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Aero Acoustics Analysis of Car's ORVM

Roshan Kumar Gopal[1], Remin V.[2], Richard Sen[3]
[1]Technical Support Engineer, CAD SOLUTIONS, Coimbatore-641 008, Tamil Nadu, India
[2,3]UG Student, Department of Mechanical Engineering, Saveetha University, Chennai, TN, India
([1]aeroross@gmail.com, [2]remin47@gmail.com, [3]richardsen2493@gmail.com)

Abstract- The air stream induced aerodynamic noise generation at the outside rear view mirror at high speeds could make discomfort for the driver and the passenger in a car. This is due to poor aerodynamic characteristics of the ORVM's design. Designing a new ORVM with low noise generation could be a complicated process since it requires the design to be less noise generating and should not sacrifice the aerodynamic stability of the component. The objective of this study is to perform a comparative numerical study on aero acoustic characteristics of car outside rear view mirror (ORVM). A simple ORVM geometry of existing design has been modeled and analyzed with and without indicator using ANSYS-Fluent.

Keywords – *Aero Acoustics, k-ε turbulence model, ORVM, Broadband Noise Source model*

I. INTRODUCTION

The recent developments in the field of Computational Fluid Dynamics (CFD) let to a new field of Computational Aero Acoustics (CAA). This field enables us to analyze the aerodynamically generated noise around a body so that we could find the actual noise generation point, intensity of the noise, propagation of noise etc.,. This field has become popular in the car development process to find and reduce the noise generating parts on the car's external body, such as Outside Rear View Mirror, Antennas, Spoilers etc.,. During high speed these external add-on parts will generate a noise which is induced by the air flow over it. Even the noise isolation cabins of nowadays are insufficient in stopping the noise getting inside the cabin and produce discomfort to the passengers and the driver.

Aerodynamically speaking the car's ORVM is considered as a bluff body in a high speed flow. In this paper the car's ORVM is taken and analyzed for Aero Acoustics. By using the k-ε turbulence model and broadband noise source model two sets of generic mirror model is analyzed and based on the results the ways to reduce the aerodynamically generated noise are exposed.

II. ANALYSIS METHODOLOGY

Even though the direct method can be used for calculating both noise generation and noise propagation at the same time, it takes huge amount of computing power and computing time. To simplify the analysis process steady state analysis in done on the model by using k-ε turbulence model and broadband noise source acoustics model. The assumptions made are that the flow is a steady and incompressible flow since the body is considered to travel at low Mach number.

III. MODELING OF THE MIRROR

For the mirror a simple generic model is created with two sets of variations. One is the varying of inclination angle of the mirror to the car body and the second one is placing a turn indicator on the outer edge of the mirror. All the dimension are in millimeters (mm). For each model same set of dimensions are provided as shown below:

