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THE IDENTIFICATION OF POWERTRAIN SOUND QUALITY TARGET SOUNDS

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ABSTRACT
This paper reports on the techniques applied by Jaguar Cars in setting and evaluating Powertrain Sound Quality targets. A Sound Quality profile has been used to subjectively quantify a number of semantics that define the character for a given vehicle. Data reduction techniques are used to identify the primary semantics of Powerfulness and Pleasantness, enabling a large number of luxury vehicles to be located within a 2-Dimensional Emotional Space. Through the use of digital filtering techniques on recorded sounds, and subsequent jury evaluation listening studies, the changes in character defined by the two primary semantics are identified. By relating the results of the jury study to the results of vehicle drive appraisals Jaguar has developed the capability of establishing where the Sound Quality character of a concept sound would be positioned relative to existing luxury vehicles.

1 - INTRODUCTION

Powertrain Sound Quality has increasingly become a factor that can be used by automobile manufacturers to establish and maintain a competitive advantage. This is particularly the case in the luxury car sector, where the sound levels of competing vehicles are comparable, but the difference in perception lies in the quality of the sound. To respond to this changing market requirement Jaguar Cars has developed a customer-focused Sound Quality Engineering (SQE) process. This process consists of setting detailed subjective and objective vehicle level Sound Quality targets, that can subsequently be cascaded to the system and component level specifications that are needed to drive the detailed design. Prior to cascading these targets the first step in the process must involve developing a means of quantifying the Sound Quality character at a vehicle level. The concepts developed by Jaguar Cars to provide the capability of quantifying the subjective Sound Quality character of a vehicle relative to the competitor vehicles in the same class, and to identify the objective acoustic features within the sound signature that determine the subjective character, are outlined in this paper.

2 - BACKGROUND: SOUND QUALITY PROFILES

Previous work conducted by the author [1] has resulted in the development of a Sound Quality Profile that can be used to capture the Sound Quality character of a vehicle. Through the use of market research and jury evaluation studies, combined with the means of quantifying Jaguar's brand identity, it has been established that a total of twelve semantics can be used to characterize the Powertrain Sound Quality for a given vehicle. These semantics are arranged to form a profile as illustrated in Figure 1. The semantics have been classified into four groups that represent the different driving experiences. The *Refinement Character* and *Driven Emotion* groups represent the acoustic and impressionistic semantics required to achieve a refined vehicle. The *Driving Character* and *Driving Emotion* groups represent the acoustic and impressionistic semantics required to achieve a driver-inspiring vehicle. A vehicle biased towards the upper half of the profile is one that places priority on refinement and noise isolation, whereas a

vehicle biased towards the lower half of the profile places priority on the performance enhancing effects of Sound Quality. The measures for each semantic are derived through the use of vehicle drive appraisals conducted by experienced vehicle assessors who have been selected and trained to reflect the views of the Jaguar customer. Assessment sheets involving the use of the Semantic Differential evaluation technique [2] are completed following the drive appraisal, and reflect the overall driving experience taking into consideration the biasing effects of both vehicle brand and performance. The influence of these two parameters on the perception of Sound Quality have been well documented [3]. However the purpose of the drive appraisal evaluation is to reflect the customer's views, and as such the total drive experience including the Sound Quality and performance aspects along with the brand expectations of the vehicle must be evaluated. Figure 1 illustrates the Sound Quality Profiles for three vehicles. Vehicle A is biased towards the lower half of the profile. It sounds Powerful, Sporty and Aggressive, and consequently this makes the vehicle feel Spirited, Exciting and Fun-to-Drive. In contrast Vehicle B is biased towards the upper half of the profile, and is particularly noted to be Effortless, Quiet and Refined. Vehicle C does not excel in either category, implying that its Sound Quality character is neither refined nor aids in the enhancement of the performance feel of the vehicle.

