configurations. The first configuration was the original factory configuration and the second was the original factory configuration with the passenger side mirror removed. This allowed for the determination of the effects of an upstream obstruction on window buffeting.

NOTRE DAME EXPERIMENTS – A similar set of data was acquired at the Hessert Laboratory at the University of Notre Dame. Two models were used in this study. The first model was a thin walled flow-excited Helmholtz resonator. The model consisted of a rectangular box of dimensions 50 x 50 x 60 cm attached to the floor of a closed 0.61 x 0.61 m test section. A schematic of the experimental setup is shown in Fig. 2. A square orifice of 12.5 x 12.5 cm was cut from a 0.16 cm aluminum plate. The edges of the orifice were cut to a 30 deg angle to avoid any effects that the thickness of the orifice edges might have on the flow field. The approach boundary layer thickness was found to be 1.65 cm with a momentum thickness of 0.19 cm.

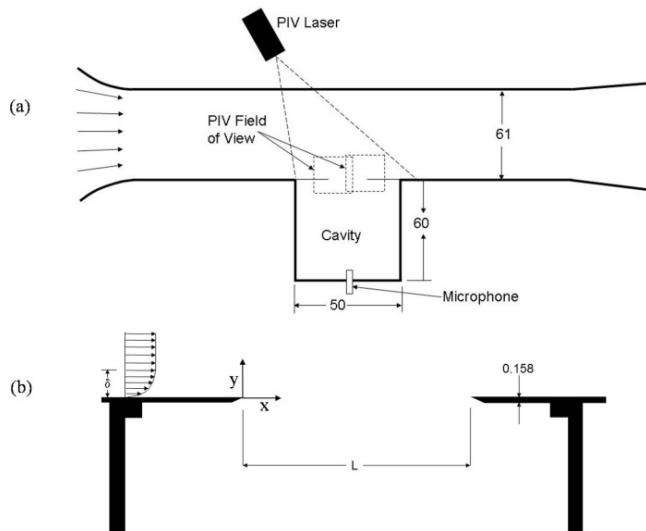


Figure 2. a) Schematic of setup for microphone and PIV measurements in laboratory for 2D resonator. All distances are in cm. b) Magnified view of resonator orifice.

A 1.27 cm B&K microphone was placed in the center of the bottom of the resonator. The test section was attached to an open loop wind tunnel with a maximum speed of approximately 40 m/s. The wind tunnel was

computer controlled and a Pitot static tube was used to measure the free stream speed. This configuration will be referred to as the 2D resonator due to the nominally two dimensional approach flow conditions.

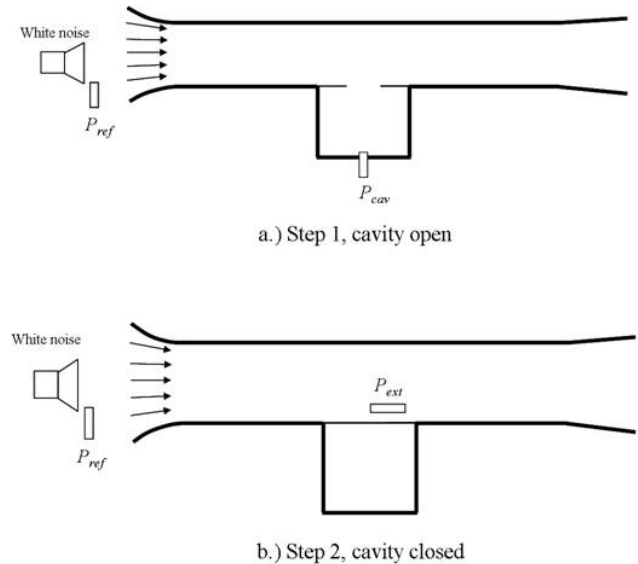


Figure 3. Schematic of two step acoustic response test.

The acoustic properties of the cavity were determined through a two step process. A schematic of the setup is shown in Fig. 3. A loudspeaker with white noise excitation was placed far upstream of the resonator with a reference microphone close to the speaker. The second microphone was placed inside the cavity. In the second step, the cavity was closed and the second microphone was placed just above the closed orifice. Data were acquired at 10 kHz for 105 s for both steps. The resulting acoustic response of the cavity was the ratio of the transfer functions between the two microphones from each step shown in Fig. 4. The magnitude of the peak of the response curve in Fig. 4 was the quality factor, Q , of the cavity and the frequency of that peak was the Helmholtz frequency of the cavity. In Fig. 4 the frequency was normalized as $\omega^* = \omega / \omega_{HR}$ where ω_{HR} is the Helmholtz frequency of the resonator. For this resonator, Q was found to be 11 while the Helmholtz frequency was found to be 46 Hz.

The flow excited resonator data were acquired by bringing the tunnel from 0 to 40 m/s in increments of 0.2 m/s. Resonator pressure fluctuations were acquired at each speed. Data were acquired at 10 kHz for 13 s at each speed with a pause of 15 s between speeds to allow the tunnel to adjust to the new speed.

PIV data of the flow field in the orifice were acquired for the simplified flow-excited Helmholtz resonator. The plane of interest was perpendicular to the floor of the test section and aligned in the streamwise direction. The two PIV cameras were placed side by side and calibrated to be used in a 2D configuration to increase the overall field of view and resolution in the orifice. The resonator was seeded independently from the free stream and was only seeded before taking data to maintain a zero net mass