

# Wind Noise Measurements for Automotive Mirrors

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## ABSTRACT

In order to understand the flow and wind noise characteristics generated by the outside rearview (OSRV) mirror, a series of wind noise measurements for two production mirrors was conducted at the GM Aerodynamics Lab (GMAL) wind tunnel. These measurements included the time-averaged static pressures, surface noise sources, and far field propagation noise. The data obtained in this investigation will be used for future CFD numerical validations. The two mirrors chosen for the test are the GMT360 (a truck mirror) and the GMX320 (a sedan mirror). The test mirror was mounted on an elevated table which was specially designed for the current project to avoid any significant flow boundary layer buildup on the wind tunnel floor. The test conditions reported in this paper include four inlet speeds of 30, 50, 70 and 90 mph at 0 yaw angle. To record the wind noise sources, nine surface flush-mount microphones were used. The microphones were arranged in such a pattern that the sound directivity could be identified in the wake region downstream of the mirror. The far field noises were monitored at six locations by microphone probes located 18 inches above the table top surface. In addition to the microphones, 13 pressure taps were installed along the centerline of the table to record time-averaged surface pressures. Furthermore, noise data were also collected for the wind tunnel and the table without the mirror(s) for further comparison.

## 1. INTRODUCTION

Outside rear view (OSRV) mirror on a vehicle is a major source of wind noise during high speed driving. The noise generated by the OSRV mirror is generally

categorized as a broadband high frequency noise (up to 5000 Hz). At this frequency range, numerous CFD efforts have been attempted in the past at GM but failed to produce acceptable correlations between the CFD predictions and the noise measurements. It isn't clear whether such discrepancy between the test data and the numerical simulations can be improved by further refining the mesh alone. The difficulty of producing good numerical correlations with the GMAL test data for the whole vehicle simulation is thought to be attributed to the following three factors: (1) broad band noise, (2) mid to high frequency range, and (3) complex flow interaction between the mirror wake flow and the A-pillar vortex. Due to the lack of detailed data from the GMAL test for the whole vehicle, except for the sound intensity probe 18 inches away from the driver side window, it is very difficult to identify the sources of the discrepancies between CFD simulations and experiments. In order to better understand the fundamental issues of the flow physics and the noise simulation, more detailed test data are needed preferably for a simplified mirror arrangement, such as an isolated mirror. With such an arrangement, more test data can be obtained for the mirror alone so that one of the difficulties described above can be removed (i.e. no A-pillar). To achieve this goal, the "mirror-on-the-table" study is conducted. This study is to collect detailed flow and noise test data for mirrors mounted on an elevated table. Both the noise sources and the propagated noise were measured. The noise sources for the current study are the time-dependent pressure fluctuations on the top surface of the table and the mirror.

To avoid the significant flow boundary layer on the wind tunnel floor and to facilitate the installation of the flow and noise measuring instruments, the mirror was

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mounted on a specially designed table. The table was carefully designed for the current study to minimize any self-induced wind noise and to be sturdy and heavy enough to withstand the high speed wind load. Two production mirrors, one for the GMT360 (SUV mirror) and the other for the GMX320 (sedan mirror), were used for this study. The test conditions include four flow speeds (30, 50, 70 and 90 mph) at 0°, -10° and +10° yaw angles. Only the test data with 0° yaw angle condition are presented in this paper. A total of nine surface mounted microphones are arranged in a pattern that can reveal the noise source strength for both ahead and behind the mirror and sound directivity behind the mirror. Free stream microphone probes were used to record the far field sound pressure levels at six locations. Noise data were also collected for the table without the mirror at the same test conditions for quantifying the mirror generated noise.

## 2. DESIGN OF THE TABLE FIXTURE

The table is used to hold the mirror model in place and to facilitate the installation of the measuring instruments. With this in mind, the following criteria were used to guide the design:

1. The length and width of the table should be long and wide enough to cover the recirculation zone behind the mirror.
2. The height of the table should allow the mirror to stay mostly in the free stream of the wind tunnel and allow easy access to install and remove the measuring instruments.
3. The table should be sturdy and heavy enough to minimize vibration under the test wind condition.
4. The edges of the table need to be aerodynamically shaped to minimize or eliminate non-mirror related wind noise.
5. The legs of the table should be aerodynamically shaped as well. It should be mentioned that the noise generated from the flow around the legs is not a major concern for the data collected above the table due to the fact that they are under the table and thus are out of sight.
6. The microphones should be easy to install and secured tightly onto the table and the same for the removal of the microphones.

