WilliamT.Cardwell Jr.
TheoryandPractice
of
Trumpet AirColumn Design

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CHAPTER 1 - TRUMPET AIR COLUMN CONSIDERATIONS

1.1 Introduction

William T. 'Bill' Cardwell Jr. was born on May 27, 1917 and obtained his Bachelor/Masters Degree in Chemical Engineering from California Institute of Technology in 1939. He quickly gained employment with Standard/Chevron Oil Company where he served as a chemical engineer, research scientist and patent advisor until his retirement in 1981. Bill was an active and enthusiastic trumpet player, and played in dance bands and dixieland groups in southern California. He found that his studies on seismic wave exploration and vibration theory at work could be combined with and applied to his hobby of playing the trumpet. In 1959 he started on a quest to advance the state of the art of trumpet design to improve intonation, response, and the tone quality beyond that of commercially available trumpets. He intensified his efforts in 1965 following a detached retina which forced him to give up playing the trumpet.
Bill was a dedicated researcher and strict adherent of scientific method:

> "In scientific research, we consider it a significant accomplishment when we are finally confident that we are arriving at the right questions."

He began with an exhaustive study and critical review of prior early musical physics and acoustic theory: D. J. Blaikley (1878), Hermann von Helmholtz (1863), Lord Rayleigh (1894), Henri Bouasse (1929), T. H. Long (1947), Philip Morse (1948), F. J. Young (1960). This study provided a solid basis and understanding from which Bill could advance with theoretical derivations and experiments in the lab. As Bill put it (paraphrasing Sir Isaac Newton):

> "The fun in science is in standing on the shoulders of giants, trying to see farther than they saw, not in trying to prove they are not as tall as everyone thinks."

One conclusion he reached was that Bouasse's theory was not successful in predicting the required shape of the trumpet bell only because he did not recognize and include the tuning effect of the mouthpiece and leadpipe. Based on experiments, Bill developed a rough first approximation of the mouthpiece tuning effect, and additional study of Bouasse led him to a full understanding of phase matching when joining flaring sections of tubes. Bill's first significant contribution to the art was the method he developed to calculate the internal shape of the bell stem required to match a particular mouthpiece and leadpipe in order to properly tune the lower modes of the instrument to align with the upper modes. Bill believed this would result in an instrument with easier response and superior intonation that would be easier to play in tune so the trumpeter could concentrate more on musical expression rather than on working around shortcomings of his instrument.

Bill set out to design trumpets that played and responded better in the upper register. He believed that better alignment of the playing modes (the open tones of the instrument) would result in a trumpet that would sound better with less effort. He considered that playing Johann Sebastian Bach's Brandenburg Concerto Number 2 was perhaps the most challenging thing that a trumpet player had to do. As he put it:

> "...I thought that the trumpeters in the most need of help were the tortured souls who played Bach's Brandenburg Concert No. 2 in F".

So, as his first endeavor he chose to design a high sopranino F trumpet, and had Dominick Calicchio construct and adjust two F trumpets to his specifications. The resulting Athena F trumpets received very positive reviews from respected professional players, and gained him recognition within the Acoustic Society of America (ASA). When Bill presented his method to the ASA in 1966, Earl Kent (Conn Corporation's Director of Engineering Research), Jody Hall (Conn's Chief Acoustical Engineer), and John Backus (well known acoustician, professor at University of Southern California and chairman of the 1966 ASA session) were all in attendance. Backus later related that he didn't believe Bill's theoretical descriptions of the mouthpiece effects until he went back to his lab and verified them experimentally himself. Hall indicated that Bill, working alone, had solved the problem that the Conn team had been working on for years! As Bill, the scientist, put it:

> "The critical part is the second mode phase matching maneuver that involved having the bell contain a quarter wave at the frequency of the second mode, which was not found in any prior art."

Bill's method was patented and published and is believed to be the only published work describing how to quantitatively design an in tune trumpet air column from scratch in any key or desired bore, based solely on constants measured from the mouthpiece and leadpipe. Bill stated that the improved playability of the Athena F trumpet resulted from the natural modes of this design being more in tune with each other than those of conventional trumpets of the day.

