The Legacy of William T. Cardwell, Jr.

By Gary J. Bast

Wouldn't you want your trumpets to have better intonation, easier response, and the tone quality you are looking for? This was the question that started Bill Cardwell on a lifelong quest to advance the state of the art of trumpet design. While the name William T. "Bill" Cardwell, Jr., is well known to a few, his accomplishments and contributions are largely unknown and under-heralded.

Bill was born on May 27, 1917, and obtained his bachelor's/master's degree in chemical engineering at the 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. Bill began serious acoustical studies of the trumpet in 1959, and he intensified his efforts in 1965 after developing a detached retina, which forced him to give up playing the trumpet.

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Bill set out to design trumpets that would play and respond better in the upper register. He believed that improved alignment of the playing modes (the partials of the harmonic series, or open tones of the instrument) would result in a trumpet that would sound better with less effort. He considered that playing Bach's Brandenburg Concerto No. 2 was perhaps the most challenging thing for a trumpet player to do and said, "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." Being a dedicated researcher and strict adherent of the scientific method, Bill began with an exhaustive study of prior early musical physics and acoustic theory by

Domenick Calicchio brazing the bell for the Athena trumpet such researchers as D. J. Blaikley (1878), Hermann von Helmholtz (1863), Lord Rayleigh (1894), Henri Bouasse (1929), T.H. Long (1947), Philip Morse (1948), and many others too numerous to mention. This study provided a solid basis and understanding from which Bill could advance with theoretical derivations and experiments in the lab. Bill paraphrased Sir Isaac Newton, saying, "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 that Cardwell reached was that Bouasse's theory was not successful in predicting the required shape of the trumpet bell *only* because Bouasse 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's work led Bill to a full understanding of phase matching when joining flaring sections of tubes. His 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

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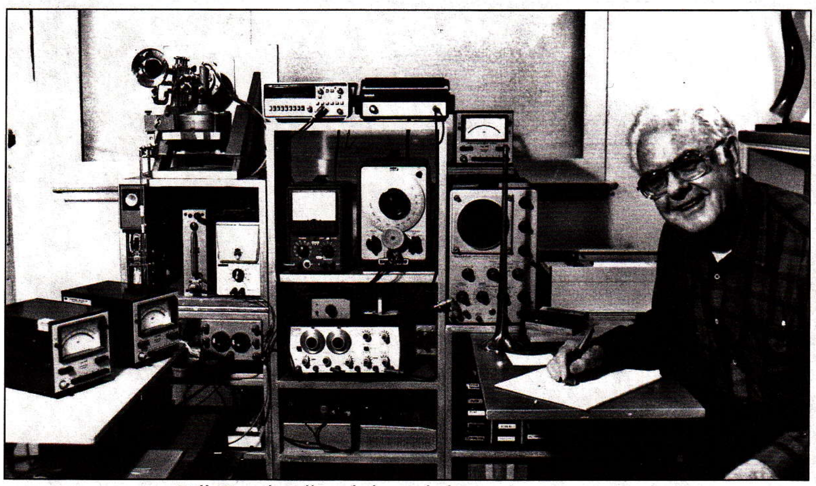


Bill Cardwell in lab with his salpingometer

with the upper modes. Bill believed that this would result in an instrument with superior response and intonation that would be easier to play in tune so the trumpeter could concentrate more on musical expression rather than on working around the shortcomings of the instrument.

Cardwell designed a high sopranino F trumpet and had Domenick 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 Cardwell recognition within the Acoustic Society of America (ASA). When Bill presented his method to the ASA in 1966, Earl Kent (Conn Corporation Director of Engineering Research), Jody Hall (Conn's Chief Acoustical Engineer), and John Backus (well-known acoustician, professor at USC, and chair of the 1966 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 himself experimentally. Hall indicated that Bill, working alone, had solved the problem that the Conn team had been working on for years! Bill stated, "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 quantitatively how to 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.[1] 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.