### 2.1 Table Top

To satisfy the first design criterion above, a preliminary Fluent analysis was conducted to estimate the length and width of the table by visualizing the flow field behind the mirror. The second criterion was satisfied by the same Fluent analysis and also by referring to an earlier

work in the literature [1]. With the first two criteria investigated and finalized, the other four criteria were considered further into the design by looking into the details of each component. Figure 1 shows the final design of the entire table. The table includes a 25.4 mm thick lexan rectangle which was fitted with elongated NACA 0012 profile aluminum leading and trailing edges. The two side edges of the lexan table were rounded with radius of 12.7 mm. Excluding the aluminum leading and the trailing edges, the table has the dimension of 1802.4 mm (length) x 1143 mm (width). The leading and the trailing edges are 97.23 mm long and 132.32 mm long, respectively. Figure 2 shows the detailed profiles of the leading and trailing edges, respectively. The leading and the trailing edge profiles are the same as the NACA 0012 airfoil with different axial stretches. The airfoil was designed to achieve a maximum thickness of 25.4 mm. As seen in Figure 2, the trailing edge is relatively longer and thinner than the leading edge profile. The two side edges of the table are half circular profile with a radius of 12.7 mm. The side edges of the table weren't in the direct path of the flow and thus the simple half circle side profile was thought to be smooth enough to serve the purpose. The table top surface is 762 mm above the wind tunnel floor.

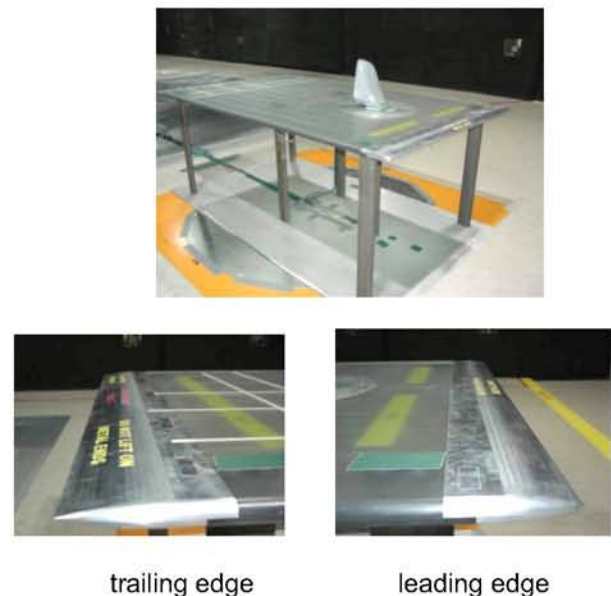


Figure 1. The test table with GMX320 mirror: the inserts are leading and trailing edge, respectively.

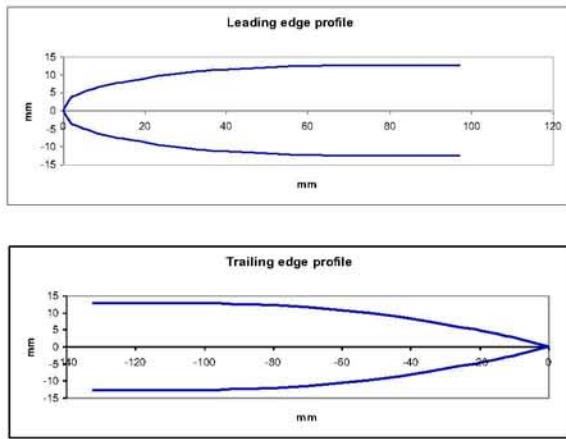


Figure 2. Leading and trailing edge profiles of the table.

