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Compound Bow Sound Quality

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ABSTRACT

Compound bows are used by hunters and target shooters. A compound bow uses two cams, mounted at the end of a stiff spring and connected by a string, to efficiently transfer energy from the flexed spring into arrow motion. Like many industries, the compound bow industry is faced with the challenge of creating a product that meets consumer's expectations for sound quality without sacrificing its functional quality. This generally means designing toward good sound quality in the "showroom", where the consumer's perception of performance and quality is based on a "test run". However, the compound bow industry faces additional challenges, including how to design the product for optimal performance and design the sound to blend into the natural background noise which is made of birds chirping, leaves blowing, etc.

The sharp, impulsive sound made by a compound bow is clearly different from any other naturally occurring sound and will likely be noticed by the wildlife. In this paper we will discuss a compound bow's acoustic signature in reference to consumer perception of quality and design variations for bow performance.

1. INTRODUCTION

Hunters purchase compound bows after testing them in indoor shooting ranges, typically adjacent to the showroom. Other than aesthetics and cost, the subjective impressions that most affect the purchasing decision are tactile (vibration) and sound quality. The compound manufacturers are trying to design their products to make them more appealing to the end customer and in order to do this, they need to understand the dominant attributes and how they impact the purchasing decision. Figure 1 shows a compound bow by Hoyt.

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With this objective in mind, we conducted both objective and subjective tests of a few different compound bows, with different dampers and cams. The majority of the tests were conducted indoors, in an acoustical lab with low background noise, which guaranteed controlled boundary conditions. Three bows were also tested outdoors, at a shooting range, by the same shooter who is also an experienced hunter. In the outdoor tests, the noise of the bow was captured by a microphone positioned in proximity of the right ear of the shooter, who was right-handed (see Figure 2). For the indoor tests, each bow was also instrumented with an accelerometer on the handle. Microphone position and shooter were the same (Figure 1).

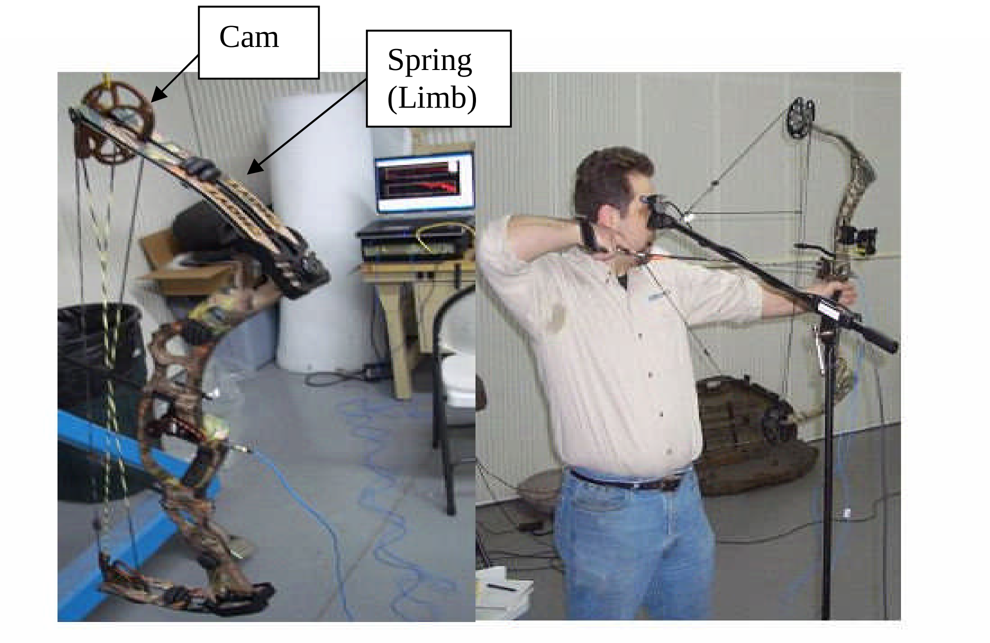

Figure 1. Indoor test set-up

Figure 2. Outdoor test setup

2. OUTDOOR MEASUREMENT FOR SOUND QUALITY

A. Outdoor measurements for Sound Quality

Three bows were shot in an outdoor setting which included an open field with a target set at 40 meters and microphones placed near the shooters ear and 20 meters down range. The microphone located at the shooter ear location will be used in this section to understand the sound of the bow as an arrow is released.

