



DESIGN OF AUTOMOBILE COMPONENTS FOR THE MINIMIZATION OF AEROACOUSTIC NOISE

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Abstract

In recent years, automotive manufacturers have invested significantly in measures to minimize the noise level within an automobile cabin. Today, aeroacoustic noise produced by airflow over car accessories such as vehicle side-mirrors, windscreen wipers and roof carrier systems make a significant contribution to the sound level within the automobile cabin. Consequently, the design of these components to minimize aeroacoustic noise has become important. This paper is concerned with minimizing the aeroacoustic noise of a roof carrier system.

INTRODUCTION

To meet consumer demand, automotive manufacturers have placed considerable emphasis on reducing in-cabin vehicle noise. Consequently, in-cabin noise has been reduced to a level where aeroacoustic sources produced by airflow over accessories such as side mirrors, windscreen wipers and roof racks have become a significant contributor to the noise level inside the cabin. Thus, the production of a minimum level of aeroacoustic noise has become a necessary characteristic for accessories on modern vehicles.

In this paper, the design of a roof carrier system is considered. Roof carrier systems are becoming increasingly popular on modern vehicles. The roof carrier system is mounted on the roof of a vehicle and is used for holding items such as bicycles, kayaks, skis and roof boxes. A typical roof carrier system is shown in figure 1 below.



Figure 1. A typical roof carrier system mounted on a vehicle roof

METHOD

The following method was used to design a roof carrier system that produced a minimum level of aeroacoustic noise. First, all possible noise generation mechanisms by which a roof carrier system could produce aeroacoustic noise were identified. Next the relative level and spectral content of the aeroacoustic noise produced by each of these mechanisms was quantified using an experimental investigation (using the noise measurement procedures described below) and the parameters that influence the noise generated by these mechanisms were identified. Finally a component that produced a minimum level of aeroacoustic noise was designed. The process is described in more detail in the following sections.

Crossbar noise measurement procedure

Two methods were used to measure the aeroacoustic noise produced by the roof carrier systems. These were 'isolated component testing' and 'partial vehicle testing'.

Isolated component testing

In isolated component testing, the aeroacoustic noise produced by the roof carrier system was measured using the following procedure. The roof carrier system was immersed in the airflow at the outlet jet of the low-noise wind tunnel in the Department of Mechanical Engineering at the University of Canterbury and the sound that was produced was measured using a microphone situated outside the airflow. The aeroacoustic noise of the roof carrier system measured in an isolated component test is assumed to be representative of the noise produced by the roof carrier system installed on the vehicle. Isolated component testing is typically cheaper and more convenient than full vehicle testing.

Partial vehicle testing

A method was developed to measure the aeroacoustic noise produced by a car carrier system installed on the roof of a vehicle by modifying the relatively small, low-noise wind tunnel in the Department of Mechanical Engineering at the University of Canterbury (see figure 2). The method involved mounting the carrier system on the roof section of a vehicle positioned at the outlet jet of the wind tunnel and making measurements in a cabin (with similar acoustic characteristics to an actual vehicle cabin) beneath the vehicle roof.

This method has the advantage over isolated component testing in that the airflow over the roof carrier system will be almost identical to that over a roof carrier system mounted on an actual vehicle, and thus noise level measurements should correspond closely to noise levels within the cabin of an actual vehicle due to the aeroacoustic noise produced by a roof carrier system.



Figure 2. Partial vehicle test experimental set-up

IDENTIFICATION OF AEROACOUSTIC NOISE GENERATION MECHANISMS

Several mechanisms by which the roof carrier system produced aeroacoustic noise were identified. These were (1) edge tones, (2) roof-wake interaction noise, and (3) crossbar self-noise.

Edge tones

Edge tones are produced by airflow over a sharp edge or discontinuity. Past studies (e.g. Powell [1]) have shown that the noise produced is associated with vortex shedding from the edge, which produces a tone at the frequency of vortex shedding. However, for a sharp edge or discontinuity placed on a surface on which a laminar

boundary layer exists, laminar boundary layer instabilities may produce tones via a feedback mechanism. Edge tones are typically relatively loud and occur at relatively high frequencies.

Wake-roof interaction noise

Wake-roof interaction noise occurs when the unsteady wake, which forms downstream of the roof carrier system, impinges upon the roof. The unsteady flow in the wake impinging on the vehicle roof produces sound which radiates into the vehicle cabin.