The table top has a 200 mm radius recessed hole to accommodate the mirror model with the adaptor disk. Figure 3 shows the table top with the recessed hole. The center of the hole is located at 535 mm from the airfoil leading edge of the table.

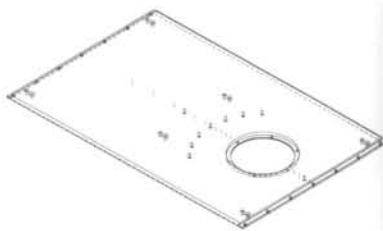
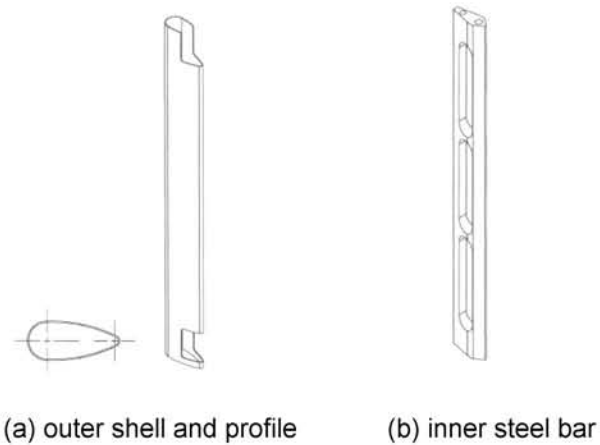


Figure 3. The table top with the mirror adaptor hole.

## 2.2 Table Legs and Base Plate

Six of the seven legs that support the table are made of steel bars with an outer thin airfoil shape casing. With this design, the inner steel bars provide the necessary structural support while the thin outer airfoil casing minimizes the flow interferences and noise generation. Figure 4 shows both the inner steel bar and the outer airfoil casing including the airfoil shape.

The table/legs assembly was fastened to a base aluminum plate with a dimension of 2032 mm (L) x 1143 mm (W) and 12.7 mm thick. The leading and the trailing edges of the base plate were tapered to zero thickness at both ends with 14 degrees. The two side edges of the base plate were machined to form a quarter circle with a radius of 6.35 mm. The whole assembly of table/legs/base plate is secured by screws to the existing holes in the wind tunnel floor (see Figure 1).



(a) outer shell and profile

(b) inner steel bar

Figure 4. The supporting legs of the table: (a). Outer airfoil casing for the center leg. (b). Inner steel bar.

## 2.3 Mirror Adaptor Disk

The mirror was not directly secured to the table top. Instead, it was attached to an aluminum adaptor disk with a radius of 200 mm. The thickness of the adaptor disk is 19.4 mm. The use of the adaptor disk made it easy for swapping mirror models and the instrumentation in the wind tunnel. Figure 5 shows the mirror adaptor disk and the mirror. It also reveals the pre-installation of the static pressure taps and tubes. The design of the adaptor also allows the whole disk to rotate between  $\pm 10$  degrees with a  $5^\circ$  increment yaw angles.



Figure 5. GMT360 mirror with adaptor disk.

## 2.4 Instrumentation

Both time-averaged pressure and unsteady microphones are flush-mounted on the top surface of the table and microphone probes were mounted on a moving stand for far field radiated sound measurements.

**2.4.1 Static pressure taps** – Time-averaged static pressures were measured by 13 pressure taps located along the centerline of the table at both upstream and downstream of the mirror. They were flush-mounted to the top surface of the table. The tip of the probe is 1/16 inch in diameter made by Scanivalve [2]. Out of

the 13 pressure taps, 10 were located downstream of the mirror (nine on the table and one on the adaptor disk) and extended to 1000 mm from the bottom center of the mirror. There are 3 pressure taps installed upstream of the mirror. Figure 6 shows the exact locations of the pressure taps.