Of the three bows that were used one is a new bow provided by the bow manufacturer (Z3) and set to a 60 pound draw weight, one is a used bow (PL 1&1/2) set to 60 lb draw weight and the third is a used bow (Phantom) set to 70 lb draw weight. The three bows were selected for their range of characteristics and perceived quality to better understand the components of the shot sound that are important to perception. The Z3 was described as sounding sharp or strong with a slight twang, and louder than the other two bows. The PL1&1/2 was described as having multiple impacts (that while not preferred, were not offensive) but with less of a twang than the Z3. The Phantom was described as having a buzz or twang, and sounding "cheap" and rated a unanimous third place. The subjective assessments were made by an informal jury, some of whom are experienced hunters. Table 1 summarized the results of an informal subjective evaluation and ranking for the three bow sounds.

	Most preferred	Least preferred	Verbal Description
Z3	37.5%	0%	Slight twang, Strong, Sharp, Louder than PL1&1/2
PL1&1/2	62.5%	0%	Short, Solid, Multiple impacts, Quietest
Phantom	0%	100%	Twangy, Reverberation, Tonal, "Cheap", "Shot from a cardboard box"

Table 1: Subjective ranking for three bow sounds recorded outside.

The time history of the sound pressure measurements taken at the shooter's ear are shown in Figure 4. As shown in this plot the Z3 has a higher peak level than that of the other two signals. Other noticeable differences are the longer duration of Phantom and the presence of multiple impacts in PL1&1/2 and Phantom.

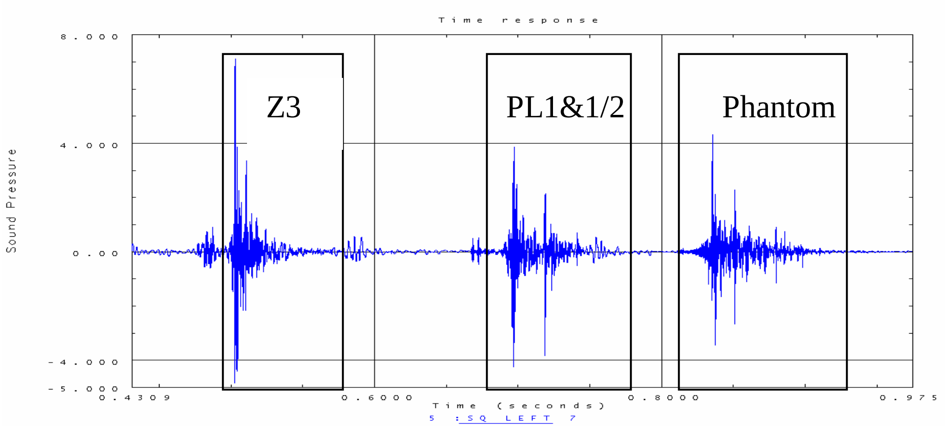

Figure 4. Time histories of microphone signals of Z3 (left) PL1&1/2 (middle) and Phantom (right).

The specific loudness per bark (frequency scale) vs time for these sounds is shown in Figures 5, 6 and 7.

