Rising demands on the level of internal noise in current high performance convertibles require specific development methods and the use of specific materials. The example of the Mercedes CLK convertible developed by Wilhelm Karmann per specifications by Daimler-Chrysler demonstrates which theoretical possibilities for aero-acoustic noise optimisation are available and how this knowledge can be integrated into the construction of the hood and into the seals.

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1 Introduction

In saloons in the upper medium class, wind noise above 100–130 km/h dominates internal noise and even covers noises generated by the chassis and transmission. The main wind noise comes over the windscreen and seals because of the lower insertion damping compared to steel [1].

Even at low speeds, wind noise is the dominant source of noise in a convertible with a soft top. There are a number of reasons for this:

- The hood system means that a convertible has more seals than a saloon (e.g. hood top to wind deflector, hood clip to hood boot lid).
- The hood material has a lower insertion damping than steel.
- Parts of the hood (e.g. the rear windscreen) can vibrate, which causes rumbling noises.
- Unlike most saloons, convertibles have frameless side windows.

Figure 1 compares the internal noise range at 160 km/h in a Mercedes CLK convertible and the coupé built on the same platform. In the recorded area between 200 and 1,000 Hz, differences of up to 7 dB(A) are observed. However, the area > 1 kHz which is important for a subjective approach, shows a continuously falling range as with the coupé. No obvious gaps are observed with this convertible. In the area < 100 Hz the range of the convertibles is comparable with that of the coupé. Any excessive levels in this frequency area, which can be observed in most convertibles, were assumed to be rumbling. It can therefore be concluded that a driver of a Mercedes CLK convertible at 160 km/h will subjectively have a similar or perhaps slightly louder impression of noise than a driver of the coupé.

Figure 2 shows a comparison of the recorded internal noise and the ease of conversation of a Mercedes CLK convertible with competitors at a speed of 160 km/h.

2 Aero-Acoustics

2.1 Causes of Aero-Acoustic Problems

There are three main causes of aero-acoustic problems, which define internal noise in three different frequency ranges:

Airflow noise:
Airflow noise is caused in particular by airflow and buffeting. The highest levels are recorded with three-dimensional turbulence [3]. Airflow noise is transferred from outside to inside the car. Therefore the insertion damping of the car’s external skin is the correct size for the internal noise. In a convertible the hood material is particularly significant in determining the extent of insertion damping (cf. Chapter 2.4.2).

Gaps:
Gaps allow noise to penetrate directly from outside into the passenger compartment and also mean that resonant vibration can be caused in the existing volume of air inside the car and therefore cause whistling noises (cf. Chapter 3.2).

Vibrating Components:
Wind buffeting can cause components in the car to vibrate. The rear windscreens and C-pillars are particularly susceptible in convertibles. Buffeting can also cause vibrations in fixed parts of the rear windscreen to transfer to the hood material and also upper areas of the windscreen to vibrate. These vibrations can cause disturbing rumbles in the passenger compartment (cf. Chapter 2.4.4).

2.2 Testing Methods for Aero-Acoustics

Analyses of aero-acoustic phenomena are carried out in aero-acoustic wind tunnels or on test tracks using dummies. In order to reduce testing time in the aero-acoustic wind tunnel, various conditions of the car can be assessed in advance on a dry test track when there is no wind. The wind tunnel can then be used for specifications testing and assessments/tests that are only possible in the wind tunnel:
- analysis of airflow with smoke lance
- measurement of vibrations in hood material / rear windscreen with a laser vibrometer
- internal intensity measurements to localise sources of noise
- measurement of airflow noise e.g. with the concave mirror test
- analysis of impact of airflow under the chassis.

2.3 Aero-Acoustic Simulation

As aero-acoustic phenomena are caused by pressure vibrations, it is possible to calculate these movements directly. This requires a transient airflow simulation. Software programmes such as Powerflow, which work with the computer time-intensive solution process, provide results for aero-acoustics and power coefficients (resistance and uplift). The time scale in a simulation is in the range of 1 – 3 * 10^-9 seconds depending on resolution. This provides a theoretical prediction of > 20 kHz. Practice has shown that noise pressures on the surface of the car of 1–2 kHz can be sufficiently predicted. Calculating the pressure vibrations on the car skin is a possibility that arises from an early project phase of the first assessment criteria of the car shape with regards its aero-acoustic qualities.

For aero-acoustic simulations of wind noise in the driver’s ear the first software tools now exist that use Statistical Energy Analysis (SEA). These methods are however still being researched and are not yet standard in the aero-acoustic development process.

2.4 Influential Parameters on Wind Noise

2.4.1 Hood Shape

An aero-acoustically favourable hood shape allows low airflow around the car. This requires the smoothest possible joints between the hood and the bodywork and windscreens. [3] shows that even low airflows induce intensive pressure vibrations in the boundary area, which as a result of their “longevity” downstream from the source cause with high fluctuating pressures on large areas of bodywork/hood. In order to avoid unsteady airflows with strong buffeting around the rear windscreen, the angle of the rear windscreen should not be close to 30° [2]. A steeper angle of the rear windscreen with a defined edge on the corner support or a flatter angle, which allows an adjacent airflow, is favourable for aero-acoustics.

2.4.2 Hood Material

In order to minimise airflow noise for passengers, the insertion damping (ratio of noise pressure outside/inside) of the vehicle skin should have the highest possible value. Figure 3 compares the extent of in-