1.2 Athena F Trumpet Design

On to the heart of the matter, starting with a 1965 unpublished working paper and the resulting 1966 ASA presentation which chronicle the Athena F trumpet design process. This first document is an unpublished and incomplete working paper which was a precursor to Bill’s 1966 paper presented to the ASA.

The starting design principle of T.H.Long’s equation(from The Performance of Cup- Mouthpiece Instruments, JASA Volume 19 No 5 1947) is presented here. Cardwell noted Long’s paper was a strong influence on his own work “although I would say now that some of those teachings were misleading, and it took me years to separate the good parts from the no-so- good parts....”Long’s equation represents two moving boundaries, one at the mouthpiece and one at the bell. The function of the bell to adjust lower modes, and the mouthpiece as a Helmholtz resonator providing the effect of adjusting the higher modes of the trumpet are asserted. The early quantification of the mouthpiece effect along with the introduction of the dimensionless factorK are detailed here. The mouthpiece effect is measured and demonstrated, along with notes that diagrams in Earle Kent’s patent imply it, but never describe it.

D. J. Blaikely’s conclusion that the trumpet is a closed-open resonator system is stated. Bousasse’s contributionsarenotedalongwithrecognitionthathisfailuretocalculatepractical and useful bell shapes was due to unawareness and omission of mouthpiece contributions to the tuning effects. References are provided to the work of F.J. Young and Earle Kent which were other important early touchstones for Bill’s research. A discussion of test apparatus for measuring resonances includes Webster’s active driver method (see patent 2,571,97910-16-1951) for driving point impedance, and introduces a form of passive excitation preferred by Bill until the mid 1970’s. Early intonation charts are log-log, with ideal intonation represented on a straight 45° line.

...and now, the first working paper.

1.2.1 1965 BASIC DESIGN THEORY OF THE TRUMPET AIR COLUMN, (unpublished W. T. Cardwell Jr. working paper)

ABSTRACT

Unfinished paper, the following are not included

Basic Design Theory of the Trumpet Air Column

ABSTRACT

An exact theory of the trumpet is undoubtedly impossible to formulate at the present time, but an approximate theory explains the essential functions of the mouthpiece, the main tubing and the bell. Trumpets designed using the theory give quantitatively satisfactory resonances. The starting assumption is that the apparent effective length of the resonating air column of the modern trumpet needs to vary between 3/4 L at the second mode and 15/16 L at the eighth mode, where L is the length of a symmetrically-ended, tubular resonator of constant cross section having the same frequencies (of the second and higher modes) that are desired from the trumpet. The above two requirements can be met if the actual length of the resonating air column is given an intermediate value such as 7/8 L. The apparent shortening at the low modes may be obtained from the bell effect. The apparent lengthening at the high modes may be obtained from the mouthpiece effect. The mouthpiece, acting as a Helmholtz resonator, can add an apparent length equal to approximately a quarter of its resonant wavelength.

INTRODUCTION

The first purpose of this paper is to explain the empirically-developed shape of the air column of the modern trumpet, from the mouthpiece to the bell. A second purpose is to indicate how to design the air column for a trumpet in any desired key. A proper air column is taken to mean one that will give the musically proper intonation of the ‘open’ tones. A third purpose is to indicate at least an approach to the problem of purposefully changing the timbre.

The paper does not deal with valve problems, either the mechanical problems connected with their motions, or the acoustical ones connected with achieving the proper effective added length combinations. It will be apparent, however, that the theory of the latter problems must be subordinate to some of the theory given here on combined bell and tube lengths.

Some of the findings indicated here to be new may not actually be new to certain of the experienced instrument manufacturers.However, the knowledge of the instrument manufacturers is not well represented in the literature, and the extent of that knowledge is difficult to estimate. There is some slight evidence that the traditional ‘trade secret’ customs of the instrument manufacturers might give way to the more modern custom of using the patent system, which permits disclosure of information for the ultimate benefit of the public, and allows are turn privilege for the inventor in the form of a temporary, restricted, but legally enforceable monopoly. Study of the patent literature indicates that this modern custom prevails among manufacturers of electronic musical instruments. However, with the pre-electronic musical instruments we seem to be still in the ‘trade secret’ era, partly because of tradition, and partly perhaps because closely-held knowledge evades objective measurement and discussion, and sometimes the impression of kept secrets that do not even exist has an actual commercial value.