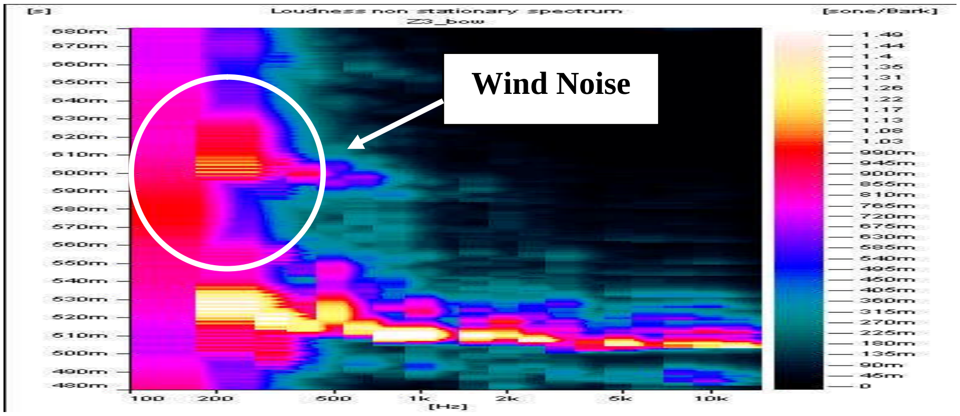

Figure 5. Specific loudness vs time of microphone signal of Z3 bow

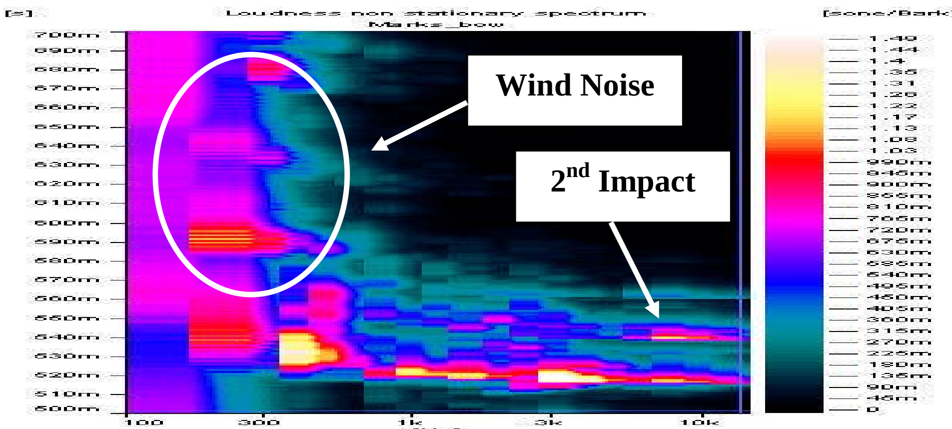

Figure 6. Specific loudness vs time of microphone signal of PL1&1/2 bow

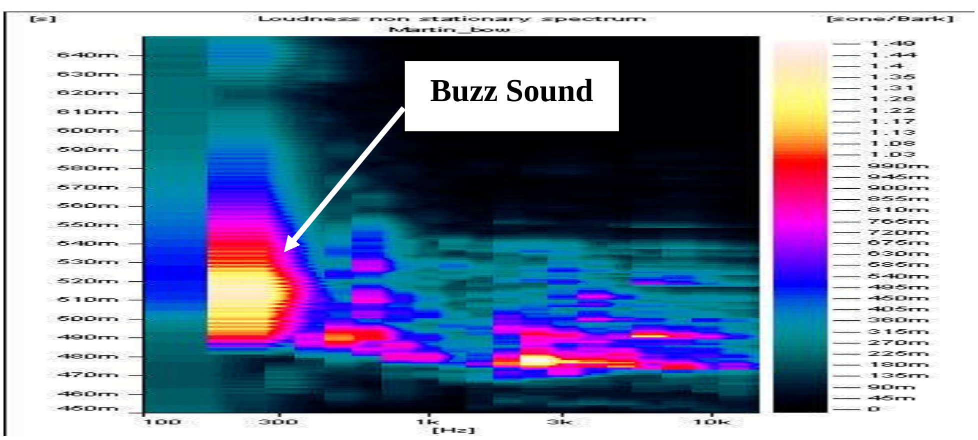

Figure 7. Specific loudness vs time of microphone signal of Phantom bow

Based on discussions raised from listening sessions using the sounds of these three bows, the dominant characteristics are:

1. Buzz/twang, associated to a sound which less instantaneous, more prolonged in time
2. Sharpness (high vs lower frequency sound),

3. Presence of multiple impacts
4. Level

Of these features, the buzz (or twang) was verbally described as the least pleasant, as it is not consistent with the expectation of the shooter for an instantaneous and precise type of sound. A longer sound duration, especially of the ringing of the string, could create this buzz impression. We expect that a longer duration of sound with relatively uniform level may not be appreciated by the user of the bow. This is the main reason for the Phantom bow being rated a unanimous third place, despite being the quietest bow, Figure 10.