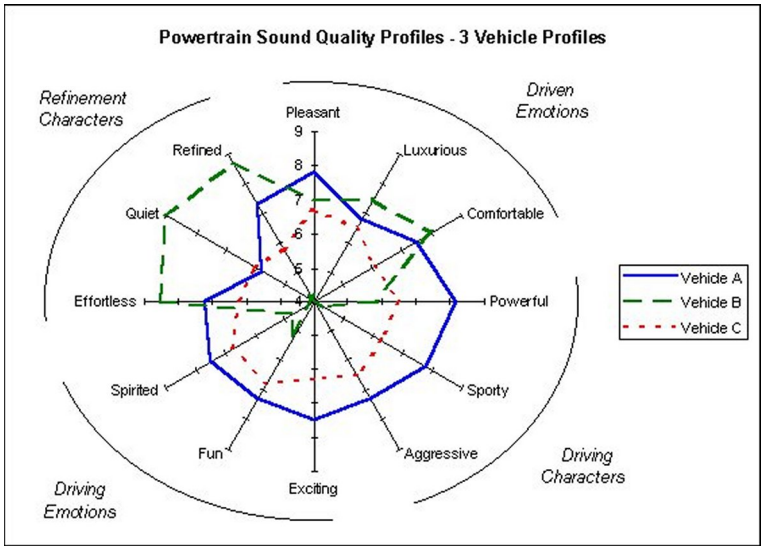

Figure 1: Powertrain sound quality profile format & profiles for vehicles A, B & C.

3 - DATA REDUCTION: PRINCIPAL COMPONENT ANALYSIS

The use of the Sound Quality Profile has enabled Jaguar to quantify the Sound Quality character of different vehicles. However, in order to be able to identify a target character that differentiates, not only Jaguar's products from all of the other vehicles in the luxury car sector, but also between the different products within Jaguar's own expanding product portfolio, it has proven necessary to reduce the number of factors used to quantify this character. This has been achieved through the application of Principal Component Analysis techniques to the twelve semantic ratings of the Sound Quality profile for 33 different luxury vehicles. It has been established that the variation in Sound Quality character can be attributed to two factors. They have been identified as a Powerful, or Potency, factor and a Pleasant, or Agreeable, factor, accounting for 56% and 33% respectively of the variation across all vehicles. It is possible to map the location of each of the 33 vehicles in a 2-Dimensional Emotional Space defined by these two factors. This is illustrated in Figure 2.

Figure 2 also identifies the two factor scores established from the Sound Quality Profiles for Vehicles A, B and C. Vehicle A exhibits high factor scores for both the Powerful and Pleasant factors, whereas Vehicle B exhibits a high Pleasant factor score but the lowest Power factor score for all vehicles assessed. Vehicle C exhibits a medium Power factor score, but a relatively poor Pleasant factor score. It is possible to locate the Sound Quality character for all the vehicles assessed within this 2-Dimensional Space, enabling Jaguar to quantify the degree of Sound Quality character for all the products in its own portfolio and also those of the other luxury vehicle competitors.

4 - TARGET SETTING: DIGITAL MODIFICATION & JURY TESTING

It is possible to identify a target location for a given vehicle within the Powerful/Pleasant 2-Dimensional

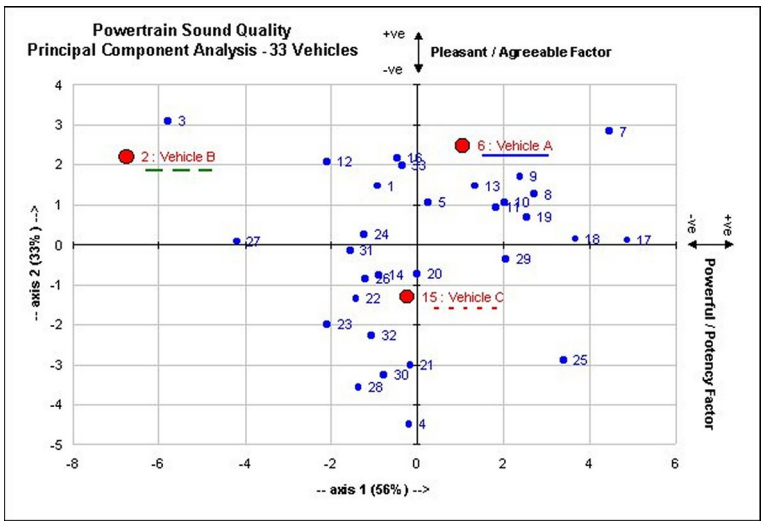

Figure 2: Principal component analysis for 33 vehicles − first two principal components.

