Perceptions of the Stuart & Sons Piano Sound: 
Realising a creative, active vision

Kevin Hunt

Thesis and creative work submitted in fulfilment 
of requirements for the degree of 
Doctor of Philosophy

Sydney
University of Sydney
2016
I declare that the research presented here is my own original work and has not been submitted to any other institution for the award of a degree.

Signed:

Kevin Hunt

Date: 20 November 2015

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Permanent email address: kevin.hunt1@bigpond.com
Abstract

This research examines the position of the Stuart & Sons piano in the three hundred year evolution of piano design. It demonstrates how the Stuart piano design is indicative of the technology of its period, the music of its period, and the place of its development. This thesis argues that the Stuart & Sons piano design implementations of the bridge agraffe and the expansion of its frequency ranges demonstrate that the new Australian instrument is of its time and place. Its use of 21st century technological advancements in steel wire drawing and its production of a distinctively new sound aesthetic which appeals to Australian contemporary music composition are indicative of a piano design of this period. The experimental ideas of the 19th century piano designers Henri Pape, John Broadwood and Sebastian Erard have been taken up by Stuart to expand the piano’s frequency range to the widest in the history of the piano, from 16Hz to 5587.65 Hz with a proposed extension of 6 higher notes to 7901.72 Hz. This proposed extension achieves a 108 note keyboard compass and eight full octaves for each pitch of the chromatic scale.

The thesis examines Wayne Stuart’s claims that today’s modern piano design, standardized in the late 19th century, represents a pause in the evolution of piano design that has not adapted to the changes in musical style and technology of the 20th century, whereas the Stuart design supports the vertical emphasis in sound production implemented by the impressionist, contemporary & electronic music composers of the 20th century. This research compares the sound of the modern piano with the Stuart piano sound to demonstrate the differences of the Stuart’s vertically enhanced harmonic characteristics and its increased capacity to project a comprehensive tonal spectrum over a longer distance.

How audiences decipher the differences found by this research, in the sounds of the Stuart and modern pianos is tested in a series of audience-survey concerts. Verbal attributes used to describe piano sound quality are compiled into glossaries and used in survey questions.

Australian aspects of the Stuart piano are described and associated with the oblique connection that exits between contemporary Australian music composition and Australian Aboriginal art forms. Compositions for the Stuart piano are devised from perceptions of the Stuart piano sound established by this research. The compositions reflect social aspects of Australian society and enable a musical activity and response to the urgent need for cross-cultural collaborations in the arts-education sector between Indigenous and non-Indigenous systems of education.
Acknowledgements

I feel very fortunate to have had the experience of working with many talented and experienced professional people throughout the course of this research project. It has been wonderful to be free to produce intuitive and creative research about the sound of the Stuart & Sons piano, in conjunction with the expertise provided by these professional people. The whole journey has added to my total sense of what it means to be a creative working musician.

Thank you to the Albert family for making this research possible by providing the Stuart Scholarship to the Sydney Conservatorium of Music. Thank you to Wayne Stuart OAM. The thrill and excitement of meeting regularly with Wayne on the premises of the Stuart & Sons factory was always a privileged experience. To work with Wayne in recording sessions, on the making of the Byal-la DVD, and in setting up the Menindee ‘Painted Piano’ project culminated in life changing experiences for me. Thanks also to Katie Stuart for her continued assistance.

My academic supervisors Professor Anna Reid and Dr Keith Howard have managed to allow the creative process to continue throughout the entire period of this research. I greatly appreciate their guidance, experience, advice, patience and encouragement. Thank you also to Dr Helen Mitchell for her preparatory and ethical assistance.

Thank you to the audio technicians involved in this project, Yao Wang, John Bassett, Phil Sawyers, and Jonathan Palmer. Each technician has engineered recordings and produced videos that illustrate the processes and outcomes of this research. I am also grateful for the assistance I have received from several piano technicians, Ron Overs, Vahe Sarmazian, Owen Geary, David Kinney, and Geoffrey Pollard. Special thanks also to the French piano and strings maker Stephen Paulello and technician historian Paul Corbin for their continued assistance, their contributions to the research and communications over the long distance. Thank you to Peter McMurray for his production of the Byall – la DVD and the high quality footage of the collaborative ‘Painted Piano’ project filmed on location in Menindee NSW.

