ON INVESTIGATING THE C-TRANSITION CURVE FOR NOISE REDUCTION

Azma Putra[1*], Or Khai Hee[2], Saifudin Hafiz Yahaya[3]

[1,2]Faculty of Mechanical Engineering,
Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya 76100, Durian Tunggal, Melaka, Malaysia

[3]Faculty of Manufacturing Engineering,
Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya 76100, Durian Tunggal, Melaka, Malaysia

ABSTRACT

Among the application of a transition curve is to design the curvature of a highway to ensure smoothness of a moving vehicle in high speed. Investigation on C-Transition Curve (CTC) is presented here on its effect to reduce noise due to airflow. A simple C-Transition Curve is generated from mathematical calculation using a parametric equation and the Computer Fluid Dynamics (CFD) model is developed to assess the turbulence flow generated on the surface of the C-Transition Curve structure. Analysis is also conducted on a semi-circle shape for comparison. It is found that the structure constructed from the C-Transition Curve gives lower Reynolds number. Validation through experiment is also conducted showing lower output of noise level from the C-Transition Curve structure.

KEYWORDS: *C-transition curve; Computational fluid dynamics; Noise*

1.0 INTRODUCTION

In civil engineering, transition curves are the geometric solutions which have been used widely in road design by engineers to provide smooth path for vehicle moving on the road where the curves will introduce action of centrifugal force during cornering (Kobryń, 2011). When a car is on a curved line, centrifugal forces are developed and applied in full scale at the start of the curve (Easa & Hassan, 2000). However, the case will be different when a transition curve is used because the transition curve allows the centripetal acceleration of the vehicle to increase or decrease gradually as the vehicle enters or leaves the circular curve (Pirti & Yücel, 2012). Thus, in modern road and railway construction,

* Corresponding author email: azma.putra@utem.edu.my

the transition curve is applied in the design stage in order to prevent a sudden change of the centrifugal force, which is due to the impact of the motion in a sharp curve (Pirti & Yücel, 2012).

Kobryń (2011) finds out that sight distance in a highway curved line can be optimized when the minimum curvature radius and the radius of the appropriate easement curve are the same, where this can be provided by a transition curve. This enables a secure and suitable sight distance for a driver which can contribute to road safety. Beside for the later purposes, the transition curve is also used to enhance highway esthetics (Easa & Hassan, 2000).

The transition curves are further developed with the development of mathematical calculations and computer simulation. The equations for various shapes of transition curves have been proposed by Walton and Meek (1999). Figure 1 shows the C-Transition Curve (CTC) which is used for designing the highway and railway path. Figure 2 shows the effect of the shape control on generating the transition curves (Habib & Sakai, 2009).

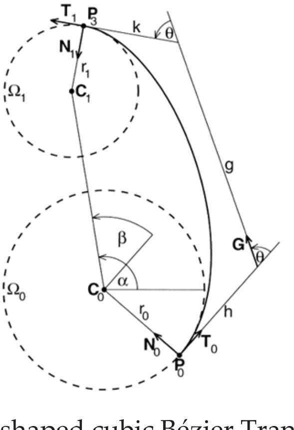


Figure 1. A C-shaped cubic Bézier Transition Curve
(Walton & Meek, 1999)

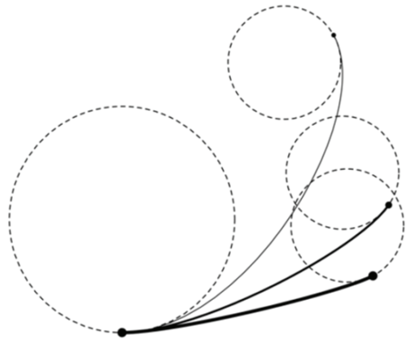


Figure 2. Various designs of C-Transition Curve by using shape control technique (Habib & Sakai, 2009)

This paper proposes the application of the CTC to reduce generated noise due to airflow. The smoothness provides by the CTC is aimed to reduce the air drag to provide smoother flow of air which can reduce the turbulent flow and therefore results in reducing the noise.