The second most important feature differentiating the sounds of the three bows was found to be the overall pitch perception, which was described as the sharpness of the sound, and therefore associated to the relative level of high and low frequency content. During the subjective comparison the Z3 bow was rated as having a higher pitch than the PL1&1/2 bow, shown in Figures 5 and 6. However, the preference of the jurors during the informal listening session was equally divided among Z3 and PL1&1/2, with half of the jurors preferring a sharper sound and the other half preferring a duller sound. This is a case where a formal jury study of a sample representative of the actual customer population would be very beneficial to the bow manufacturer.

The third feature mentioned by about 1/4th of the jury panel was described as the presence of multiple impacts, evident in PL1&1/2 bow and generally undesirable but not as unpleasant as the buzz. Percentile Frequency plots [(1)] are very useful to quantify the frequency content of very short and transient sounds. Figure 8 shows the 50th percentile of the Specific Loudness Pattern for the three bows. The multiple impacts in the signature of PL1&1/2 are clearly visible.

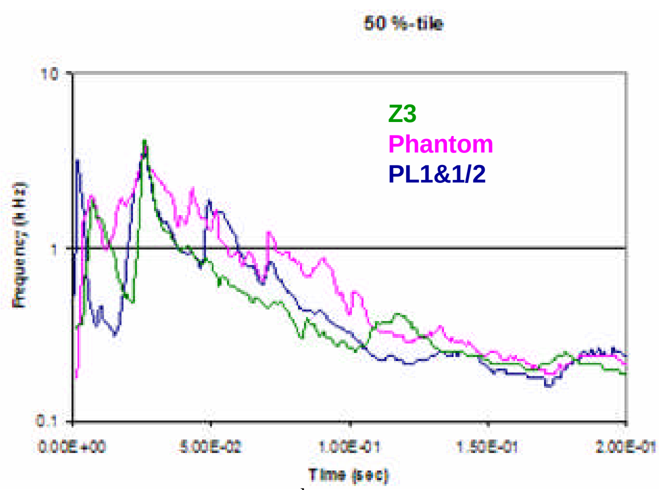

Figure 8. 50th percentile curves for the 3 bows

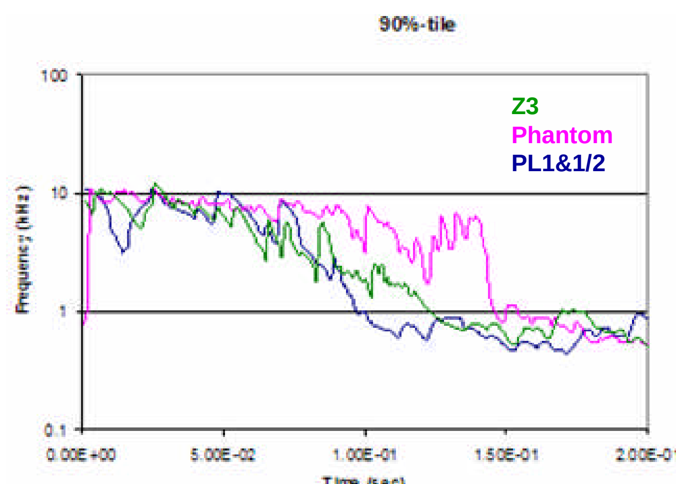

Figure 9: 90th percentile curve for the three bows

Figure 9 shows the 90th percentile of the Specific Loudness Pattern for the three bows. The longer duration of the Phantom is very evident, and indicates that there is also higher frequency content in the sound that does not die out as quickly as the other two bows.