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Special thanks to electronics engineer and reproducing piano expert Peter Phillips, for constructing the electronic striker and for conducting the string vibrations tests in chapter two.

Thank you also to Professor Bob Anderssen at the CSIRO, for contributing his expertise on the behaviour of transient soundwave envelopes.
My special thanks go to acoustic scientist Dr John Bassett for introducing me to the analytical techniques and theories of sound wave analysis. John spent many hours supervising my analytical processes and trialling experimental methods for the testing of piano sound quality. Dr Bassett devised the 180° microphone array for the tests conducted in chapter four and he engineered each recording session.

Thank you to my Aboriginal music colleagues in Sydney and Menindee for introducing me so generously to the stories and cultural business of our land. Especially, Richard Green, Matthew Doyle, Clarence Slockee, Marlene Cummins, Karen Smith, all the Kirk family, Peter McKenzie, Charlie Trindall, Graeme Merritt, Brenda Gifford, Clint Bracknell, Vic Simms, Jodie Edwards, Michael Birk and Kayleen Kirwin. Thank you to the students and staff at Eora TAFE Chippendale and the students and staff of Menindee Central School for their highly valued participation in the various musical and visual art projects for this research.

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Thank you to Warwick Ross and the Elizabethan Theatre Trust, firstly for introducing me to the Stuart & Sons piano sound. Secondly for the use of the excellently maintained Stuart & Sons pianos which resided at the beautiful Independent Theatre, North Sydney.
Thank you to my sister Marianne Goodyer for her tireless encouragement and assistance in compiling the audience survey results. Thank you to friends and family for your constant encouragement, support and understanding during these past years of the all-consuming research.

Finally and most importantly thank you to my dear wife Maria Lopes for assisting me constantly and lovingly, and for providing the home to work in. None of this work would have been possible without Maria’s assistance in so many ways.

This thesis is dedicated to the loving memory of my parents, Margaret and Ellis Hunt.
Presentation Guide

This written thesis of six chapters is accompanied by supplementary support material in the forms of audio .wav files, visual .mov files, and music scores presented in Scores Books 1 & 2, as PDFs. The USB drive contains:

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The Audio and Visual resources are referenced throughout the thesis in sound tables: For example: The sound table below, sound table 3.1 indicates where the actual sound file is located.

C5 523.25 Hz USB audio 3: trk. 1
C5 v54 STU MW mxd array.wav
C5v54 MW mixed array. Sound table 3.1

This particular sound, C5v54 STU MW, is a Stuart piano sound, (STU) of the note C5, at the mf volume, (v54) recorded by the mixed array of microphones, in the Music Workshop venue, (MW). Presented as a .wav file, the sound is located in the USB folder Audio 3, track 1.

Note Names:
The coding of the note names and their registers used in this research, spans a range of 8 octaves, for example for the note ‘C’ is denoted as C0 to C8. The octave numeral coding of each note is also notated in subscript font, for example C₀ to C₈. The numeral is not indicative of the harmonic relationship of the note to a key centre. In the illustration below, the numeral indicates the number of groups of 12 semitones above the given note C₀. Therefore C₄ indicates the note that is eight groups of 12 semitones (octaves) above C₀.

![Fig. 0.1 note names.](image)

Keyboard compass chromatic spans of 11 semitones.

When describing the ambitus or compass of the piano keyboard ranges which extend above the standardised 88 keys of the modern piano, the term "chromatic span" is used in this research. Chromatic spans denote the groups of 11 semitones above the given note, omitting a repeat of the given note. For example, the 102 key compass of the Stuart piano launched in 2010¹, has a compass range from C₉ to F₈. An 11 semitone chromatic span which repeats 8 times, occurs above the notes C, C♯, D, D♯, E and F. The compass is therefore described having 8 chromatic spans for these 6 notes.

Score Book I & II

The music manuscript scores of the compositions associated with this research described in chapter 6, are presented in two score books I & II. The scores are also presented with the recordings of the pieces on the USB drive in folder 11 of USB A/V Audio, Scores 6.2.