The nextsectionreviewsbrieflytheliteratureuponwhichtheexperimentalandtheoreticalwork reported here was based. A few critical comments seem appropriate because the literature relevant to the trumpet ranges widely in scientific sophistication. Some of the less rigorous material states experimental truths that should not be disregarded, and some of the apparently rigorous material sacrifices relevance for sophistication.

BACKGROUND LITERATURE

The significant literature on the acoustic behavior of brass instruments might be said to have begun with the 1878 article of Blaikley 1. Blaikley expressed a principle that is extremely helpful in the experimental and the oretical investigation of brass instruments. His principle is that the frequencies produced by a player blowing upon a cup-mouthpiece instrument are the same as the frequencies to which the instrument will respond as a closed-open resonator, the mouthpiece being closed off at the plane of the rim to which the lips are meant to be applied.

It is obvious without discussion what tremendous experimental simplification Blaikley's principle might provide, but the principle has not been well enough known and respected, probably because the ‘open’ resonances of the trumpet (and of the related cup-mouthpiece instruments) have frequencies that are approximately proportional to the numbers in the full series of small whole numbers:(1), 2, 3, 4, 5, 6, 7, 8, etc. (The reason for the parenthesis around unity will be discussed later.) One does not expect the full series from a closed-open resonator, because the simplest, familiar, closed-open cylindrical tube resonator gives frequencies proportional to only the odd whole numbers: 1,3,5,6, 7, etc. All of this was well understood and discussed by the physicist Bouasse nearly forty years ago, 2 but as regretted by Benade in his excellent modern book3, Bouasse "is not nearly as well known as he deserves to be." Some of the relatively modern literature still spends words discussing the question of whether the trumpet is a closed-open, or open-open resonator.4

Bouasse formulated well the fundamental problem of trumpet design, which is to find a bell-flare, whose frequency-dependent, apparent shortening effect will just change the modes whose frequencies would be proportional to the numbers 1, 3, 5, 7, etc. to musically useful modes whose frequencies are proportional to the numbers (1), 2, 3, 4, 5, etc. In fact, Bouasse laid out the difficulties of the problem so well that they might still seem discouraging to the most modern reader.5

The present paper will show that the possibilities are not as gloomy as indicated by Bouasse because in some senses at least, the bell behaves more simply than available theory would lead one to suspect.

In the otherwise thorough treatment of Bouasse, the most important deficiency was perhaps lack of appreciation of the effect of the cup mouthpiece on intonation.

On the other hand, the late, eminent acoustical authority, E. G. Richardson7, may have attributed at least one effect too many to the mouthpiece. He presented evidence of edge-tone effects. To the present author's knowledge these effects have still not been proved to exist. If they do, it is intriguing to speculate that they might be usefully modified to provide a trumpet that would be more easily excited in the high register.

In 1947, T. H. Long4 presented some interesting experimental results and theoretical explanations of trumpet behavior. Some of Long's theoretical conclusions, for instance the one that "all such [trumpet-like] instruments should have the same effective length vs. frequency except for a constant length of cylindrical tubing depending on the key of the instrument," are over-simplified. Nevertheless, the Long article is one of the most important sources of modern experimental information.

A companion article to the one of Long, by J. C. Webster,8 gives perhaps the most complete description in the literature of intonation-measuring experimental apparatus and methods. The present author prefers the passive resonator method, based on Blaikley's principle, to the active driver method of Webster, but the two methods undoubtedly have their relative advantages and disadvantages, and the Webster article is an indispensable reference.

Aninteresting advanced theoretical and experimental article by F. J. Young9 looked at the reverse of the air column design problem: given a horn with a certain flare function, what should beits natural frequencies.