2.0 DESIGN OF THE C-TRANSITION CURVE

In this study, the C-Transition Curve (CTC) is developed resembling a semi-circle shape as in Habib & Sakai (2009). Here the parametric form of the function can be written as

$$f(x,y) = [x(t), y(t)] \tag{1}$$

where $x(t) = 2(1-t)^2$ and $y(t) = 2(1-t)^2 + 4t(1-t)^2 + 2t^2(1-t)$ for $0 \le t \le 1$

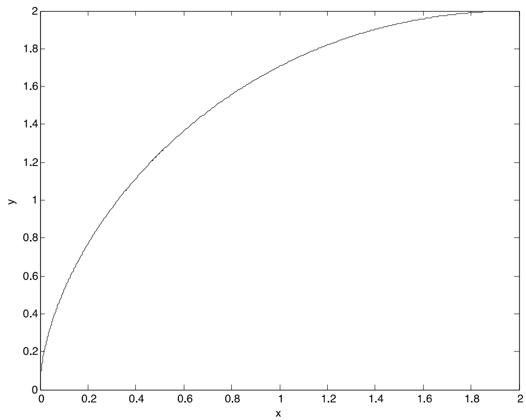


Figure 3. Half section of the C-Transition Curve

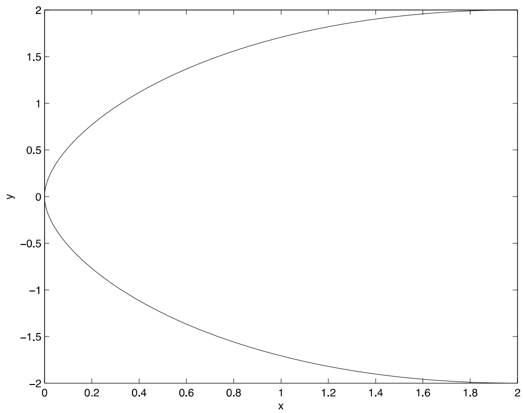


Figure 4. The generated C-Transition Curve

For the purpose of comparison, a half-circle shape is also developed. Figure 5 shows the comparison between the half-circle curve and the CTC. Both curves can be seen to depart from the same point, but then differ in the route to reach the same end point.

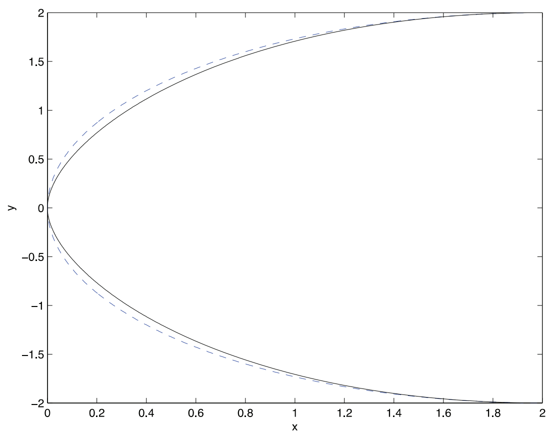


Figure 5. Comparison of the C-Transition Curve (solid line) with the half-circle curve (dashed line).

3.0 COMPUTATIONAL FLUID DYNAMICS (CFD) ANALYSIS

The performance of the CTC subject to airflow is accessed using the Computational Fluid Dynamics (CFD). The Fluent-Ansys software is employed for this purpose. In this analysis, the flow is considered to be compressible and turbulent where the fluid is air with high velocity and the Reynolds Number (Re) is more than 2×10^6 (Çengel & Cimbala, 2010). The solver used the Density Based Implicit Solver, which can produce good results for high speed compressible flows.

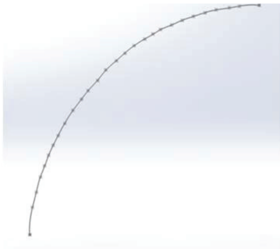
From the CFD simulation, the results obtained from the analysis of CTC and half-circle are compared to investigate the curve producing higher noise level. The noise level from the analysis are referred from the Reynolds Number, which is a dimensionless equation to determine the type of flow given by (Çengel & Cimbala, 2010)

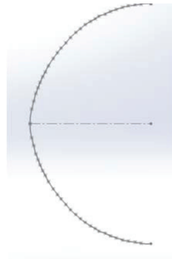
$$\mathrm{Re} = \frac{\rho V D}{\mu} \tag{2}$$

where ρ is the density of fluid, V is the mean velocity of fluid, D is the diameter of a cylinder or sphere and μ is the dynamic viscosity of the fluid.

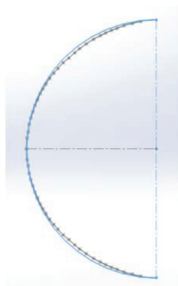
According to Thompson (2005), high air velocity and air turbulence can increase the noise level in the ventilation system. For example, by increasing the air velocity by a factor of 2, the noise level can increase up to 20 dB. Fuchs et al. (2010) also agree that higher velocity and greater cavity downstream of the point where the turbulence occurs increases the intensity of the noise.