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¹ See page 35
² See ‘Vertical Colour and Sound’ section of this introduction, where Stuart says it was dervied from the incapacity of the
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Introduction

This research is essentially a record of my investigations and perceptions of the Stuart & Sons piano sound. Since the launch of Stuart piano No.1 in 1995, this new Australian piano design has keenly interested pianists, composers and listeners from all over the world because of its new sound. My evaluations of its tonal qualities and my compositional settings of its sound are collectively presented in this paper as a journey of practical investigation and research.

The overarching aim of this research is to demonstrate how my artistic musical objectives are informed by my research objective. More succinctly, how my engagement with the Stuart piano sound in composition and performance, is informed by my objective to describe distinctive qualities of its sound.

By recording the piano sounds and implementing processes of tonal analysis, I have detected four distinctive characteristics in the Stuart & Sons piano sound that combine to produce its unique tonal colour:

i) A slower rate of decay in the fundamental partial frequency

ii) An earlier transition into the after-sound states of string oscillation.

iii) A wider harmonic spectrum in the onset state of the sound.

iv) A more comprehensive projection of sound to 6 metres.

The detailed processes and theories used to measure and illustrate these characteristics are presented in chapters three and four of this paper.

As my perceptions of the Stuart piano’s sound developed, my awareness of its tonal intricacies made it possible to arrange and notation the piano sounds in fine detail. I found I was interacting with the elements of the sound itself, being led by the sound to produce musical statements. Defining the distinctions of the sound quality in an active creative way prompted me to interpret this piano sound as being an embodiment of many Australian characteristics. The fine attention I was giving to the elements of the sound produced for me an environment of sound to compose within. The vibrating Tasmanian King William pine of the Stuart soundboard, the Huon Pine wood of the Stuart panels, the pictorially abstract sounds enhanced by the expanded Stuart keyboard compass, and the aurally significant sustain in the Stuart sound throughout its frequency range, all established to me that this piano presented a clear Australian departure from the traditional standardised European and American piano sounds we are accustomed to today.

The Stuart piano sound itself engendered for me the promise that an exploration of its characteristics would produce composition that could connect me musically with Australian Aboriginality. So I invited several Aboriginal musicians who were connected culturally in the Sydney region to collaborate with me in creating compositions using the Stuart piano sound. The music we composed has enhanced
my awareness of ‘place’, the place of this piano’s creation, this place, my place. The experiences of studying and describing the qualities of this instrumental sound have in turn inspired me to use the sound in composition and improvisation that informs me about the place of its making. The sound has moved me to act in this particular artistic and cultural manner. My artistic creativity, the outcome of my investigations, is therefore discussed as being a consequence of the Stuart piano design and sound.

Throughout the six chapters of this thesis, I write about the science of sound, historic piano design, social opinion of the Stuart sound, my perceptions of the Stuart piano tone, and its sonic capacities to enable my collaborations in Australian Aboriginal music practices. How the Stuart & Sons piano has been utilised in the contemporary music scene by various artists in Australia since 1995 is also examined.

I describe the Stuart piano as a piano of this time and place. The design implementation of the bridge agraffe in combination with the most recent developments in hybrid steel drawing of piano wire and the elimination of the traditional piano string down-bearing, are indicative of very recent, even controversial developments in piano design. There is a general sense that this is a modern Australian piano that presents a new soundscape of projection and tone. My application of the Stuart piano sound with Aboriginal music practice is also indicative of a contemporary approach. Each of the inter-cultural collaborative compositions produced by this research are indicative of the cultural developments in the Australian Arts where Indigenous and non-Indigenous artists producers, writers, composers and funding corporations work together to produce symphonies, popular songs, rock bands, schools of modern art, arts festivals, novels, plays and film.

In a sense this research asks, does instrumental design influence musical composition, or is it the reverse? Both questions are answered here in the affirmative. The sound of the Stuart piano sound has influenced, even instigated the compositions, and later in this introduction, Wayne Stuart the maker of the Stuart piano, describes his motivation to create the new piano design as being directly related to specific musical styles of the 19th Century. So we have music being created because of an instrumental sound and the impetus for the design being born out of the maker’s reaction to specific musical style.