Not completely satisfied with his first efforts to define the qualitative tuning of the mouthpiece, Bill developed a formula to predict the tuning effect of a mouthpiece and leadpipe more accurately and quantitatively. Even with simplifying assumptions, he generated an equation that accurately predicts the tuning effect up to 1000 Hz (roughly concert high C) and can be used qualitatively through the remaining playing range. To demonstrate this in a dramatic way, he designed an "anti-mouthpiece leadpipe," which exhibited the *opposite* tuning effect from that of a normal mouthpiece leadpipe. Where the normal mouthpiece leadpipe demonstrates an apparent acoustical length that increases while ascending through the normal playing range, the anti-mouthpiece leadpipe apparent length decreases over the same range. This clearly demonstrated the wide range of tuning effects that could be achieved. In other words, with consideration of the player, by varying the design of the mouthpiece and leadpipe, with the proper matching bell, any reasonable desired tuning can be accomplished by adjusting the shape of the air column. This research was presented to the Acoustic Society of America in 1973.[2]

Bill recognized the need to have quantifiable and repeatable test results to support his research. An expert musician with a well-trained ear could be expected to repeat within five musical cents. In addition, in order to remove any human predispositions or bias to experimental results, he used "extra-human" (machine) testing. In the early days of his research, he set up an apparatus to drive the instrument externally, but this required careful placement of microphones and loudspeakers and had both perceived and real limitations. In order to address these issues and to communicate more effectively with his peers in the ASA, he developed what he called his "salpingometer." This apparatus determines the resonances where the instrument naturally "wants to play," unencumbered by conscious or unconscious adjustments from a musician. This device, five times more accurate than expert human testing capability, is rooted in similar devices used by others in the field, including those at the renowned Conn research laboratories.[3]

This equipment provided the accuracy and repeatability to measure the intonation curve of an instrument including mouthpiece to within one musical cent (1/17 of one percent), and provided Bill with the tools needed to continue and communicate his research effectively. While some musicians are somewhat skeptical of this approach, Bill stated, "Over more than three decades of this kind of work, my results have never disagreed directionally with those of a skilled human tester. Many times I have shown [the results] to a trumpeter and have had him exclaim, 'That's my horn!'"

In the late 1960s, Bill also consulted for Zig Kanstul, who was factory superintendent at the F.E. Olds Corporation, and performed some testing and analysis of trumpets and bugles. In the early 1970s, Dale Olson, a friend of Bill's and prior director of research for the F.E. Olds Corporation, urged Chicago Musical Instruments/Olds to enter into a contract with Bill to apply his patented method to design a B-flat soprano trumpet. Bill designed several B-flat trumpet air columns, varying only the final skirt flare, and the design finally chosen by CMI was marketed as the Olds CHR (Custom High Range) and Reynolds ERA (Extended Range Altissimo). The final flare of the bell leaned more toward a C trumpet than the typical soprano B-flat bell skirt. The intonation curve of this air column demonstrated well-aligned, very high, well-defined resonance peaks further into the upper register than standard B-flat instruments, resulting in tight slotting and marked pitch stability over the full dynamic range. In other words, this horn provided the player with more secure attacks in the upper register and one that was easier to keep on pitch during crescendos and decrescendos. Bill felt that the marketing of this horn as a "high range" instrument was unfortunate, as expectations were unreasonably raised, and the resulting reaction to the horns was somewhat mixed. Ultimately, with a change in ownership of the company to Norlin/CMI, a shift in priorities, along with disappointing production and sales led Bill to terminate the contractual agreement in 1978, and fewer than 600 of these instruments were produced.

Family of four trumpets with varying tone quality. The top bell skirt flare is extreme for a soprano instrument, similar to a sopranino trumpet, and results in a very bright tone. The second is shaped and sounds more like a C trumpet. The third is closer to the bells of traditional Besson/Bach 37 trumpets. The bottom broad bell skirt flare (reminiscent of Bill's old Martin instrument) has a very dark tone.