The final verbal descriptor that was mentioned was the level of the sound, but it was considered the least decisive factor. Figure 10 compares the instantaneous loudness level vs time for the three different bows. It is interesting to note that the bow that was ranked unanimously as the least preferred has the lowest peak loudness level, and clearly has the longest duration. It is also interesting that the PL1&1/2 bow was rated as the quietest on multiple occasions, but actually has a higher loudness level than the Phantom bow.

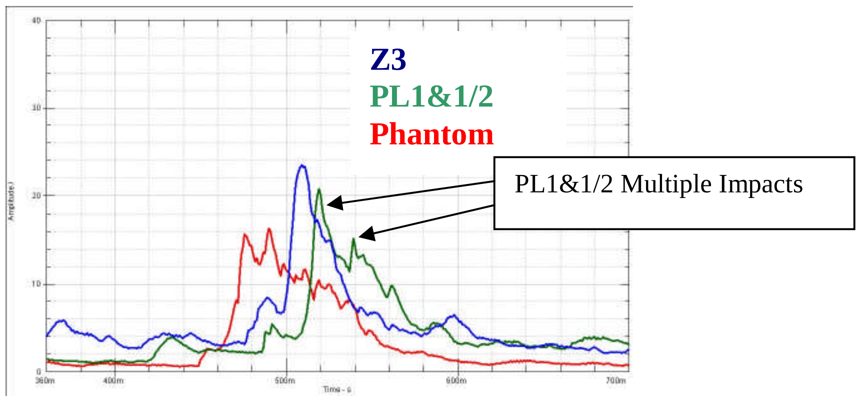

Figure 10: Instantaneous loudness vs time for the three bows

It is also interesting to note that although only about ¼ of the panel initially mentioned the multiple impacts present in the PL1&1/2 recording, shown again in Figure 10, once it was pointed out most of the panel then recognized the multiple impacts as a negative feature of the bow sound.

3. CUSTOMER PREFERENCE INDOORS

A. Sound Quality

After the bow sound quality characteristics were understood in a free field environment the test was moved indoors to test in a controlled environment. This testing was performed in a quiet room with low background noise and a target placed about 10 yards from the shooter, which is a configuration that is similar to the "showroom" experience that a prospective customer may encounter. The test was performed with microphone placed near the shooters right ear and accelerometers placed directly above and below the shooters hand. During the indoor testing four different cam designs were tested and subjectively ranked. Additional testing was also performed with a single bow to better understand the effectiveness of the limb dampers and string contact dampers that are used to improve the bows noise and vibration characteristics.

All of the sound quality analysis performed on the indoor measurements was done on a trimmed section of the data that does not include the arrow impacting the target, as shown in figure 11.

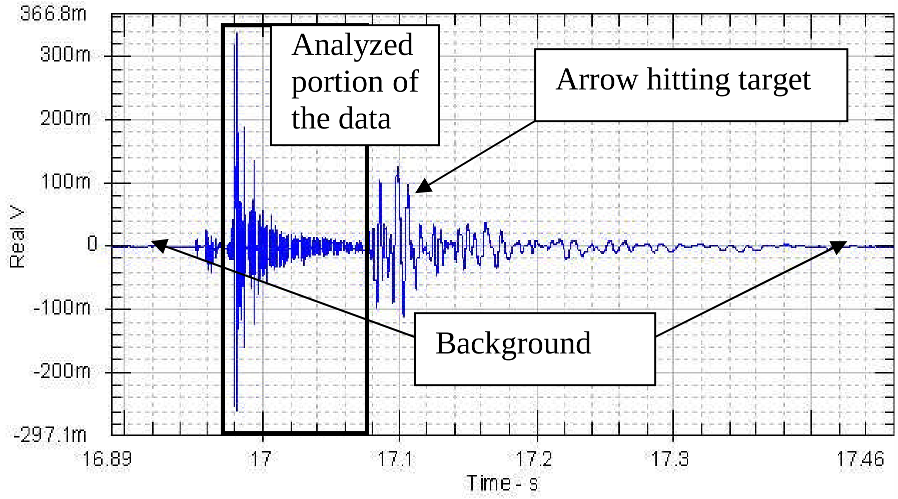

Figure 11: Time history of the shooters ear sound pressure measurement.