**2.4.2 Surface flush-mount microphones** - Nine 0.5 inch (12.7 mm) diameter B&K high sensitivity microphones were flush-mounted to the top surface of the table. It was laid out in such a way that seven of them were installed in the wake region downstream of the mirror. In the wake region, they were arranged in a circular arc pattern with a 400 mm radius from the mirror bottom center within  $\pm 45^\circ$  with  $15^\circ$  increments. The upstream microphone is located 320 mm from the center of the mirror and the one in the far downstream wake region is 600 mm away from the center of the mirror. Figure 7 shows the pattern of the surface microphone layout. To hold the microphones in place with flushness to the table and firmly attached to the table, a specially designed quick-release plastic collar and screw for each microphone was used from underneath the table. Figure 8 shows this arrangement. For the tests without the microphones, circular cylinder aluminum plugs with 12.7mm diameter and 55.5 mm length were used to seal the microphone holes on the table.

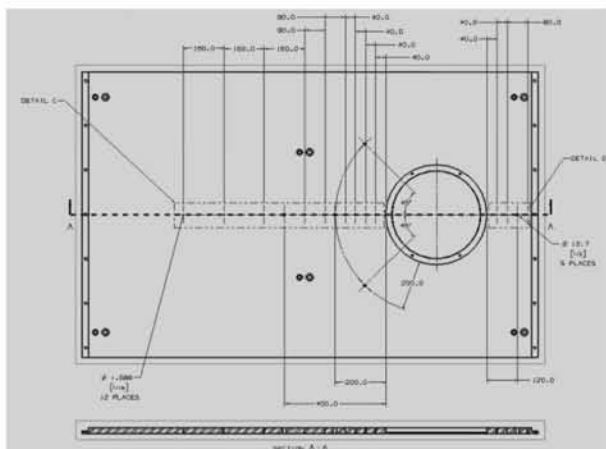


Figure 6. Static pressure tap layout along the centerline of the table.

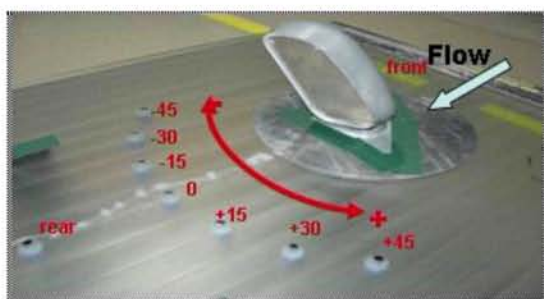


Figure 7. Surface mount microphone layout.



Figure 8. The plastic collar and screw underneath the table to secure the flush mount microphones.

### 3. TEST DATA COLLECTION

The test conditions include two mirror models, four flow speeds (30, 50, 70 and 90 mph) at  $0^\circ$ ,  $-10^\circ$  and  $+10^\circ$  yaw angles. In addition to the tests with mirror models, the table without the mirror installed was also tested for four flow speeds as well to establish a baseline data for mirror noise comparison. Due to the space limit, only the test data with  $0^\circ$  yaw angle condition are presented in this paper. The  $\pm 10^\circ$  yaw angles test results will be reported in the future. The geometries of the two mirrors are shown in Figure 9.

#### OSRV Mirror Test models



Figure 9. Profiles of the two mirrors.

#### 3.1 Time-Averaged Static Pressure

Figure 6 shows that there are 13 pressure taps, 3 in front and 10 behind the mirror. The centerline pressure coefficients for all the test cases are shown in Figure 10. The pressure coefficients are nearly independent of the flow speeds for all GMX320 mirror data. In all speeds for

these two mirrors, the pressure distributions show a pressure sharp rise near the model base due to the stagnation flow and a significant drop behind the mirror model due to flow separation. After the flow separation, the pressure recovers to the incoming flow pressure level for all test conditions within the length of the table. The pressure coefficient,  $C_p$ , is defined as

$$C_p = P / (1/2 \rho_r V_r^2)$$

where,  $\rho_r$  and  $V_r$  are the reference incoming flow density and velocity respectively.