Having gained wider recognition, musicians began to come to Bill with requests to solve specific issues. Correcting intonation problems on specific instruments was a common request. Among others, Bill worked quite extensively with Bernie Adelstein on intonation correction of C trumpets. As always, Bill addressed this aspect of trumpets with careful analysis and complete rigor. He developed specific rules and quantifiable combinations for changes to be made to an existing air column to shift and correct the intonation of existing instruments. To fully prove the effectiveness of these methods, he demonstrated the ability to move a single mode of an instrument without significantly altering other modes. He recognized that there is no one-note, one-place tuning relationship; in other words, there is no single location in an instrument that belongs to one note, and there is no note that belongs to a specific location. To adjust only the fifth mode required precise and careful placement of five separate changes along the air column.[4] In this case, he raised the fourth space E, which was flat on that specific instrument, to be properly in tune without affecting the other open tones.

"To adjust only the fifth mode required precise and careful placement of five separate changes along the air column."

Bill noted that Blaikley had observed in 1878 that the rapidly flaring section of trumpet bells did not significantly affect the intonation of the air column,[5] and Bill's study of Morse led Bill to conclude that reflections from the rapidly flaring skirt and the resulting change in the transmitted frequencies were a major determinant of tonal quality. In the early 1980s, in order to demonstrate this principle dramatically, Bill designed a family of four B-flat soprano trumpets with different bell skirts, made by Larry Minick. These instruments all had the same leadpipe and bell stem and differed only in the shape and cutoff frequency of the bell skirts. All of these trumpets play with the same excellent intonation, but they have dramatically different tonal qualities.

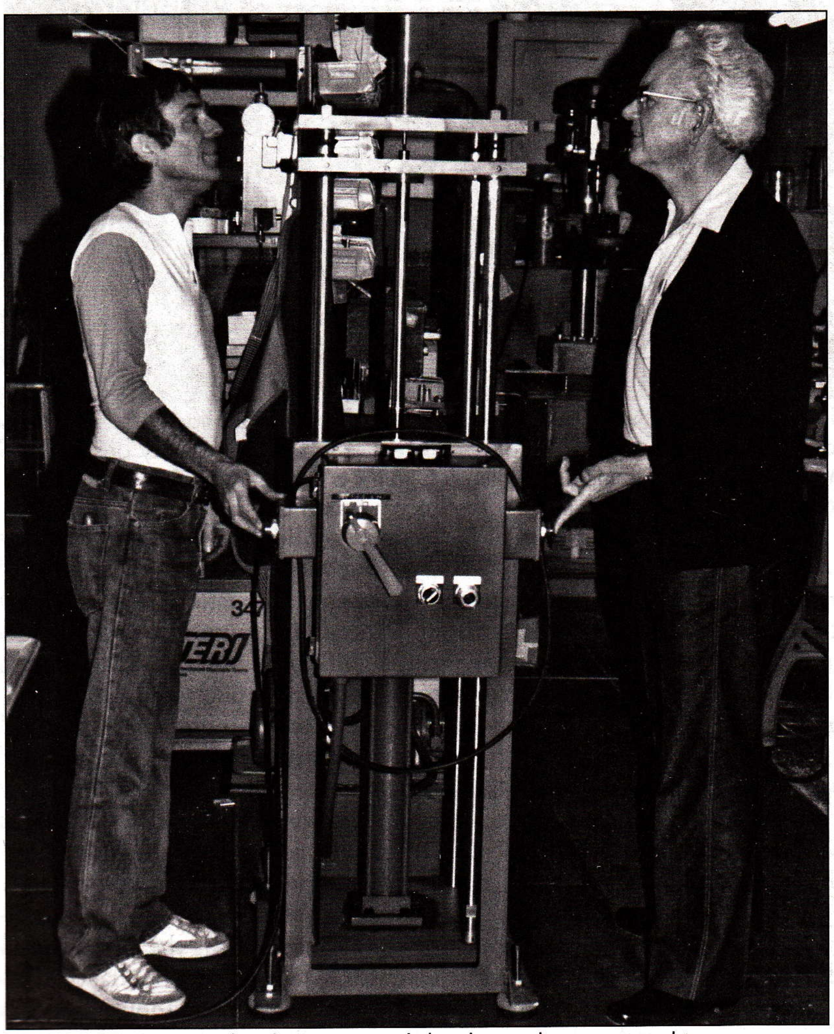
"Bill found that by applying his 1973 equation and the method from his patent, the resulting computed bell stem matched that of the Bach 37 bell within manufacturing tolerances."