During the indoor measurements four identical bows were evaluated with variations in cam design, referred to as Z3, VX5, Z5.5 and G5. The cam variations cause slight differences in the draw force vs. draw length profile with the major differences being in the transitions between 0 force (0 inches) to full draw force and full draw force to max let off (full draw position). These variables affect the subjective feel of the draw weight profile, such as the "wall" that is felt when the string is moved slightly forward from full draw, as well as the amount of energy that is transferred to the arrow.

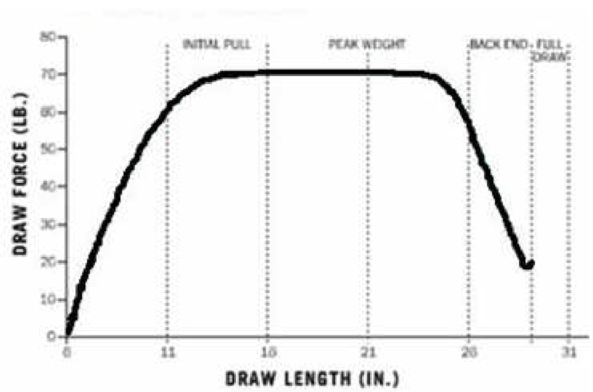

Figure 12: Typical draw force vs draw length curve.

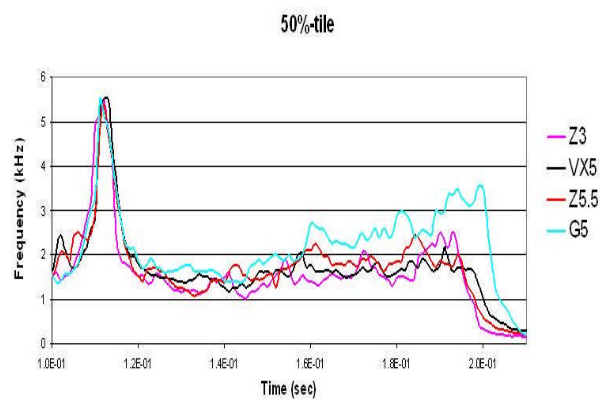

Figure 13: 50%-tile specific loudness for four different cam designs.

In addition to the variation in the draw force curves the different cam designs may cause subtle variations in pitch of the shot sound. The four bows sounds were subjective ranked by an informal jury for pitch alone and it was determined that the G5 bow was consistently ranked as having a slightly higher pitch than the Z3, VX5 and Z5.5 bows, which were not statistically separable. The plot in figure 13 compares the 50%-tile curves for specific loudness for the four different cam designs. As there is no current objective method for defining the pitch of an impulsive sound the 50%-tile curve is used to understand the spectral balance. The spectral balance, frequency content and duration of the impulse are tied to the subjective pitch[1, 4].

Additional measurements were conducted indoors to evaluate the effectiveness of the dampers that are placed on the compound bows to reduce string and limb vibrations. A single bow was shot in four configurations including G5, G5_nolimbdampers, G5_nolimb_nostringdampers and G5_nostringdamper, listed in order of overall preference ranking. The shooters ear measurements were recorded during the ranking process then reanalyzed to evaluate the sound quality for these configurations. The most significant feature that was highlighted while listening to the shooters ear recordings was the buzz event that is present in the two recordings without the string damper present. This buzz was a detractor from the subjective quality of the sounds when the target impact was trimmed out, but was significantly masked when the target impact was included. This suggests that a perspective customer that shoots the bow in an indoor range may be less influenced by the buzz than an outdoor range where there is no arrow impact to mask the buzz. The instantaneous loudness (per bark band) vs. time for the G5 bow and the G5_nostringdamper and G5_nolimbdamper are included in Figures 14, 15 and 16. These plots show that the buzz event occurs in the 170-279 Hz frequency range (2nd bark band).