Before proceeding to the simulation to observe the fluid dynamics, the CTC is first generated from the parametric equation as in Equation (1) by using “Spline” in SolidWorks in order to be compatible as the input in the ANSYS Fluent. From the equation, 28 coordinates are created and joined together to form the half section of the CTC as seen in Figure 6(a). This is then mirrored to form the other half of the section as shown in Figure 6(b). Figure 6(c) shows the comparison with the half-circle curve which can be seen to have the same contour as that developed using Matlab in Figure 5.





(a) (b)

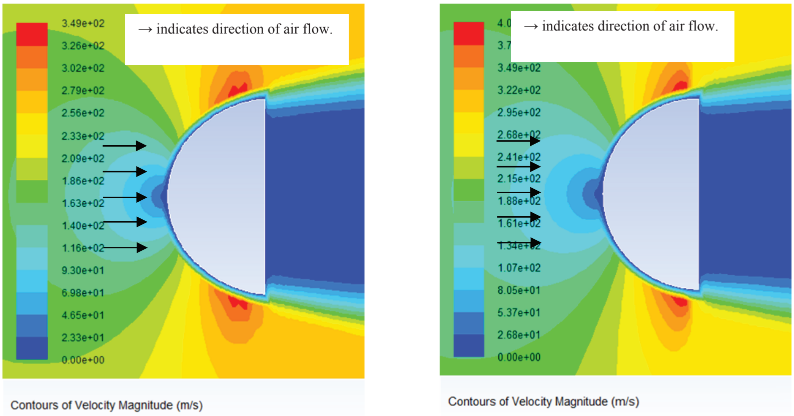


(c)

Figure 6. The curves created using SolidWorks: (a) Half-section of CTC created from 28 coordinates, (b) Full section of CTC and (c) Comparison with the half-circle curve

The CFD simulation in ANSYS Fluent is then developed with the fluid properties of Mach number 0.7 (velocity of air = 236.15 m/s), the Gauge pressure 73048 Pascal, the turbulent intensity 0.01 % and temperature 283.24 K. The simulation was run for 1000 iterations. The flowing fluid is ideal gas.

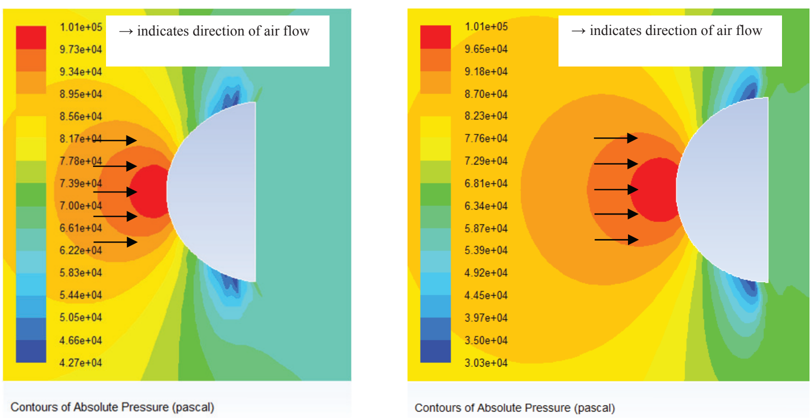
Figure 7 shows the velocity contour from the CFD simulation for the CTC and the half-circle curve. It shows that the high velocity air flow for both curves is concentrated on the upper edge and lower edge of the curve, close to the discontinuity boundary of the circle. The CTC can be seen to have contour with smaller velocity magnitude compared to the half-circle curve.



(a) (b)

Figure 7. The velocity contour from CFD simulation for (a) CTC and (b) Half-circle curve

Figure 8 presents the simulation results for the pressure. As for the velocity, the high pressure region concentrates at the tip of the curves. The positon of the highest pressure is now contrary to the location of the highest velocity obeying the Bernoulli's law. The half-circle now shows more low pressure region compared to the CTC.



(a) (b)

Figure 8. The pressure contour from CFD simulation for (a) CTC and (b) Half-circle curve

Figures 7 and 8 are the results for the flow coming in normal direction to center of the curve. To enhance the analysis, simulation is also made for flow with angle of 10 degree from the horizontal, normal axis of the center of the curve. Figure 9 shows the velocity contour with 10^{o} angle of flow incidence. The results also show that CTC still has lower velocity magnitude compared to half-circle curve.