### 3.2 Surface Microphone Data

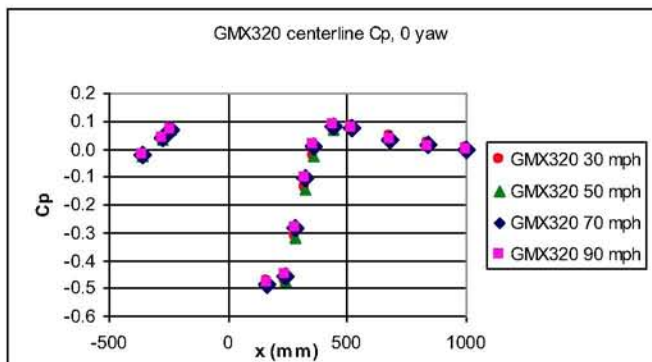
#### 3.2.1 GMT360 mirror

(a). For surface microphones (GMT360): "front", "0" and "rear" at 0 yaw angle

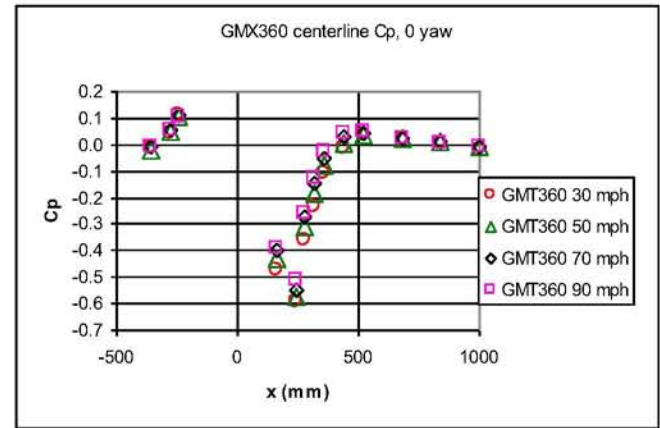
These three microphones are the surface microphones located along the centerline of the table (see Figure 7). Figure 11 shows the surface microphone "front" which is the microphone located between the mirror and the leading edge of the table. The Sound Pressure Level (SPL) is defined as,

$$SPL = 20 \log \left( \frac{p}{p_0} \right)$$

where  $p_0$  is the reference pressure and is equal 20  $\mu$ Pa. Since it is located upstream of the mirror, the influence of the mirror presence is very minimal. As seen in Figure 11, the noise spectra with and without the GMT360 mirror are almost identical for all flow speeds. The noise levels for frequencies above 500 Hz reveal a sharp increase from 30 mph to 50 mph and become rather flat with speeds for 50, 70 and 90 mph. This indicates that the noise level for this table design is relatively low for flow speed below 50 mph for most of the frequency range. The noise levels at this location are mainly contributed by the leading edge of the table where the free stream flow is suddenly brought to rest and then accelerated around and after the leading edge.



(a). GMX320 mirror



(b). GMT360 mirror

Figure 10. Time average static pressure coefficient along the centerline of the table for (a) GMX320 mirror and (b) GMT360 mirror.

Also it should be noted that the noise source for the surface microphones (on a no mirror run) is most likely the boundary layer noise (i.e. the flow interacting with the microphone). There might be other possible noise sources contributed from the wind tunnel walls, floor and ceiling. Their contributions are thought to be embedded into the data already and they are all treated equal with and without the mirror model installed. Figure 12 shows the sound spectra for the "0" surface microphone with and without the GMT360 mirror for four speeds. The "0" microphone is right behind the mirror and on the centerline of the table. At this location, it is inside the recirculation zone of the wake region when the mirror is present. Figure 12 reveals that the spectra for four speeds without the mirror model (thin lines) are very similar to the noise spectra of the "front" microphone. In other words, the noise contribution is mainly from the leading edge (and possibly, the "other sources" described above). However, with the mirror model installed, the noise curves (thicker lines) are different, particularly for the lower frequency range. The noise levels are much higher for the frequencies lower than 3000 Hz for 90 mph, 2000 Hz for 70 mph and about 1000 Hz for 50 mph. The effect of the mirror can still be seen for the higher frequency range, however, its effect seems to diminish above those frequencies. Similar findings can be seen for the "rear" microphone in Figure 13. In general, the peak SPL's in Figure 13 are lower than the one in Figure 12 with the mirror model installed. This is due to the location of the "rear" microphone which is farther away from the "action zone" behind the mirror.