The very concept of the first piano in the early 1700s, a keyboard instrument with a more responsive keyboard action and than the harpsichord, is reportedly associated with the characteristics of the musical style of that period which emphasised the performer’s individual musical expression. To support the notion that piano design and musical style are creatively and historically linked, I have listed and illustrated piano designs in the ‘Early Piano Design Associated With New Musical Style’

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2 See ‘Vertical Colour and Sound’ section of this introduction, where Stuart says it was derived from the incapacity of the standardised modern piano, in his view, to produce the clarity of complex sound quality instigated by the Impressionists composers of the early 19th Century and Electronic music composition later that same century.
section of this introduction, emphasising the expanding range of the piano keyboard compass and its deployment by the influential composers, pianists and musical styles of the day.

To establish a compendium for my understanding of piano sound and design, in the first three chapters of this paper I describe the dimensions of the piano, its nature of sound production, the physics of piano string oscillation and the harmonic nature of sound. These fundamental aspects are examined in order to understand how aspects of the Stuart piano design influence the tonal colour of the Stuart piano sound.

In chapter four I have identified and compared the mysteries and miracles of piano tone by evaluating and comparing sounds of the Stuart & Sons piano with the sounds of the modern piano. In this process I observed the science of its sound under the tutelage of acoustic scientist Dr John Bassett while consulting a wide range of published research and methodology. During this time I aurally started recognising particular characteristics of the new soundscape and began to document my perceptions of its sound into musical notation thus creating a palette of ‘Stuart’ colours. These, my perceptions of the Stuart piano sound, are documented as music manuscripts and audio extracts in chapter six as a creative conclusion to this research.

The Stuart & Sons piano is presented as a different instrument to the ‘modern piano’ in this research for the comparative study of the two soundscapes. The physical design differences of the both pianos are presented in detail in chapter one. The ‘modern piano’ is a widely used descriptive title that encompasses most pianos made since the 1880s. The piano is a highly complex instrumental design. Since 1700, for approximately 180 years, the development of piano design advanced with the technological development of its materials, particularly in steel. It is also generally accepted that before the late 19th century, piano design was more closely associated with new developments in musical style, than it is today. Subsequently, today’s modern piano design has not been subject to such a progressive development since approximately 1880, when the design was standardised, with the adoption by the majority of piano manufacturers, of a specific dimensional assembly. The modern piano is often epitomised by the Steinway piano of 1867 which emerged after Henry Steinway’s patent in 1859 of the cross strung grand piano, which by the 1880s was considered to be the blue print of the standardised piano design.

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8 Good, 212. See also Arthur Loesser, Men, Women and Piano A Social history: (New York: Dover, 1954),564.
Pianos made before the Steinway revolution are of interest today primarily to music historians, antiquarians and collectors of furniture. Those made since have adopted the Steinway’s main features or earned a rapid obsolescence. The Stuart piano and the modern piano share many similar characteristics of design. The fundamental difference is how the piano strings are attached (coupled) to the bridge and soundboard. This research has established evidence that finds the manner in which the strings are coupled to the bridge influences the string vibration and subsequently the quality of the sound, the tonal colour. This evidence of the Stuart piano’s unique string vibration is illustrated and discussed in chapter two. Comprehensive evidence of the unique Stuart piano soundscape is analytically illustrated throughout chapter four. The contrasting transient tonal qualities of the Stuart & Sons and the modern piano are clearly demonstrated both visually and aurally.

In the chapter five, the research discussion is opened up for interaction with public audiences. Audience responses to survey questions about the differences in the Stuart and Steinway piano sounds are collected from a series of six audience survey concerts which presented performances on both the Stuart and Steinway pianos. Audience members were encouraged to answer survey questions about the sounds they are experiencing. The pianos used in the concerts are the same pianos tested in chapter four. The derivation of the verbal attribute terminology used in the survey questions was compiled into glossaries and presented throughout chapter five.