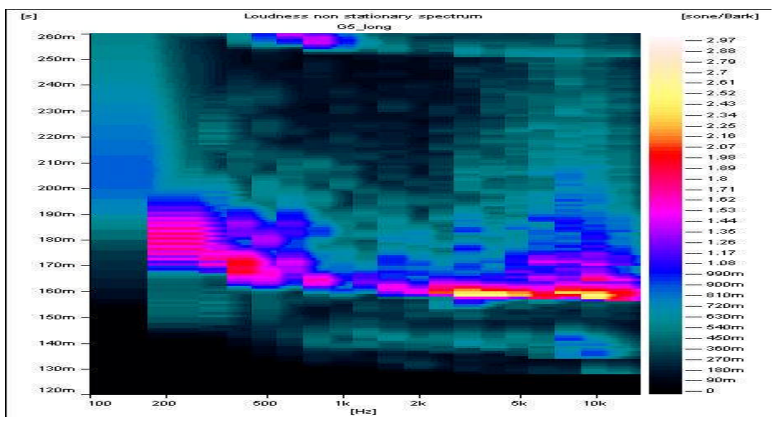

Figure 14: Instantaneous loudness(per bark band) vs. time for the G5 bow shot indoors.

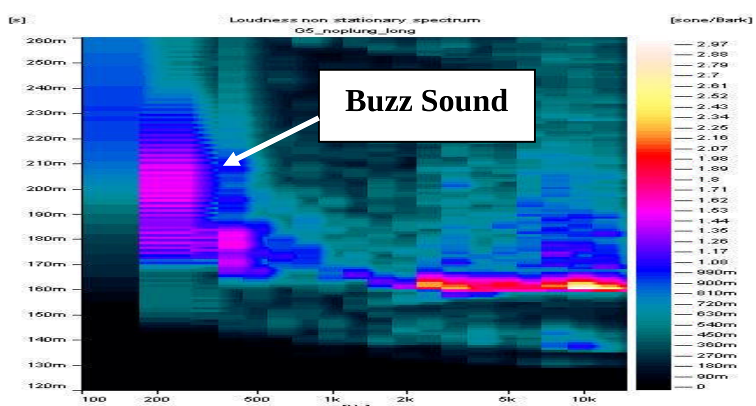

Figure 15: Instantaneous loudness(per bark band) vs. time for the G5 bow with no string damper.

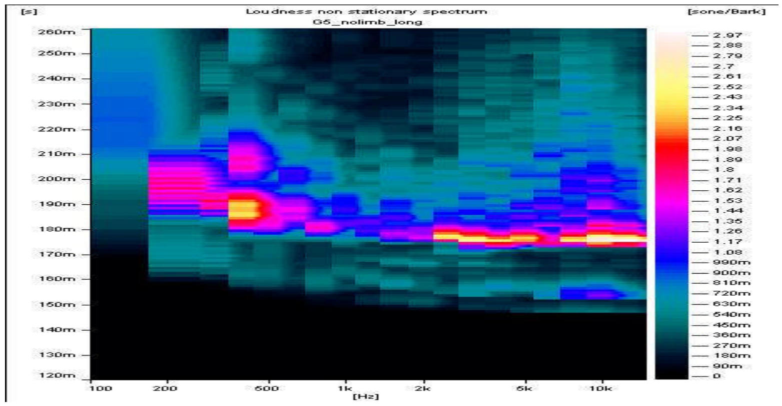

Figure 16: Instantaneous loudness(per bark band) vs. time for the G5 bow with no limb damper.

Figure 17 shows the instantaneous loudness, band-pass filtered between 170-280 Hz, vs time. This plot clearly shows the long time duration of the buzz event.