Emotional Space. However, this would be purely a subjective target. In order to define a vehicle level target that can be readily cascaded to the system and component level specifications that are needed to drive the design detail, it is necessary to relate this subjective target to the acoustic features in the sound signature that are responsible for determining the subjective character. To illustrate this concept a donor vehicle sound recorded under a full load Drive pull-away maneuver, was digitally modified by applying time domain modifications and frequency and order based filtering techniques to change the character. This donor vehicle sound could either be an early prototype or an outgoing model. Figure 3 illustrates the frequency map vs. time of the recorded sound and the modifications made in both the frequency and time domains. The Drive pull-away maneuver can be seen as the vehicle accelerates through 1st gear, up-shifts to 2nd gear, and then up-shifts to 3rd gear.

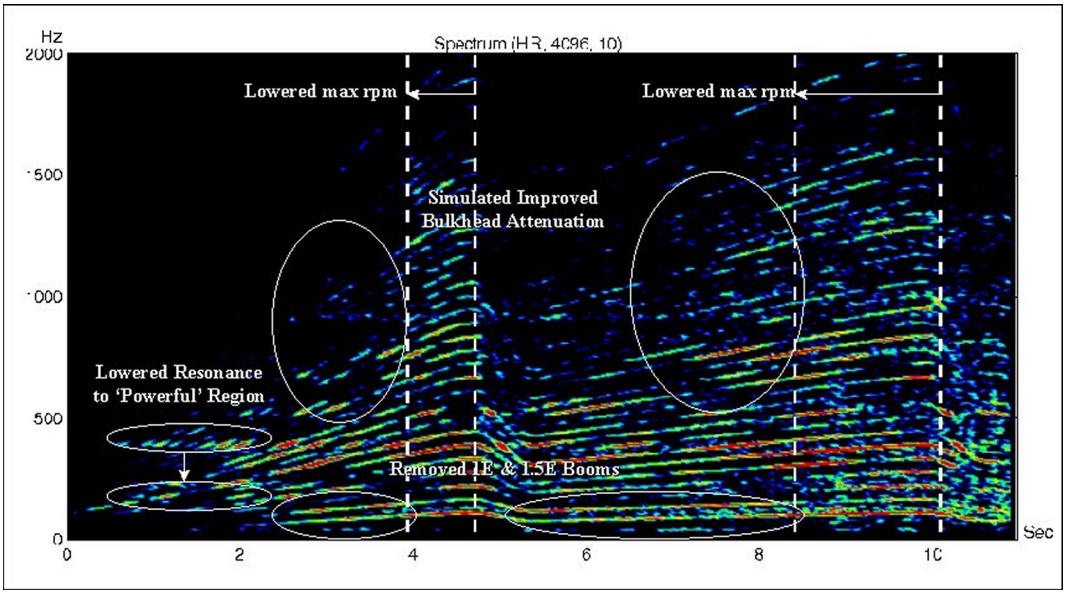

Figure 3: Frequency map of digital modifications made to Donor sound F.

In order to evaluate how the modifications applied to the sound affected the Sound Quality character it was necessary to conduct a jury evaluation listening study. The modified sound along with the original sound and those of the competitor vehicles in the same class, including the previously identified vehicles A, B and C, were evaluated through the Semantic Differential jury evaluation procedure, using the semantic pairs Powerful/Weak and Pleasant/Annoying, i.e. the two principal Sound Quality factors. The sounds were replayed to a panel of jury subjects, totalling 38 respondents. The jury subjects rated

each sound for each of the two semantic pairs. Figure 4 illustrates the results of the study for each of the seven sounds evaluated, displayed in a 2-Dimensional plot defined by the two principal factors Powerful/Weak and Pleasant/Annoying. The transition in Sound character from the donor sound F to the filtered sound G is illustrated. The sound became more pleasant, but at the same time lost a lot of its Powerful character.