My perceptions of the Stuart piano sound are detailed throughout chapter six. Here I suggest how my musical background has influenced how I interpret the qualities of the sound. A glossary of sounds created on the Stuart piano is presented to illustrate how the characteristics I have identified as being distinctive of the Stuart sound are integral in creative sounds. Following this, the Indigenous influences on my concepts of composition are discussed and the collaborative compositions are presented in audio and manuscript extracts.

When I first heard the Stuart & Sons piano I aurally envisaged new Australian piano composition. Following the long gestation time of this research, I felt buoyed with the knowledge and experience of the new Australian piano sound to compose with it collaboratively. The knowledge and experience provided the impetus I needed, emboldening me to enquire how I could collaborate musically with the first peoples’ of this nation in their music practices. I subsequently used Stuart piano sounds as ‘my sound’ to collaborate musically with a collective of Australian Aboriginal musicians. The collaborations introduced me to the contemporary vibrancy and artistic depth of Aboriginal culture here in this busy cosmopolitan city of Sydney. As an outcome of these collaborations and with the assistance of Gadigal descendent and researcher, Julia Torpey Hurst, and Darug composer and educator Dr Chris Sainsbury, I instigated an educational model for Indigenous and non-Indigenous music students. Entitled OUR MUSIC, performing place, listening to Sydney, we devised the model to encourage and facilitate the creation of intercultural music collaborations. In 2012 and 2014, I

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produced two OUR MUSIC events at which Indigenous and non-Indigenous music students performed with the Stuart & Sons piano. Manuscripts and links to the recordings of these events are also presented in chapter six.

The Modern Piano

The modern piano design is defined by the culmination of technological design advancements since its inception in 1700 by Bartolomeo Cristofori. The principles of Cristofori’s responsive piano key action are still applied in the modern piano today. Essentially the modern piano has an 88 key compass, is cross-strung with high tensioned steel strings, and importantly to this research the strings are coupled to the bridge and soundboard by pinning the strings in a horizontal plane, with an applied down-bearing force through the bridge to the crowned soundboard. The modern piano design has been universally deployed in most piano design throughout the late 19th, 20th and 21st centuries. Since approximately the 1880s, this standardized piano design is generally referred to as the modern piano in piano literature.

In the sixty or so years before the modern piano design was standardised, the fundamental changes from ‘wood based’ to ‘iron based’ pianos were led by the technological advancements in steel wire manufacture. Piano strings made of finely drawn high tensile steel wire, stretched to high tensions in heavy iron frames were found to produce a superior piano tone. William Brockendon’s invention for drawing wire through holes in diamonds and rubies, in 1819, eventually established an efficient process for the production of hard drawn steel wire. Many of the innovative piano design developments in the 1800s were made possible by the advancements in steel wire manufacturing. Some examples of these are Alpheus Babcock’s one piece iron frame patented in 1825, Henri Pape’s expansion of the keyboard compass to 97 notes in 1842, and the successes of American piano manufacturers, Chickering and Steinway at the International world trade exhibitions of the 1850s with their iron framed grand pianos. It is widely recognised that the eventual standardisation of the modern piano sound was influenced by the desirable tonal improvements of the higher tensioned steel wire. The piano wire manufacturer Moritz Poehlmann of Nuremberg is accredited for improving steel tensile strength and wire hardness in the 1850s.

...all the leading piano manufacturers of Europe and America adopted the Poehlmann make for their pianos.

Between 1867 and 1893, music wire tensile strength increased by 44%.

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10 I was privileged to play a remake of Cristofori’s piano in Rome in January 2015 at the Museo Nazionale degli Strumenti Musicali di Roma.
11 Good, 37-38.
12 the 19th-century painter & inventor
13 Samuel Wolfenden, A Treatise on the Art of Pianoforte Construction; (Old Unwin Brothers Limited, 1975), 6. Also: Good, 104.
15 Wolfenden, Art of Pianoforte Construction, 7
The modern piano sound is produced for this research by a Steinway Concert D piano made in Hamburg Germany in 2005, No 574500 and is identified throughout the paper with the acronym (STE). The Stuart sound is produced by the 2.9m Stuart concert piano No19, made in Newcastle, Australia in 2002, and is given the acronym (M19,STU) throughout this paper. At the time of this writing (2015), there had been 58 Stuart pianos built since 1995. The ‘M’ in the Stuart acronym is the grade of Paulello strings used for the notes examined on this particular instrument.