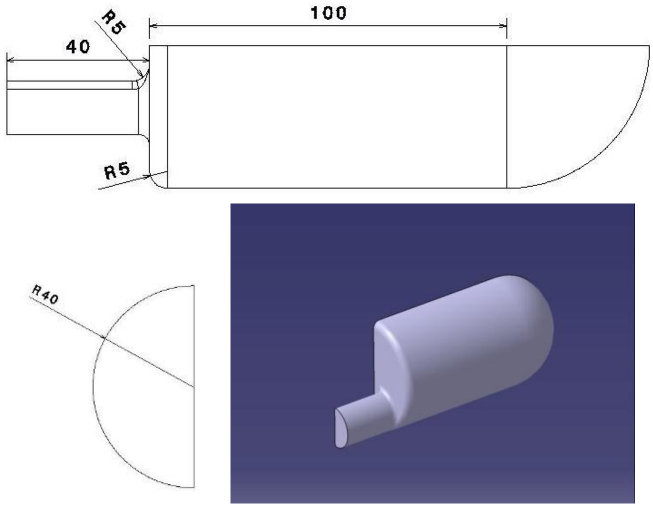


Figure 1. Generic ORVM model without turn indicator

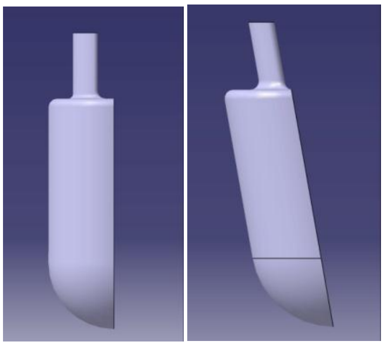


Figure 2. 90 and with 80deg inclination

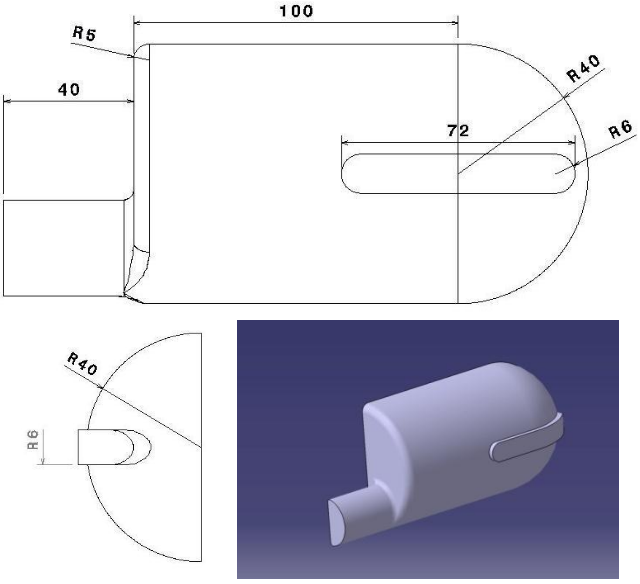


Figure 3. Generic ORVM with turn indicators

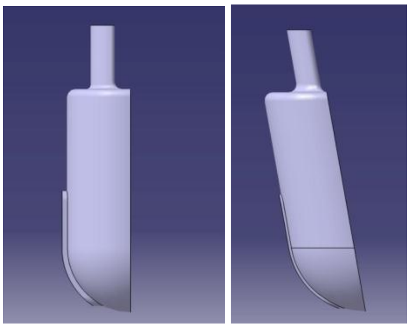


Figure 4. Without and with 80deg inclination

Around the generic side view mirror a rectangular flow domain is created for analyzing the flow properties around and far away from the mirror. This provides the opportunity to visualize the noise generation and propagation around the mirror.

IV. MESHING

The meshing strategy used here is unstructured mesh with tetrahedral elements. The mesh has been made finer for accurate results.

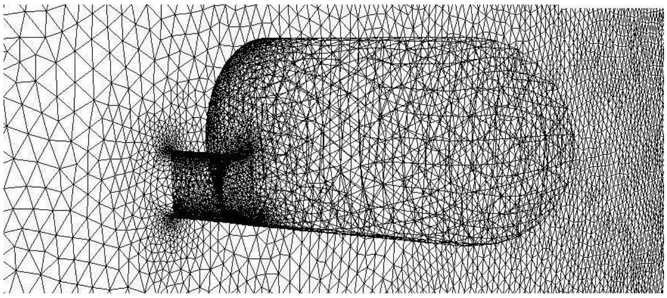


Figure 5. Tetrahedral mesh for mirror without turn indicator

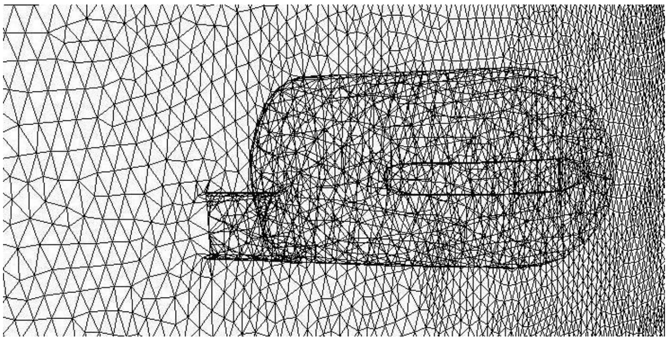


Figure 6. Tetrahedral mesh for mirror with turn indicator

The mirror is surrounded by a cuboid flow domain which enables us to see the noise generation and propagation around the mirror.

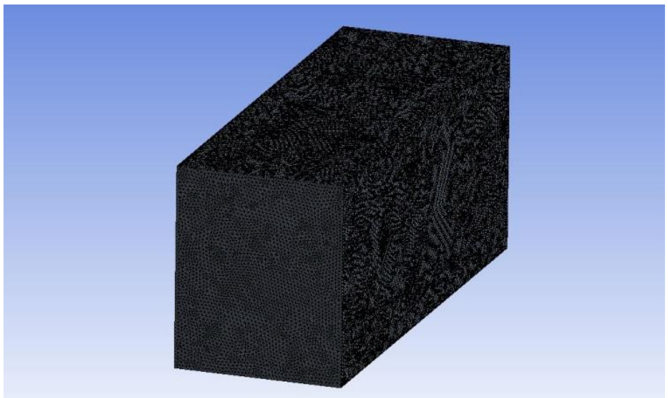


Figure 7. Flow Domain

V. TURBULENCE MODELS AND ACOUSTICS MODEL

Being determined to find out the aero acoustic noise source, one should carefully select the turbulence model for the flow around the side view mirror. The Reynolds Averaged Navier Stokes (RANS) model shows the possibility to analysis for acoustics in a steady flow. Among the RANS models k-ε turbulence model with enhanced wall treatment turned out to be appropriate turbulence model for analysis. The transport equations for standard k-ε turbulence model are:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}[(\mu + \frac{\mu_t}{\sigma_k})\frac{\partial k}{\partial x_j}] + G_k + G_b - \rho\varepsilon - Y_M + S_k$$

$$\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_j}[(\mu + \frac{\mu_t}{\sigma_\varepsilon})\frac{\partial \varepsilon}{\partial x_j}] + C_1\frac{\varepsilon}{k}(G_k + C_3 G_b) - C_2(\frac{\varepsilon^2}{k}) + S_\varepsilon$$

