Influence of Attack Parameters on the Playability of a Virtual Bowed String Instrument

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Abstract

The transient behavior of a virtual bowed string is measured under different conditions of bow-force and bow-velocity onset. The results are compared with the constant-force, constant-velocity case, and with published physical measurements made using a bowing machine. Issues related to “playability” of virtual bowed-string instruments are discussed.

1 Introduction

Bowed string instrument players are aware that the “attack” of a played note can strongly influence the sound quality of the entire note. In this paper, we investigate the influence of attack characteristics on the “playability” of a bowed-string instrument model, where playability is defined as the time required to achieve classic Helmholtz motion. The attack characteristics are formulated in terms of the main bowing parameters: the force, velocity, and position of the bow.

2 Evaluating Playability

The “playability region” can be defined as the region of the multidimensional parameter space in which “good tone” is produced. In most cases, the playability region coincides with Helmholtz motion—the well known “sawtooth” bowed-string motion that players try constantly to achieve in steady state (see the output waveform in Fig. 1).

In previous work [SSW99], we analyzed the playability of a bowed cello D-string model which includes simulation of transverse and torsional waves, constant-Q string resonances, and a nonlinear hyperbolic friction curve to model the bow-string interaction [Fl53, MSW83, Sch94, Smi82]. The main parameters driving this model are bow velocity $v_b$, bow force $f_b$, and bow position $p_b$, as depicted in Fig. 1.

An example of the results of the playability simulations for a steady-state case is shown in Fig. 2. The playability region identified is in good agreement with the one measured by Schelleng [Sch73] for a real instrument, as shown in figure 3. The measured region was used to set parameter limits in a real-time synthesis model of a bowed-string instrument, and this made the model significantly more robust in real-time performance. The playability was measured, however, only for the case of steady bowing.

In this paper, we extend our previous work by simulating different kinds of attacks in order to study their effect on the playability region. In particular, since a player’s aim is normally to reach Helmholtz motion as quickly as possible [GA97], we are interested in understanding which combinations of attack parameters achieve this goal.

As an example, Fig. 3 shows the playability region of the cello D string model [SSW99] for a fixed velocity $v_b = 5$ cm/s. Simulations were carried out starting the string from rest with a constant bow velocity, force (vertical axis), and position (horizontal axis). The darkest region containing square symbols corresponds to Helmholtz motion having become established within 200 ms (30 “Helmholtz periods”).

The two straight lines delimit the playability region measured by Schelleng in a real instrument ([Sch73]). Notice how the playability region of the virtual instrument is in good agreement with the one of the real one.

Figure 4 shows the measured Schelleng diagram for the same string as in Fig. 3, but this time starting the bow

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1 We define “Helmholtz period” in this context as the period of the waveform which occurs after ideal Helmholtz motion is established. The waveform is not periodic before this time, but the Helmholtz period remains a useful yardstick, since it is roughly the round-trip time for the main stick-slip disturbance on the string.
Figure 2: “Playable” points in the sampled parameter space of a virtual bowed string. The $x$ axis is the log of the normalized bow position $\beta = p_b/L$, where $\beta$ can vary between 0 and 1. The $y$ axis is log of the bow force $f_b$, and the $z$ axis is bow velocity $v_b$. The squares indicate points in the space where Helmholtz motion was achieved within 0.4 seconds by the simulated bowed string.

more gradually with a constant acceleration $a = 40$ cm/s$^2$, until a steady-state velocity of 5 cm/s is reached (after 125 ms). The resulting waveforms, captured after 200 ms (30 Helmholtz periods), show a playability region that is strongly altered. We see that, unlike the case of a constant initial bow velocity, Helmholtz motion is not established within 200 ms for any combination of bow position and bow force.

3 Bow Stroke Dynamics

In previous work, Guettler and Askenfelt [GA97], using a computer-controlled bowing machine, measured the acceptability of attack duration in a bow stroke. They observed that it is possible, though often difficult, to achieve Helmholtz motion immediately, and that such an attack is considered ideal in smooth playing styles. In the double-bass, for example, a single period can be a significant fraction of a note’s duration, making the immediacy of Helmholtz motion important for proper musical timing.

In normal conditions, however, before reaching “steady state”, a portion of a bow stroke develops in which it is possible to observe a transition period that depends on the combination of parameters, and which determines different qualitative bow strokes. Based on listening tests, the authors judged that, for a violin $G$ string, the acceptability limit for the aperiodic part of the attack before establishment of Helmholtz motion (i.e., the pre-Helmholtz motion) is approximately 50 ms.

Longer attacks were judged by the listeners as “chocked/creaky”.

Another important parameter is the attack time, i.e., the time for the note to reach steady-state amplitude. Guettler and Askenfelt observed that shorter attacks were preferred over longer attacks. Slow building up to final steady-state gave the impression of the string being “chocked,” and the corresponding attack was judged as unacceptable.

