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Assessing the sound of a woodwind instrument that cannot be played

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ABSTRACT

Historical woodwind instruments in museums or private collections often cannot be played, by virtue of their poor condition or the risk of damage. Acoustic impedance measurements may usually be performed on instruments in good condition without risk of damage, but only if they are in playable condition: complete, with functioning mechanism, well-sealing pads and no open cracks. Many museum specimens are not in this condition. However, their geometry may almost always be accurately measured, and the measurements used to calculate the acoustic impedance as a function of frequency via a computer model of the body of the instrument. Conclusions may then be drawn about the instrument's pitch, intonation, temperament, fingerings, effects of bore shrinkage and even the timbre of the notes. A simple linear, plane- and spherical-wave computational model, originally developed for calculating the acoustic impedance of conical-bore woodwinds, is here applied to bass clarinets for the first time. The results are assessed by experimental impedance measurements and by playing tests on an historical Heckel bass clarinet in A of 1910 that has been continuously maintained in playing condition but has been relatively lightly used. The degree of agreement between the acoustic measurements and the calculations, the required measurement accuracy and the potential and limitations of the method are discussed, and specific conclusions for this instrument are drawn. Measurement of the frequencies produced in playing tests allowed us quantitatively to estimate the effects of mouthpiece and reed on the pitch of the produced notes. The method is shown to be a viable method for the examination of historical woodwind instruments.

1. Introduction

The aim of the investigations in this paper is to test the idea that it is possible to model the input impedance of a woodwind instrument sufficiently accurately that one may draw reliable conclusions about its behaviour purely from geometrical measurements of its bore, tone holes and keypads. This will enable the vast collections of woodwind instruments in museums to be used for primary evidence of their sounds without risk of damage.

There is a very large number of musical instruments in museum collections in the UK alone. These are steadily being catalogued in the MiniM database, which contains 20,000 records so far [1]. Clearly, a very important property of a musical instrument is its sound and related questions such as its pitch, temperament and fingering. However, the overall responsibility of museums is to protect and promote the tangible and intangible natural and cultural heritage [2], and many institutions preclude playing the instruments because of the risk of damage [3]. This is especially true for woodwind instruments where the act of playing rapidly introduces air at a much higher humidity and temperature, triggering potentially damaging reactions in the wood. Moreover, even if playing is permitted, it is fairly unlikely that a wind instrument 150–200 years old will be usefully playable without restoration that goes well beyond normal conservation. Sealing against leaks is crucial in these instruments; 200-year old pads – when original – are likely to leak, and cracks in the wooden body are quite frequent. These leaks strongly affect the acoustic impedance, rendering the instrument useless for the assessment of its musical potential either by playing or by acoustic impedance measurement. Occasionally a museum will permit full restoration for playing on a special occasion. Examples are the Brussels Musée des Instruments de Musique, where an Adolphe Sax instrument (B.B. mim.2601) was partially overhauled to play in the Sax bicentenary celebrations in 2014, and the Robert Schumann School in Düsseldorf, where a Stengel bass clarinet in A, originally owned by the Bayreuth Theatre and used in some original Wagner operatic performances, was restored for a demonstration concert and future use [4]. But the great majority of wind instruments in museums

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remain musically hidden from players or from direct sampling of the sound.

However, museums will normally permit the handling and careful measurement of instruments that are not too fragile, by an accredited researcher under supervision and the guidelines of ICOM/CIMCIM [5]. This has been used to study the development of types of musical instrument and their keywork (see, for example, [6–8] for clarinets), but their sounds have so far been mostly inaccessible.

The principle upon which the main methodology of this paper is based is that the sound of a wind instrument is dominated by the shape of its air column, as indicated by its input impedance. Although there are (and probably always have been) endless arguments about the influence of materials on a wind instrument, it has been demonstrated that the energy radiated by the walls of the tube into the room is inaudible in comparison with that emitted by vibration of the air column, and that wall material has little audible effect, as long as it is reasonably dense and has low porosity [9–11]. There is also very clearly an acoustic cooperation between the mouthpiece/reed and the resonator or air column, and the mouthpiece is of great importance for the details of the timbre and for the ease of playing. However, the importance of the resonator is shown by the observation that the character of the instrument appears mostly to go with this rather than with the mouthpiece [12]: a clarinet-type mouthpiece of suitably small volume works reasonably well on an oboe; the instrument still sounds like an oboe not like a clarinet, and it overblows an octave not a twelfth [13,14]. In this paper we are concentrating on the resonator. Its acoustic properties are defined by the sets of resonance, or impedance, peaks that it possesses and the relationships between them. If we can understand the influence of the detailed shape of the air column on the sound production, for all notes and all relevant frequencies, we shall know a great deal about the nature of the instrument. Furthermore, this knowledge is objective, and not subject to the physiology or prejudices of any player.