Where, G_k represents the generation of turbulence kinetic energy due to the mean velocity gradients, G_b is the generation of turbulence kinetic energy due to buoyancy, Y_M represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate, σ_k and σ_ε are the turbulent Prandtl numbers for k and ε, $C_{1\varepsilon}$, $C_{2\varepsilon}$ and $C_{3\varepsilon}$ are constants and S_k and S_ε are user defined source terms respectively.

For Acoustics, the Broadband noise source model provides the possibilities to find out the noise source in a broad range of frequencies in a steady state flow. Unlike the direct method and integral method the broadband noise source model does not require transient analysis, which takes huge amount of time and computing power to calculate the noise source and propagation.

The acoustic pressure can be calculated from the formula,

$$P_A = \propto \rho_0 \left(\frac{u^3}{l}\right)(\frac{u^5}{a_0^5})$$

Where, u and l are turbulent velocity and length scale, a_0 is the speed of sound and α is the model constant. The acoustic power is calculated in the form dB from the formula,

$$L_p = 10\log(\frac{P_A}{P_{ref}})$$

Where, $P_{ref} = 10^{-12}$ W/m^3 is the reference acoustic power.

VI. Boundary Conditions and Solver Preferences

The boundary conditions and solver settings are tabulated below,

TABLE I. BOUNDARY CONDITIONS

Boundary	Type	Value
Inlet	Constant velocity inlet	120 Km/h
Outlet	Constant pressure Outlet	0Pa (Gauge Pressure)
Domain_wall	Wall	-
Mirror	Wall	-

TABLE II. SOLVER SETTINGS

Type	Setting
Fluid	Air
Pressure-velocity coupling	Coupled
Pressure	Second Order
Momentum	Second Order Upwind
Turbulent Kinetic Energy	Second Order Upwind
Specific Dissipation rate	Second Order Upwind
Energy	Second Order Upwind

The coupled solver provides better results when compared to Simple solvers, since it solves for both velocity and pressure at the same time.

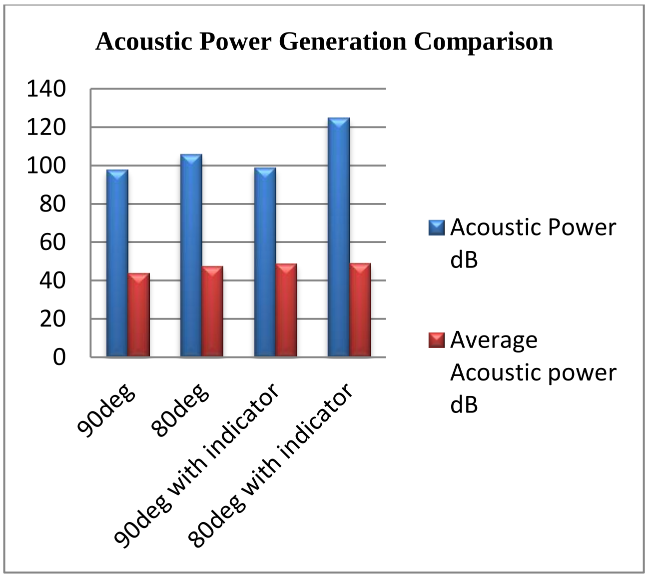
VII. Analysis and Results

The aero acoustics analysis is done for all four models and the results has been tabled and plotted. The noise generation of all the models is given below:

TABLE III. RESULT COMPARISON

	90deg	80deg	90deg with indicator	80deg with indicator
Acoustic Power Max (dB)	97.8	106	98.9	125
Average Acoustic Power (dB)	43.99	47.66	48.93	49.03

CHART I. ACOUSTIC POWER COMPARISON



The above data signifies that the noise generation is much smaller in the 90deg mirror without a side indicator and the noise generation is maximum in the 80deg mirror with the side indicator. Although adding a side indicator to the 90deg mirror show significant amount of noise reduction when compared with both the 80deg mirror without side indicator and the 80deg mirror with the side indicator. But still the average noise generation and the maximum noise generation is slightly larger compared to the 90deg mirror without side indicator.