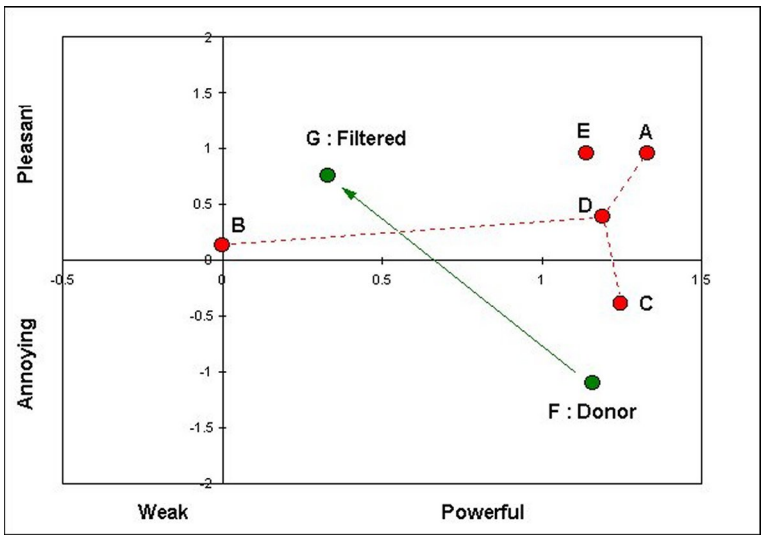

Figure 4: Results of semantic differential jury evaluation.

5 - DIMENSIONAL MAPPING

It was possible to relate the location of the vehicles identified from the jury evaluation to the location of the same vehicles identified through the Principal Component Analysis factor scores derived from the subjective drive appraisals. This 'Dimensional Mapping' of the jury results onto the Principal Component Analysis 2-Dimensional Powerful/Pleasant Emotional Space is illustrated in Figure 5. For clarity the difference in character between vehicles A, B, C and D is illustrated by the dotted connecting lines on both Figure 4 and Figure 5. Minor differences between the location of the vehicles on the two figures are noted, but the overall vehicle differentiation is consistent. Using this Dimensional Mapping approach it was possible to locate the relative positions of both the donor sound F and the concept filtered sound G in the PCA 2-Dimensional space, despite never having evaluated the donor vehicle in a drive appraisal, and obviously never having driven the concept vehicle.

This Dimensional Mapping approach of relating the results of jury evaluation tests to the results of the subjective drive appraisal evaluations has provided the capability of establishing where a concept vehicle sound would locate relative to all other vehicles in the luxury car sector. The next step would be to establish if the brand identity for the target vehicle is consistent with the Sound Quality character location. If not then it would then be necessary to develop a new target sound through alternative time and frequency domain modifications to the donor sound and repeat the Jury Evaluation and Dimensional Mapping procedure.

6 - CONCLUSION

This paper has outlined Jaguar Cars' approach to evaluating Powertrain Sound Quality. The development of the Sound Quality Profile and the application of Principal Component Analysis techniques has enabled Jaguar to quantify the Sound Quality character of a large number of luxury vehicles. Through the use of digital filtering techniques and jury testing it has been possible to relate the objective detail of concept sound signatures to the subjective Sound Quality character of the sound and establish its position relative to the competition.

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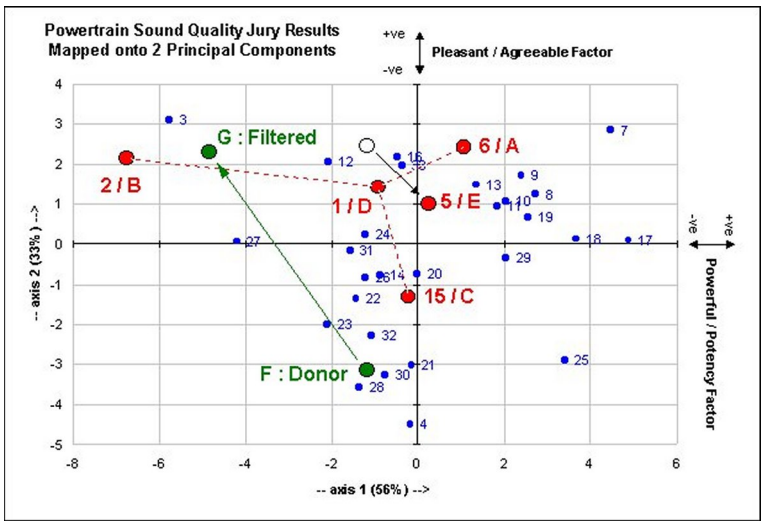

Figure 5: Semantic differential jury results mapped onto PCA 2-dimensional space.

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