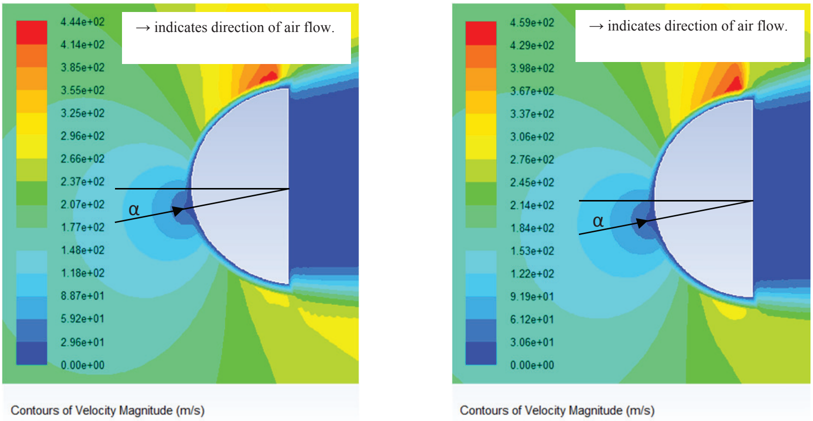


Figure 9. The velocity contour from CFD simulation with 10º angle of attack for (a) CTC and (b) Half-circle curve

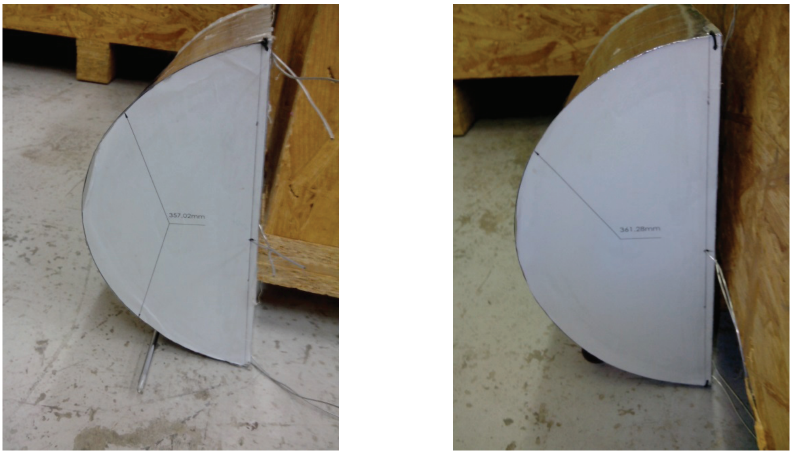
Table 1 shows the summary of the Reynolds Number for each curve which is calculated using Equation (2), where the maximum velocity of the fluid, the density and the dynamic viscosity of the fluid are obtained from the CFD analysis. It can be seen that the CTC produces lower Reynolds Number indicating less turbulence condition and therefore according to Thompson (2005) and Fuchs (2010), also generates lower noise level. This finding is then confirmed thorugh experimental work which is discussed in the next section.

Table 1. The Reynolds Number obtained from the maximum velocity for each curve

Model	Reynolds Number
C-Transition Curve (CTC)	$Re = 8.334 \times 10^{7}$
Half-circle Curve	$Re = 9.615 \times 10^{7}$
C-Transition Curve (CTC) with 10º angle of attack	$Re = 1.060 \times 10^{8}$
Half-circle Curve with 10º angle of attack	$Re = 1.097 \times 10^{8}$

4.0 EXPERIMENT

In order to confirm the findings from the CFD simulation, experimental measurement was carried out to measure the noise level generated from the airflow to the surface of the curves. The two curve models, i.e. CTC and half-circle curve have been fabricated by using sheet of metal made of Zink (Zn) with thickness 0.21 mm. The contour of the CTC especially, was followed carefully in the fabrication process. The back of the curves was then finished with a flat surface where around this area, the noise level was measured at several locations. Figure 10 shows the fabricated samples of the 3D model of the curves.



(a) (b)

Figure 10. The experimental samples of the 3D model of: (a) CTC and (b) Half-circle curve

The sample was then placed at the open end of a steel box with the flat surface facing outwards. At the other end of the box, a table fan was used to give the airflow towards the curve side of the sample. Air gap of roughly 1 cm is left between the sample and the box to allow the air from the curve surface to flow out of the box. Across the flat surface of the curve (outside the box), the generated sound pressure level was measured using a sound level meter RION Type NL-42. The measurement setup is shown in Figure 11.