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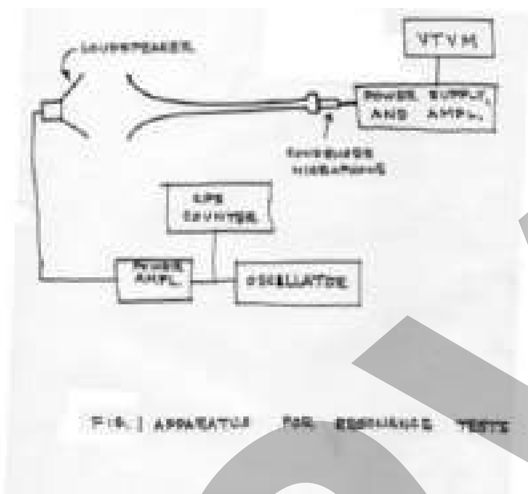
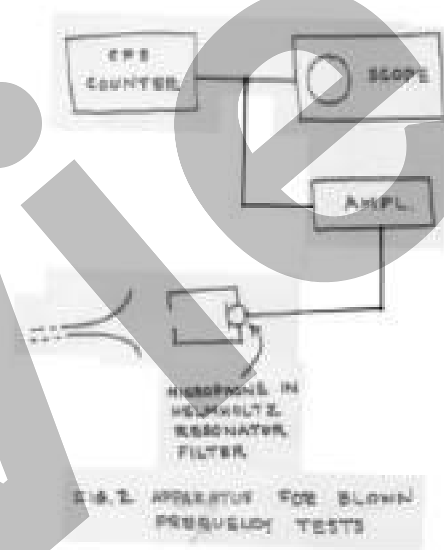
A most important reference on the trumpet is the1961 E. L. Kent patent10. The patent shows experimental results on the effects of varying shapes and dimensions of mouthpieces, mouthpipes, valve slides, and bells.

Within the last three years the same E. L. Kent, and Jody C. Hall, have presented to Acoustical Society meetings several papers 11,12,13,14 which by title and abstract, appear closely related to the present paper, but those papers have not been published.

Figures 1 & 2 EXPERIMENTAL EQUIPMENT AND METHODS





The essential equipment used in the studies reported here is represented schematically in Figures 1 and 2. Those figures are, for the most part, self-explanatory. To help the reader to make a critical evaluation of the resonance tests, it is perhaps most important to mention what was not used. In the trumpet resonance tests, the excitation level was not held constant. The arrangement was in a small, private laboratory, which undoubtedly had prominent room resonances. However, trumpet resonance peaks, in the range of interest, are so sharp that the shifting of those peaks due to slope in relative excitation was insignificant.

The filtering used for the blown frequency tests (Figure 2) was unusual, or perhaps, even unique in a modern laboratory. Blown trumpet tones are full of harmonics, which of course, provide their musical distinction. But a digital counter must have all these harmonics decidedly suppressed before it will handle the fundamental without confusion. A well equipped institutional laboratory would undoubtedly have done the filtering operation with variable-frequency, narrow-band-pass, electronic filters, but in the author's laboratory it was expedient to go back to Helmholtz's nineteenth century idea of listening through resonators. Microphones were mounted in the backs of Helmholtz resonators. This gave adequate filtering. A cubical resonator, three-inches on the side, with a quarter-inch orifice, covered the range from 200 to 350 cps; the orifice was enlarged to one inch for the range, 350 to 525 cps; a smaller cylindrical resonator one and a quarter inches in diameter, having a quarter-inch orifice covered the rest of the range. The approximate, effective depth of the cylinder was set at two inches for the range from 525 to 780 cps, and one inch for the range from 780 to 930 cps. To the author's knowledge, the best literature source on the design of Helmholtz resonators is the article of Ingard15. Applications of the idea of mounting microphones in Helmholtz resonators are described in U. S. patents to Volkmann, and to Massa16.

The amplitude versus frequency curves presented in the next section were measured without automatic frequency sweeping apparatus. The oscillator dial was twisted by hand, and then stopped during the reading of the vacuum tube voltmeter. The measurements were made with special slowness and deliberation in the neighborhood of the resonance peaks.

The essential new results of the present paper were obtained from measurements on specially made trumpet bells of calculated flare functions. These bells were made of fiberglass in the following manner. First, a hard wooden mandrel was turned, having outside dimensions equal to the desired inside dimensions of the bell. The mandrel was wrapped with glass cloth. Then the glass cloth was impregnated with the resin, which was allowed to harden. Finally the wooden mandrel was removed, leaving the desired inside bell dimensions.

In some of the work reported here, actual blowing intonation tests were involved, as has already been indicated by a brief discussion of the apparatus represented in Figure 2. A comment seems justified on the place and the value of blowing tests in general. As a playing trumpeter, the author considers blowing tests to be indispensable for any tube and bell arrangement being considered as a trumpet, or for incorporation in a trumpet. This is because we have not yet

End of Preview