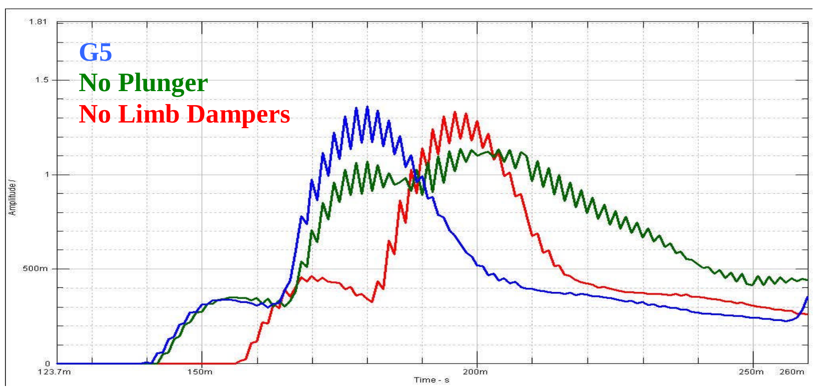

Figure 17: Instantaneous loudness vs. time (band-pass filtered 170-280Hz)

The subjective evaluation of the indoor bow shots suggest that the only affect adding the limb dampers have on the shot sound quality is a slight increase in the pitch of the sound. This can be seen by comparing Figures 14 and 16 where there is a difference in the response level in the 350-450 Hz frequency range when the limb dampers are removed. The increased level in the lower frequency range gives the sensation of a lower pitched sound for the recording with no limb dampers.

4. CONCLUSIONS

Perspective compound bow customers have a list of buying criteria in mind as they decide on a purchase for a new bow. The priority of the buying criteria will change from person to person, but the common concerns include:

- Price Range
- Energy transferred to the arrow
- Detectability by wild game
- Overall quality of the bow

In most cases the customer will shoot a variety of bows and decide which of the bows meet their buying criteria. The sound generated by the bow during a shot is directly tied to all but the price of the bow. The energy that is transferred to the arrow is driven by the cam design and draw weight set in the springs, and as discussed in Section 3 in this paper the pitch of the shot sound is affected by these settings. Some of the experienced bow shooters that were included in the subjective evaluations had an opinion on the arrow speed based on the "sharpness" of the shot.

One subject that was not discussed in this paper, but was rated as a concern by some of the evaluators was the detectability of the shot sound by wild game. This was described by a preference for the PL1&1/2 bow, in the outdoor measurements, based on the "dullness" and "low level" of the shot sound.

Finally, most of the results contained in this paper discussed the variation in overall perceived quality of the bow based on specific sound quality characteristics, including but not limited to buzz sounds, multiple impacts, sharpness, level and "strength" of the sound.

Some additional questions are raised by this paper and highlight areas of future work:

- A formal jury study of the bow manufacturers actual customer base to gain a better understanding of the sound quality expectations of the customers for:
    a. Bow performance – Is the "sharpness" or pitch of the shot really the contributing factor to perceived bow performance (arrow speed) or are there additional auditory, tactile and visual cues.
    b. Overall perceived bow quality – The results of this study have found that sound quality is a contributing factor to the subjective ranking of the bows, but does not correlate directly to the ranking. It is believed that the tactile vibration felt in the bow handle also contributes to the perceived quality, especially in an indoor setting where the arrow/target impact masks part of the bow sound.
- Better understand the detectability of the shot sound by game that is located down range of the shooters position. This study would be centered around the phenomena that is seen where wild game are able to "duck" below the arrow at distances greater than 20 yards. The hearing range of wild game would be understood and compared to the frequencies and levels of the compound bow and various natural sounds to evaluate the feasibility of "masking" the shot sound with natural sounds or using "sound shaping" methods to blend the shot sound in to the environment.
- Better understand the human perception of impulsive sounds. At this point there is no clear objective measurements that describe human perception to short duration impulsive sounds features, such as pitch.

ACKNOWLEDGEMENTS

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