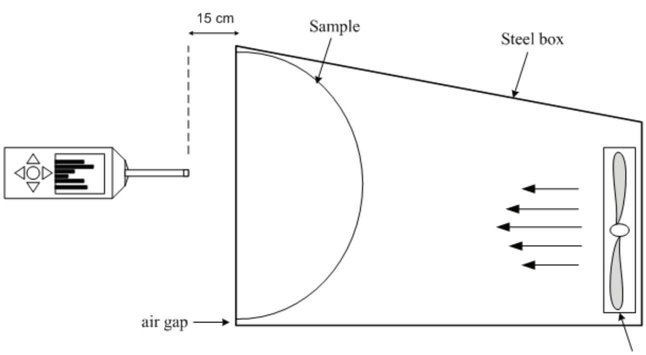


Figure 11. The experimental setup to measure the noise level generated by the curve structure

The sound pressure level was measured at nine measurement points across the flat surface of the curve structure at distance of 15 cm. The frequency range is from 31.5 Hz to 8 kHz recorded. The sound pressure level (SPL) in dB scale is defined as

$$\text{SPL} = 20 \times \log_{10}\left(\frac{p}{p_{ref}}\right) \tag{3}$$

where p is the measured sound pressure (in Pascal) and p_{ref} = Pa is the reference sound pressure. The measured pressure at every nth-points is then averaged given by

$$p_{ave} = p_{ref} \times \left(\sum_n 10^{\frac{SPL_n}{20}}\right) \tag{4}$$

Figure 12 plots the comparison between the SPL generated by CTC and half-circle curve. The results generally show that the SPL from both curves is the same across the frequency. However between 4 and 6.5 kHz, the SPL of the half-circle increases rapidly by around 5 dB in average, meanwhile the SPL of the CTC still consistently reduce towards frequency. The increasing SPL for the half-circle is possibly due to the turbulence flow and the frequency range corresponds to the width of the opening gap between the curve structure and the box.

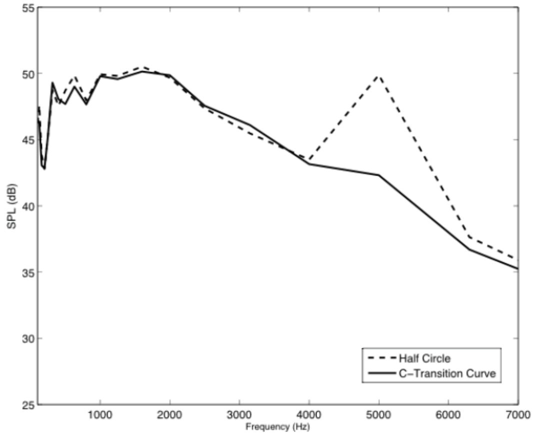


Figure 12. Measured Sound Pressure Level (SPL) from CTC and half-circle curve

5.0 CONCLUSION

Investigation on the C-Transition Curve (CTC) to reduce noise level generated by airflow has been conducted. The simulation shows that the CTC is able to reduce the effect of turbulence in the flow compared to the half-circle curve and therefore yields the reduction of noise radiation. Measurement of sound pressure level in experiment also confirms this finding. However, this work is still considered preliminary. More experiments and findings are required to give thorough analysis and conclusions. The work can also be extended to investigate the role of the CTC model to reduce generation of noise from structures, for example the aircraft propeller or to reduce the vibration of a piping system due to internal turbulence flow especially at the L-bend location of the pipe. Study on the S-Transition Curve is also of interest.

6.0 REFERENCES

Çengel, Y. A. & Cimbala, J. M. (2010). Fluid mechanics: *Fundamentals and applications* (2nd ed.), 302. New York: McGraw-Hill.

Easa, S. M. & Hassan, Y. (2000). Development of transitioned vertical curve I properties. *Transportation Research Part A: Policy and Practice, 34*(6), 481-496.

Fuchs, S., Zygis, M. & Toda, M. (2010). Turbulence and Phonology. T*urbulent Sounds: An Interdisciplinary Guide*, Berlin: De Gruyter Mouton.

Habib, Z. & Sakai, M. (2009). G2 cubic transition between two circles with shape control. *Journal of Computational and Applied Mathematics, 223*(1), 133-144.

Kobryń, A. (2011). Polynomial solutions of transition curves. *Journal of Surveying Engineering, 137*(3), 71-80.

Pirti, A. & Yücel, M. A. (2012). The fourth degree parabola (bi-quadratic parabola) as a transition curve. T*echnical Gazette, 19*(1), 19-26.

Thompson, D. M. (2005). Studio and listening room acoustics. *Understanding Audio: Getting the Most Out of Your Project or Professional Recording Studio*. Massachusetts: Berklee Press.

Walton, D. J. & Meek, D. S. (1999). Planar G2 Transition between two circles with a fair cubic Bézier curve. *Computer-Aided Design, 31*(14), 857-866.