4 Validating the Model

Since our bowed-string model is intended to be calibrated in physical units, we tried driving the model with attack parameters measured on Guettler and Askenfelt’s bowing machine. As in [GA97], we considered a violin $G$ string ($f_0 = 196$ Hz). Keeping $f_0$ and $p_b$ constant, we varied the bow acceleration from $0.4$ m/s$^2$ to $3$ m/s$^2$. The final bow velocity was 20 cm/s in all cases.

Table 1: Simulations performed varying the initial bow acceleration using the same parameters as in [GA97].

Table 1 shows the results of the simulations. Our results are in qualitative agreement with those obtained on a real instrument, although the acceleration value yielding a good attack is slightly higher (2 m/s$^2$ in our simulations versus 1.5 m/s$^2$ in [GA97]). The resulting waveforms are displayed in Fig. 5. For this bow force and position, the acceleration $a = 2$ cm/s$^2$ gave the best attack, requiring only 6 Helmholtz periods to achieve Helmholtz motion (as measured automatically in software).

5 Effect of Bow Force Variation

To examine the role played by bow force variation, we now fix the bow velocity at 5 cm/s, with a normalized bow po-
Figure 4: Measured Schelleng diagram with a bow velocity that ramps up linearly to 5 cm/s (over 125 ms).

sion of $\beta = 0.1$. This value corresponds to the eleventh sample along the horizontal axis in Fig. 3 ($\log_{10}(\beta) = -1$), and that figure shows three values of bow force for which Helmholtz motion was obtained (at samples 10, 11, and 12 along the vertical axis). We vary the bow force to create an attack portion which, starting from zero, linearly increases to one of the three values yielding Helmholtz motion. Table 2 shows the results of these simulations.

Table 2: Simulation results obtained by varying the bow force from a very fast force attack (1.6 N/s) to a slower attack (0.4 N/s). The different columns correspond to different final force levels $f_b$. The first row gives the results for a constant-force attack. Each table entry is the number of periods to Helmholtz motion.

<table>
<thead>
<tr>
<th>Rate (N/s)</th>
<th>$f_b$:</th>
<th>0.1318</th>
<th>0.1896</th>
<th>0.2728</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>17</td>
<td>4</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td>19</td>
<td>20</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>22</td>
<td>24</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>24</td>
<td>29</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>33</td>
<td>35</td>
<td>37</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6 shows the simulation waveforms corresponding to the first row of Table 2 (constant-force attack), and Fig. 7 shows the waveforms corresponding to the last row (slowest attack). Notice how the attack speed influences the playability of the steady state portion. In this case, light, fast, bow-force onsets do best.

Notice also that, as shown in Table 2, no attack has a perfect Helmholtz motion from the first period.

6 Effect of Bow Velocity Variation

Our second test measures the time to establish Helmholtz motion for different bow-velocity onset speeds. The final bow velocity is 5 cm/s in all cases, as in the case of all points in the Schelleng diagram of Fig. 3.

Table 3 displays the results. The values of bow position and force correspond to samples 11 and 10, respectively, in the playability chart of Fig. 3.

Table 3: Simulation results (pre-Helmholtz periods) obtained by varying the bow velocity envelope from a very fast attack (1.6 m/s$^2$) to a slower attack (0.4 m/s$^2$). The last row corresponds to the attack show in Fig.8.

<table>
<thead>
<tr>
<th>Bow Accel. (m/s$^2$)</th>
<th>Time to Helm.</th>
<th>Time to Full Amp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>1.6</td>
<td>21</td>
<td>13</td>
</tr>
<tr>
<td>1.2</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>0.8</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>0.4</td>
<td>120</td>
<td>26</td>
</tr>
<tr>
<td>Fig.8</td>
<td>0</td>
<td>136</td>
</tr>
</tbody>
</table>

7 Conclusions

This study extends previous playability studies of virtual bowed strings to more realistic bowed-string transients. Results for the simulated bowed string were compared against published results from a bowing machine and found to be similar. It was found that the nature of the initial attack can strongly influence the quality of the overall bow stroke. In a companion paper [OSCS00], these issues are further investigated using a force feedback device.

Empirical mapping of the playability region can be used to discover which combinations of bowing parameters yield
maximum playability. For example, for each initial bow velocity and position, the optimum bow force envelope can be determined which reaches Helmholtz motion in the shortest time. Such an envelope can be used as the default force in a practical bowed-string synthesis environment. Similarly, optimum bow-velocity curves can be determined for any given initial fixed bow force on the string, at each position. Use of such optimized default envelopes can greatly increase the playability of a virtual bowed-string instrument, especially for unskilled players.

References


Figure 6: Motion of the string at the bridge point, obtained by varying $f_b$ from 0.1318 N (top) to 0.2728 N (bottom), but keeping a constant value in each motion. It corresponds to the first row of Table 2.

Figure 7: Motion of the string at the bridge point, obtained varying $f_b$ from 0.1318 N (top) to 0.2728 N (bottom), like in Fig. 6, but decreasing the force onset rate to 0.4 N/s. It corresponds to the last row of Table 2.

Figure 8: Velocity attack, sampled at 5 kHz, measured on a human subject using a force feedback device [OSCS00].