A well-preserved instrument from 1910 was used to make quantitative comparisons for this trial. Standard acoustic computational methods (described below) were used to calculate the impedance spectrum for each note of the instrument, and two tests of the accuracy were performed: one by measuring the input impedance directly in the laboratory, and the other by playing tests on the instrument, measuring the frequency of the note emitted at each fingering and looking at the predicted intonations produced by both ‘normal’ and ‘alternative’ fingerings. Thus we investigate two questions: can we calculate impedance spectra with sufficient accuracy without playing the instrument, and does this give significant musical information about the instrument?

2. Modelling of woodwind instruments

The development of mathematical and computational methods of modelling woodwind instruments has taken place over more than a century, beginning with the analytical ideas of Hemholtz [15]. Major contributions were made by Bouasse [16] and by Benade and his collaborators [10]. The understanding of woodwind acoustics progressed through analytical expressions for lossless and then lossy systems [17–19], linear system calculations [20], analysis of the reed/mouthpiece system [e.g. [15,21–23], impedance of the bell [24,25], non-linear treatment of the reed generator [26] and other factors; an excellent recent treatment appears in Chaigne and Kergomard [27]. In 1979, Plitnik and Strong [28] first applied the computer modelling method to the whole instrument. They split the bore (of an oboe in this case) into short cylindrical segments, thus approximating the conical shape of the bore by the staircase approximation, started from the calculated impedance of the bell radiating into open air and summed each complex impedance, in series for the segments and in parallel for the tone holes. A reed cavity impedance was added in parallel at the end of the sum. The result was the spectrum of impedance peaks as a function of frequency over the audible band. Note that this and most other approaches are based on linear theory and strictly only apply to small amplitudes. The non-linear effects of large amplitudes are critical in the understanding of the peaks selected, as discussed below, but there is agreement amongst all authors cited that linear acoustics suffices for the calculation of the tube resonances.

This general approach is still used today. Developments since Plitnik and Strong include improvements to the expressions for tone hole impedances, for wall losses, for the radiation impedance of the bell, for the influence of the reed generator and in the matrix formulation (analogous to electrical transmission line theory) which significantly speeds up the calculation [29,34,35]. Nederveen [30] has added valuable insight into the elements of the modelling equations and a number of experimental measurements. Research on simulating clarinet and saxophone sounds dynamically using digital formulations of the air column and reed/mouthpiece system in the time domain are also reaching an interesting stage [23,31,32,34].

Two computer implementations of linear acoustic modelling have been made more widely available and are cited in the literature. The program IMPEDPS was written by Robert Cronin in the 1990s, based on the developments and equations given by Keefe [29] and by discussions with Keefe and Benade. RESONANS was developed around the same time by IRCAM and the acoustics department of the Université du Maine in Le Mans (a brief note on application to recorders is given by Bolton [33]). Valuable summaries of the necessary equations for each component of the transmission line matrix formulation have been given by Scavone [34] and more recently Yong [35].

It turns out that the methodology descended from Plitnik and Strong is quite general for woodwind instruments that have reed generator excitation. It may also be used for flutes and recorders by using admittance peaks rather than impedance peaks, since the open entry ends of air-driven oscillators require a pressure node rather than antinode at the entry end. We have therefore used the methodology to test the basic assertion, that acoustic impedance spectra can be calculated by geometric measurements on instruments to sufficient accuracy to give musically useful information. We first review the advances in understanding of woodwind instruments that have been made by both experimental and theoretical modelling of impedance spectra.

2.1. Applications of impedance spectra to the understanding of woodwind instruments

The understanding of the influence of impedance spectra came first through experimental measurements and approximate analytical solutions of the acoustic equations, with particularly notable contributions made by Benade (summarised in [10]), Backus [20,54] and their co-workers. Indeed, the increased understanding of instrument acoustics provided by measurements and calculations of input impedance led Benade directly to a new design of clarinet bore and keyhole placement, in which inaccuracies in intonation were corrected by enlargement or contraction of the bore around pressure nodes [36–39]. Clarinets to the ‘Benade NX design’ are manufactured by Stephen Fox Clarinets (Toronto) [40].

There are various different ways in which input impedance can be measured experimentally. Dalmont [41,42] provides a comprehensive review of input impedance measurement techniques developed during the 20th century. One of the most popular