R. Dean Ayers, professor of physics at California State University, provided Bill with impulse test results in the late 1980s, which clearly showed different reflections resulting from the bells with different flare rates. Bill told Dean that he was thrilled to see these graphs. "To formulate the quantitative bell design theory, I had to assume in the 60s that those reflections would occur there, but actually seeing them is wonderful."[6]

These simple bell skirt shapes in the family of trumpets were not representative of traditional trumpet bell skirts, which more typically have a more complex shape and resulting quality of sound. In the 1980s, Bill also worked with Ward Cole, a professor of music at the University of Calgary in Alberta, to develop a C trumpet that had playing characteristics like those of his prized B-flat Bach trumpet. Even the Bach C trumpets did not have quite the feel and sound that Ward wanted. At this time, Bill had a set of measuring gauges made so he could perform precise physical measurements of trumpets. He developed methods to calculate the multiple skirt flare rates of specific instruments that had the sound quality desired and to incorporate them with the bell stems designed using his prescribed method. In this way, he was able to provide an instrument with the improved tuning qualities and response, as well as the desired sound qualities chosen from other instruments.

To state these accomplishments in musical terms, by the end of the 1980s, Bill had demonstrated the capability to design trumpets pitched from soprano B-flat to sopranino F with superior intonation and response and to provide the desired tonal quality.

As a secondary benefit, Bill proved to his own satisfaction that the well-established and respected Bach 37 and French Besson bell stems could be accurately described by catenoids, placing them in the family of shapes addressed in his patent. With the physical measurements now available, using acoustical measurements of a Bach 7C mouthpiece with a typical lip insertion and a Bach #25 leadpipe, Bill found that by applying his 1973 equation and the method from his patent, the resulting computed bell stem matched that of the Bach 37 bell within manufacturing tolerances. This was an important, if private, vindication for him, since there had been some dissention with others who considered trumpet bells were more properly described and analyzed by other mathematical functions.



Bill (R) and Bob Reeves with leadpipe drawing machine

Bill's efforts had also gained the attention of Cliff Blackburn. After some correspondence, they met and found that they had reached similar conclusions about many aspects of trumpet design; so they began a mutually beneficial collaboration in the early 1980s. This was opportune in that it provided Bill with an active outlet to apply his theories to a line of commercially available instruments and to get his designs into the hands of more musicians. Bill continued to work with Cliff over several decades. The Blackburn instruments currently have a very good reputation, and Bill was very proud of his work with Cliff.

Bill also made presentations at conferences of the International Trumpet Guild.[7] In 1994, he shared a session with Cliff Blackburn in which Bill used his portion to address intonation correction. In a 1996 presentation, Bill addressed the ability to design an instrument to achieve desired tonal qualities, talked about the difficulties inherent in properly addressing intonation issues, and "myth-busted" some common misconceptions.

Bill was generous with his time and knowledge, providing support to many who requested it. He corresponded with well-known manufacturers, academics, and players and readily provided information to those who demonstrated both interest and ability.

Bill's decades-long relationship with the well-respected mouthpiece manufacturer Bob Reeves dated back to the late 1960s and included long-running and mutually beneficial dialogues and sharing of information, along with introductions to many players and others in the business. Bill developed computer programs and performed calculations for Bob in support of the mouthpiece business, and Bob made many mouthpiece shapes for Bill's use and analysis. Bob also procured or built many tools for Bill over the years. Bill and Bob worked together to design and build a vertical hydraulic leadpipe drawing machine.