Wayne Stuart’s Ethos.

Throughout this research period I met regularly with Wayne Stuart at his Stuart & Sons factory in Newcastle, north of Sydney, to discuss his general design ethos. The conversations were almost always about the Stuart & Sons design and sound, in comparison to the traditional standardised modern pianos’ design and sound. Being initially inexperienced with the Stuart piano concepts of design the comparative discussions were probably for my benefit. It therefore seemed logical that my study should take a similar path to the discussions and present a detailed comparison of both piano designs. At these meetings I would often play one of the Stuart pianos and occasionally under Wayne Stuart’s supervision, I would record a composition written specifically for his piano design. Of special interest to the maker, was in how his extended frequency range of the 102 key pianos was utilised in the compositions.

The discussions with Wayne Stuart showed me how valuable his words are to this study, so with ethical clearance from Sydney University and granted permission from Stuart, his words are featured throughout this paper. I stored and compiled Stuart’s words by recording the conversations and reiterating finer points with him in follow up emails.16 I also obtained the ethical clearance to interview four piano technicians, and one other local piano maker, Ron Overs. These other interviews were valuable to the study as they represented a secondary enquiry into the same design topics I had already discussed with Wayne Stuart. Interviewing others about the same issues helped me realise the main points of difference in the contrasting piano design philosophies. The main topics of discussion were, string coupling to the soundboard, downbearing, thickness and mass of the soundboard, projection of sound, string scaling tensions, string length, types of piano wire, the Stuart 4th pedal, and the extended frequency ranges of the Stuart keyboard compass.

The Stuart piano’s string coupling application to the bridge and soundboard presents its most significant change to the modern piano design. The Stuart design employs a bridge agraffe for the coupling of the piano strings at the bridge, maintaining the strings’ straight line which is fundamentally different to the standardized ‘pinned’ string attachment of the modern piano. The Stuart piano uses the 21st century technological advancements in steel wire manufacture of Stephen Paulello, enabling the

16 See Appendix 7 to view the ethical clearance approval letters from Sydney University to interview Piano Technicians about the Stuart Piano design and sound.
expansion of the keyboard compass to 102 keys. It is claimed that Paulello strings produce a wider spectrum and enhance a more stable harmonic balance within the sound of each note.\(^{17}\)

Wayne Stuart, the maker of Stuart & Sons pianos, claims the bridge agraffe produces a more vertically controlled string vibration than the modern piano. He states that the bridge agraffe eliminates the need for the traditional down-bearing force of the string onto the bridge and soundboard, and influences the string to vibrate with improved clarity and sustain. He also claims that the Stuart string vibration generates a different vibration in the lighter, thinner soundboard, radiating a new omni directional\(^ {18} \) soundscape from the piano.\(^ {19}\)

Vertical string coupling is at the core of the Stuart & Sons design concept. A special device (agraffe) is used to couple the strings to the bridge and soundboard structure. The agraffe defines the string's speaking length (frequency) and contains the reaction forces produced by bending the strings as they pass through it. This negates the need for string down bearing that is required in the traditional pinned bridge system. The soundboard can thus be designed on a speaker cone principle and not as a load bearing structure as is the case in the standard piano. This scientifically designed device encourages the strings to vibrate in a more controlled manner improving the dynamic range, increasing sustain and significantly improving tonal clarity sympathetic to the entire piano repertoire.\(^ {20}\)

The first Stuart & Sons concert grand pianos were made in 1995. Since then, the Stuart piano has been a frequent subject of inquiry and fascination in the Australian and international arts community and media. Wayne Stuart was a piano technician of international experience before he started designing pianos. In 1975, he won a scholarship to study with Yamaha in Japan, the largest maker of pianos in the world. He then went on to observe the more traditional techniques of five European piano makers.