The noise propagation of the model is calculated by placing a receiver points at two locations in the flow domain. The two point's coordinates are,

Point 1: X=0.125m, Y = 0.75m, Z = 0m

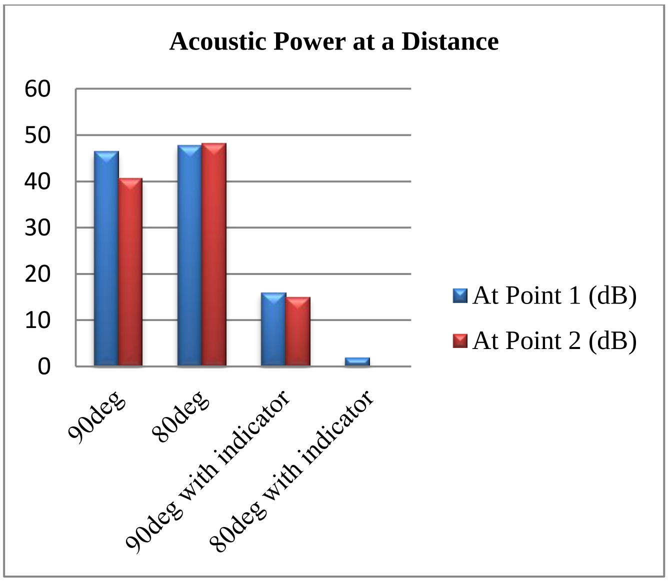
Point 2: X = 0.125m, Y = 0.75m, Z = 0.04m

The first point is aligned with the stalk of the mirror and the second point is aligned with the middle section of the mirror. The results obtained are as follows,

TABLE IV. ACOUSTIC POWER AT A DISTANCE FROM SIDE MIRROR

Acoustic Power	90deg	80deg	90deg with indicator	80deg with indicator
At Point 1 (dB)	46.49	47.84	16	1.934
At Point 2 (dB)	40.69	48.30	15.018	0

CHART II. ACOUSTIC POWER AT A DISTANCE FROM SIDE MIRROR



As an exact contrast to the noise generation chart, the noise propagation data shows that the addition of turn indicator and inclination of the incident angle to the side view mirror reduces the noise propagation extremely. The values exhibits that the noise generated by the normal mirror without inclination and turn indicator does propagates to large distances causing disturbance to the passenger inside the cabin. These values can be easily validated by the contour maps of the models.

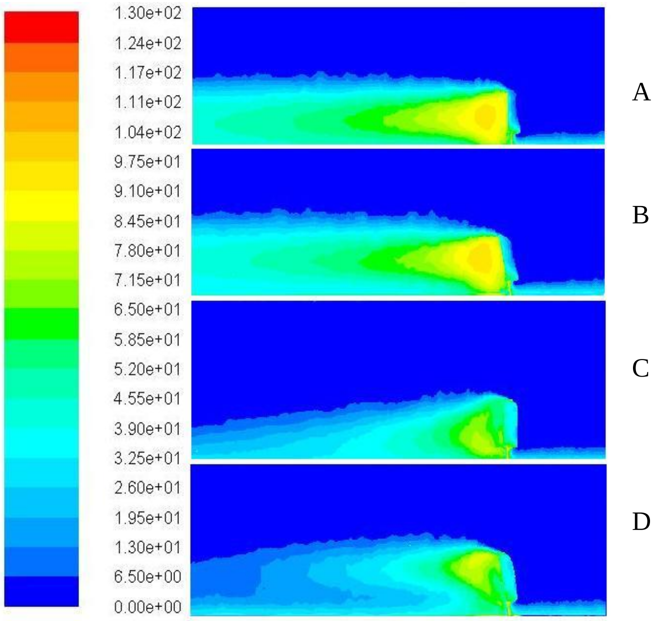


Figure 8. Comparison of noise propagation of all models (A – OVRM with 90deg inclination, B – OVRM with 80deg inclination, C – OVRM with 90deg inclination and turn indicator, D – OVRM with 80deg inclination and turn indicator.)

VIII. CONCLUSION

In this paper the primary objective is to perform a comparative study on aero acoustic of outside rear view mirror .Upon analyzing the four models, two models with 90deg inclination show better improvement in noise generation. But when comes to a noiseless cabin, the noise propagation plays an important role. Taking this into the consideration the mirror with the turn indicators (i.e., an additional bluff body) and the inclination angle does have the high acoustic power but the noise propagation from the mirror is much low than the other mirrors, especially the ones without the turn indicators on the sides. Comparative study shows that ORVM with side mirror has high power level compared to normal. So to reduce the noise level the turn indicator on the side mirror should be merged with the mirror head.

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