Bill also provided guidance and mentoring to Robert Love on mouthpiece theory and helped him develop test methods and pieces of apparatus. Robert performed some significant laboratory work on tonal quality control by mouthpiece shape variation while preserving intonation, research that he later used to formulate his own engineering model and develop his patented line of mouthpieces.

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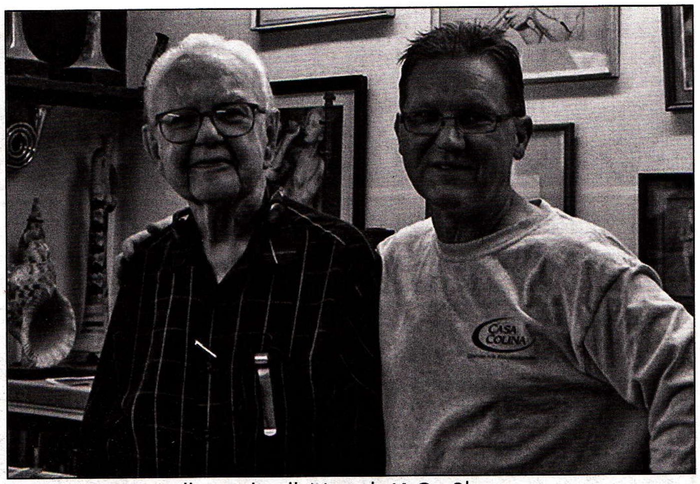
Bill met K.O. Skinsnes while working with Bob Reeves, starting a relationship that lasted the rest of Bill's life. K.O. brought his empirical experience to the table, and they spent many hours discussing the problems of the trumpet world. According to K.O., it was not uncommon for Bill to interrogate him regarding trends and/or observed results before they would dive into the math/physics to see if they could discover a scientific correlation. Bill had an unwavering resolve for staying true to the scientific process. However, according to K.O., Bill did accept that a skilled player could perceive small changes that, at the time, Bill couldn't measure. The bottom line to Bill was to improve both the trumpet playing experience for the trumpeter and the listening experience for the audience. By combining the science with real world experiences, Bill and K.O. worked to move the diagnostic side of problem solving for the individual forward. When asked how often they could relate the science to what K.O. was observing while working with players, K.O.'s response was, "Often enough to satisfy Bill!"

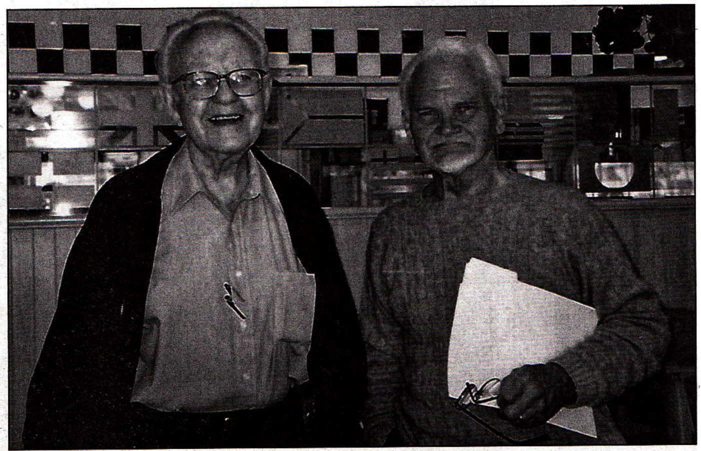
After reading the review in the *ITG Journal* of one of Bill Cardwell's presentations, this author began corresponding with Bill in 1994. Over the next two decades, Bill mentored him extensively in all aspects of the theory and practice of trumpet testing and design, assisted in establishing the author's acoustic lab, and introduced the author to both K.O. Skinsnes and Bob Reeves. Bob produced key parts for an improved version of the salpingometer for the author, with input from Bill.