“I realised that nothing was happening anywhere, it was just reproductions, all the piano makers were dead and I felt very strongly that if the piano wasn’t rethought, it would die too,” he says.\(^ {21}\)

Stuart’s comment ‘all the piano makers were dead’ suggests to me his frustration at the complacent view that ‘all pianos were alike because the instrument has reached its final form and is a perfectly finished product’.\(^ {22}\) Stuart’s comment also reveals his determination to reinstate the by-gone era phenomenon of the hand crafted piano. In his book Men Women and Pianos, Arthur Loesser describes the beginning-of-the-end of the handcrafted piano-making era in the mid 1800s, as a time when the legendary piano makers Henri Steinway and Jonas Chickering, whilst still continuing their craft of piano building, were operating as executive heads of their large companies. An episode involving the the young English pianist Richard Hoffman is recounted in the book, where having just arrived from

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21 Wayne Stuart “Innovations,”
England, the young pianist was greeted at the front door of the Chickering factory by Jonas Chickering in his work apron and tools in his hand. The reluctance of these craftsmen to adapt to the standardisation of piano parts manufacturing by specialized factories is described here by Loesser-

As executives these men brought with them the craftmen’s devotion to workmanship, his happiness in knowing that he has used his own hands to do a fine job to which he is proud to affix his own name for all to read

It was necessary to put a brake on the exuberant inventiveness of the XIXth century craftsmen and move on to rational, industrial production. Piano makers conformed progressively to the technologies of the most enterprising and well-established manufacturers of the era. Inevitably, the sonority of pianos lost its diversity to a common esthetic. Since then, the trend of standardization has been validated by the explosion of production in Asia, where the base model is conscientiously reproduced.

Wayne Stuart and the French string manufacturer Stephen Paulello have continued developing their craft in the pre-standardised spirit of ‘exuberant inventiveness’. Paulello and Stuart do not plan to produce the ultimate finished product of piano design. They are both ‘taking up the experimental challenge of piano making, from the point where it came to a halt’.

The industrialization of piano manufacturing during the 20th century abdicated the critical aesthetic choices to mechanical engineers and non piano building related disciplines. This has produced so called piano makers unable to realise a workable, individual design. Thus, copying of derivative designs and adherence to past ideologies in an attempt to hold onto the so called core essence of what many believe the acoustic piano to be, underpins a crisis in potency and direction.

After Stuart’s experience of the international piano manufacturing industry, he returned to Australia to direct the piano technology department at the New South Wales State Conservatorium of Music, and the North Melbourne Institute of Technical and Further Education, also known as Preston TAFE. Stuart initiated his experiments in expanding the dynamic and frequency range of the piano during his tenure at the Melbourne institution.

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24 Paulello, “concept page.”
25 Paulello, “concept page.”
27 now the Sydney Conservatorium of Music
Vertical Sound and Colour

Stuart claims his piano design is a response to the harmonically layered settings of new music practices heralded in the 19th Century by the impressionist composers. The Impressionists’ changed the traditionally linear composition style by placing more emphasis on the colour of sound, a characteristic Stuart says, that relates to the actual behaviour of sound itself, the physics of sound. This compositional interpretation of musical sound continued to be developed in the styles of minimalism and atonal music composers in the 1940-1960s. The vertical emphasis enabled a departure from the traditions of linear melodic-harmonic progression of the music. The following passage found in an analysis of the minimalist composition *Etymalong* by Australian composer Ross Edwards, describes the emphasis of experiencing the inner characteristics and nature of a sound, an inner look at sound itself, separate to its overall compositional context-

…….. the overall structure is less important than a contemplative appreciation of the individual events… with attention focused on each detail as it occurs instead of projecting the mind back and forth in search of structural associations.

A vertical interpretation of sound thus supported the view that composition was made up of explorations of qualities of sound, as we hear in the music of Claude Debussy.

…….discarding conventional methods of modulation, allowing relationships of a sudden, exquisite intimacy between only distantly related keys

…….the composer[ Debussy] was exquisitely sensitive to tone color; a piece like *La Mer* employs a broad, subtle timbral palette that is, in many ways, much more spatial/environmental than structural.