Crossbar self-noise

A number of different crossbar self-noise mechanisms were identified. These were dependent on the airflow speed, crossbar geometry and crossbar surface roughness. Each mechanism produced aeroacoustic noise at a relatively different level and with different spectral content.

Testing on a number of different crossbars indicated that the crossbar component of the roof carrier system was responsible for the majority of the aeroacoustic noise produced by the roof carrier system. Thus most of the effort of the research program described here was directed at identifying and reducing the aeroacoustic noise produced by the crossbar. The crossbar is an extruded 2-D section. A typical crossbar section is shown in figure 3 below.

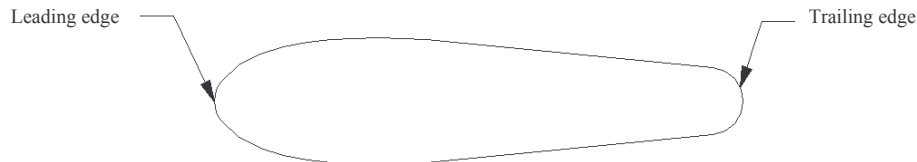


Figure 3. A typical crossbar section

Isolated component testing undertaken as a part of this investigation was used to determine the relative level and spectral content of the noise produced by each of the crossbar self noise mechanisms. A theoretical method was used to calculate the flow regime over the cross bar for each case. Each crossbar self noise generation mechanism was linked to a particular flow regime. For example a particular noise generation mechanism was observed to occur when a laminar boundary layer existed up to the trailing edge of a crossbar with a blunt trailing edge.

SOUND TRANSMISSION LOSS OF THE VEHICLE ROOF

To determine the level of noise which reached the occupants of a vehicle it was necessary to measure the sound transmission loss of the vehicle roof. A roof carrier system should be designed which will produce a minimum level of aeroacoustic noise at frequencies for which the roof provides relatively little attenuation.

The sound transmission loss (STL) of a vehicle roof was measured using the

following procedure. A speaker producing pink noise at a known free field sound intensity level was positioned just above the roof of a vehicle. The sound intensity level normal to the interior roof of the vehicle cabin directly below the speaker was measured (SIL). The sound transmission loss was calculated using equation (1) below

$$STL = SIL_{ff} - SIL \quad (1)$$

Where SIL_{ff} is the free field sound intensity level produced by the speaker at the sound intensity measurement position (normal to the vehicle interior roof). The sound transmission loss of a typical vehicle roof is shown in figure 4 below.

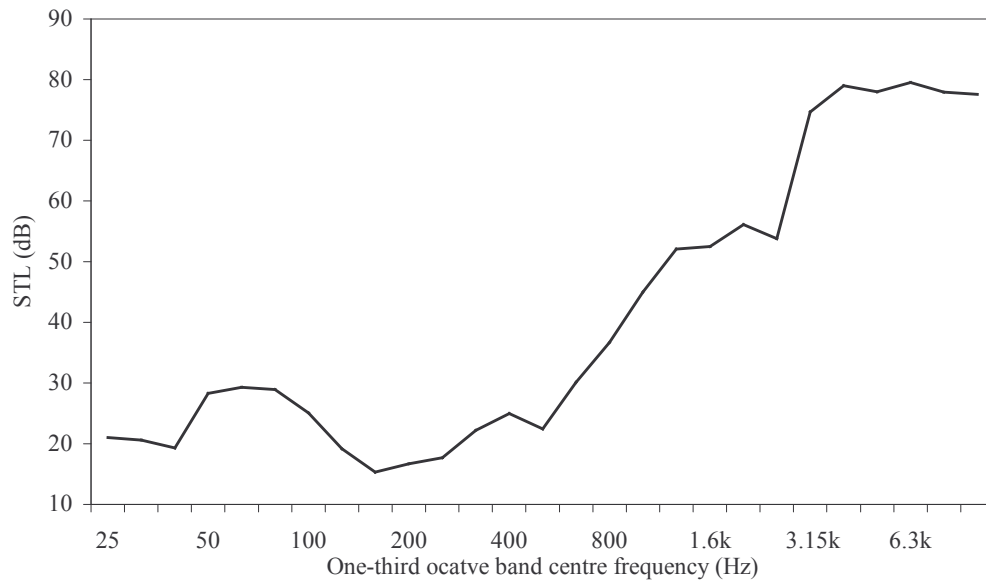


Figure 4. Sound transmission loss of a typical vehicle roof

COMPONENT DESIGN FOR MINIMIZING AEROACOUSTIC NOISE

Edge Tones

By designing a roof carrier system that does not include sharp edges, particularly in regions where the local airflow speed over the crossbar is high and the boundary layer is laminar, the production of edge tones can be avoided. For cases where sharp edges are unavoidable and an edge tone occurs, tripping the laminar boundary layer to produce a turbulent boundary layer upstream of the edge should eliminate the edge tone.