The friendship between Bill Cardwell and Dale Olson also lasted several decades. Although they met often over the years, the two started in March of 1986 to meet occasionally at the local International House of Pancakes to discuss items of mutual interest in the trumpet world. They dubbed this "The IHOP Trumpet Acoustics Conference," with a small and very select membership (just the two of them!). Dale considered Bill to be *the* ultimate authority on trumpet design.



Bill Cardwell (L) with K.O. Skinsnes

Bill was a thorough researcher who believed that, if you don't know what research has already been done, you will repeat it unnecessarily. He often noted that people were "discovering" things he had established decades before. He was totally dedicated to the scientific method and was always careful not to bias his testing with preconceptions of results. He once commented to Cliff Blackburn, "Often, we learn the most when experiments don't turn out the way we may expect." Since this would likely require additional time to reconsider design approaches, Cliff's considered response was from the perspective of a manufacturer: "Well, then let's hope we don't learn anything today!"



Bill Cardwell (L) and Dale Olson
at an IHOP Trumpet Acoustics Conference

Bill Cardwell's contributions to trumpet acoustical research were significant and noteworthy. Even so, when asked many years ago which of his accomplishments he considered the most important, his quick and sincere reply was "marrying Bette," his wife of 66 years. Together, they regularly attended the ITG conferences until 1998, and they often welcomed well-known artists and acousticians into their home. Bill passed away on May 17, 2012, and was followed soon after by

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Bette. They were gentle, sensitive, generous souls and are missed by those who knew them well.

"Often, we learn the most when experiments don't turn out the way we may expect."

The author thanks all those who provided input or advice for this article—Cliff Blackburn, Dale Olson, and Bob Reeves. Particular thanks are also due to K.O. Skinsnes, who has placed the Cardwell research library into the author's hands. Bill's library includes numerous reference books, dozens of notebooks of research and derivations, and correspondence with over fifty individuals. The author is actively curating these research and correspondence files.

Bette and Bill Cardwell

About the author: Gary J. Bast has a BS degree in electrical engineering from Lehigh University and an MS degree in engineering management from Drexel University and is a retired senior member of the Institute of Electrical and Electronics Engineers. He is also a longstanding member of the International Trumpet Guild and enjoys playing trumpet and flugelhorn in a number of settings including quintets, concert bands, jazz bands, and pit orchestras. Gary continues to be very active in many aspects of applied trumpet design and research. He can be reached via email (gjbast@ptd.net).

Endnotes

1 William T. Cardwell, Jr., "United States Patent: 3507181—Cup-mouthpiece wind instruments," April 21, 1970.

2 Cardwell, "Trumpet Acoustics – The Tuning Effect of the Mouthpiece and Leaderpipe" (presentation to Acoustical Society of America, Los Angeles, CA, November 1, 1973).

3 J.C. Webster, "An Electrical Method of Measuring the Intonation of Cup Mouthpiece Instruments," *The Journal of the Acoustical Society of America* (1947): 19; John Backus and Thomas Chase Hundley, "Harmonic Generation in the Trumpet," *The Journal of the Acoustical Society of America* (1971): 49; John Backus, "Acoustic Impedance of an Annular Capillary," *The Journal of the Acoustical Society of America* (1975): 58; John Backus, "Input Impedance Curves for the Brass Instruments," *The Journal of the Acoustical Society of America* (1976): 60.

4 Cardwell, "Trumpet Intonation Acoustics," unpublished manuscript, 1973; Cardwell, "Trumpet Acoustics: Correcting Intonation Faults" (presentation to Acoustical Society of America, San Diego, CA, November 19, 1976).

5 D.J. Blaikley, "On Brass Wind Instruments as Resonators," *Philosophical Magazine and Journal of Science* 6 (July – December 1878): 119.

6 Cardwell, letter to R. Dean Ayers, February 21, 1989.

7 William T. Cardwell and Cliff Blackburn, "Trumpet Design and Building: Science, Art, and Craftsmanship" (presentation to International Trumpet Guild, Urbana, IL, June 1994); Cardwell, "Trumpet Intonation Control and Tonal Quality Control" (presentation to International Trumpet Guild, Long Beach, CA, June 1996).