Wake-Roof Interaction

To minimize the level of noise produced by wake-roof interaction the crossbar should be situated high enough above the roof such that its wake does not impinge upon the roof. An appropriate height could be determined using the partial vehicle method described above and using a sound intensity scan of the vehicle cabin roof to identify locations where the wake was impinging upon the roof.

Minimizing the size of the wake that forms downstream of the crossbar will also reduce the level noise produced by wake-roof interaction

Crossbar self-noise

A crossbar was designed which produced a minimum level of aeroacoustic noise by ensuring that the flow regime over the crossbar which produced a minimum level of aeroacoustic noise occurred over the range of airflow speeds and angles of incidence that the crossbar might be subject to when installed on a vehicle roof. A theoretical method was used to calculate the flow regime over the surface of the crossbar for each case. The crossbar design also met the required aesthetic and strength requirements.

RESULTS

Isolated component testing (at the University of Canterbury) and independent full vehicle testing (by an automotive manufacturer) indicate that the new roof carrier system produces a minimum level of aeroacoustic noise. The sound pressure level produced by the new roof carrier system in an isolated component test is shown in figure 5 below (bold curve). The sound pressure levels produced by several other roof carrier systems are also shown (thin curves).

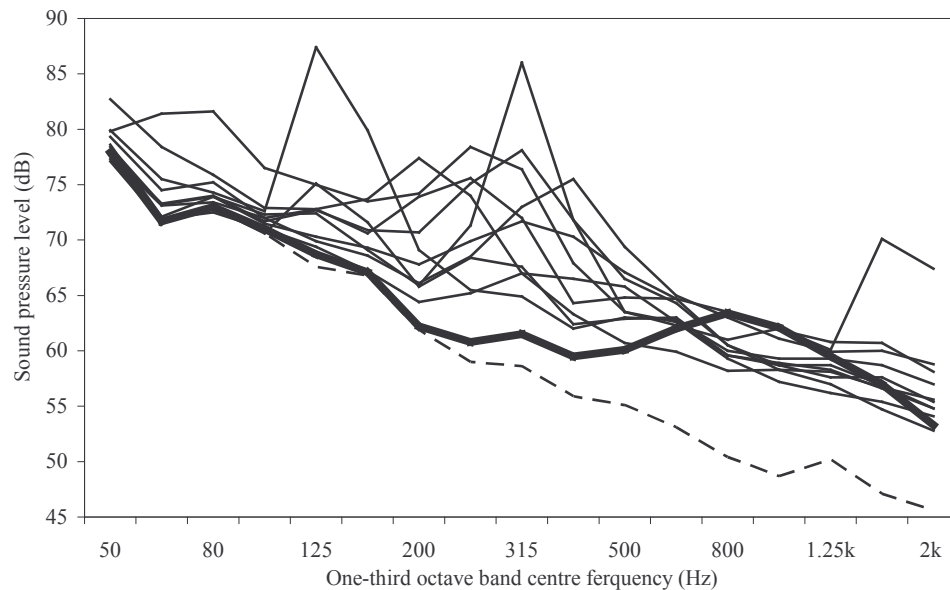


Figure 5. Sound pressure level (measured in isolated component testing at the University of Canterbury) produced by a number of different roof carrier systems: The dashed curve indicates the wind tunnel background noise level

CONCLUSIONS

The method used to design a roof carrier system that produced a minimum level of aeroacoustic noise has been described. The final roof carrier system design produced a significantly lower level of aeroacoustic noise than any other identified commercially available system. The general method could be used to design other automotive accessories that produce a minimum level of aeroacoustic noise.

ACKNOWLEDGEMENTS

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REFERENCES

- [1] A. Powell, "On the edge tone", Journal of the Acoustical Society of America, **33**, 395-409, (1961)