Stuart states that it is this continued development of vertical concepts in atonal composition through the 1940s and in the electronic music that emerged in the 1960s that has influenced his work in expanding the capacity of acoustic piano sound to sustain and decay in a more stable, steady manner. In electronic music the attributes of the sound envelope, the attack, sustain and decay transients are electronically manipulated to produce the tone colour of the sound. Stuart says this fundamental aspect of today’s music production has influenced his ethos in producing a vertically enhanced acoustic piano sound to expand the capacity of the piano soundscape to sustain.

The development of minimalist concepts and atonal music during the 20th century was making a lot of the old wooden instruments incapable I thought, of actually communicating it effectively. The Standard piano just was not communicating it effectively because the music needed great clarity throughout the frequency range, extraordinary sustain, and an ability

to have a very quick attack, and be able to speak in extreme frequency ranges at the same time and not have masking or muddying of the soundscape.35

The nature of coupling in the standard piano of the two pin system produces muddiness because of complex counter phasing issues at the point of annunciation of the sound.36

Vertical Concepts.

Vertical definition of sound is the Physics of sound, how sound behaves. Traditional western music has relied on lineal notation and a lineal concept of sound to convey its aesthetics and ethos…but the Impressionists decided that wasn’t working and what they wanted to explore was the colour of sound, how sound behaves. Most music, unless its regressive, has been composed through the 20th Century and to our current time has sort to explore the vertical soundscape, in other words the colour and the way sound behaves. This has become a very important aspect for post 1945 music, particularly with electronic musical instruments, because we now have an energy source that is capable of sustaining and exploring that vertical soundscape, whereas in the tradition acoustic instruments, particularly in the percussive ones, you have a diminishing energy resource once the string is struck, you’re losing energy.37

Both Wayne Stuart and Stephen Paulello suggest36 that early in the 20th Century, piano makers were prevented from responding to changes in music composition aesthetics as they had traditionally done, because of the newly industrialised mechanization of piano manufacturing that was associated with the standardisation of piano design and sound. The Stuart piano agraffe is claimed (above) to be a design response to contemporary trends in 20th Century music composition.

The detailed comparative data of piano sound quality presented in chapter 4, demonstrates four tonal characteristics that were found to be unique to the Stuart piano sound. These findings support Wayne Stuart’s claims to have achieved a piano sound with an expanded dynamic range and an enhanced clarity and sustain.37 The Stuart piano design is therefore presented in this research as a piano design that has adapted to changes in how music is produced and generally listened to in the 21st century.

Wayne Stuart and Stephen Paulello suggest 38 the reason the piano ‘lost its footing’ as the central instrument of contemporary art music in the late 19th century was because it had discontinued its association with contemporary composition and was more focussed on the efficiency of production, accepting its musical evolution was complete.39

It is well documented that the first piano, Cristofori’s invention of the piano in the early 1700s, was a response to the contemporary musical forms of its time. The harpsichord had limitations for timbre

34 2 Stuart speaking on, Know Your Music.
35 5 Stuart speaking on, Know Your Music.
36 2 Paulello “Concepts page” & 3 Stuart, A Bright Light in a Stagnant Pond.
37 Wayne Stuart’s claims: see p.17 & p.53
39 Piano historians Good, Ehrlich, Loesser, Schonberg and Gardner, all discuss this change of emphasis in piano design, due to mechanization and standardization.
change and crescendo and diminuendo whilst in the flow of a musical phrase. There was great interest at this time in the dynamic and interpretive expression of Italian Opera music, the violin, and the music of the Pantalon, a dulcimer style instrument which influenced a new style of expressive, interpretive keyboard music performance. Cristofori’s response presented the world with a keyboard instrument that expanded the harpsichord player’s capability to play dynamically and with greater expression. Later in the 18th century the interaction between the piano designers and the pianist-composers CPE Bach, Mozart, Clementi and Beethoven brought many changes to the design of the piano.

Throughout musical history the catalyst for instrumental design change has varied. Sometimes the instrument designers responded to new musical style, alternatively composers adapted their musical style to suit new instruments. Wayne Stuart says his design is a response to the changes in the musical composition styles that occurred early in the 20th century, where the traditional linear ethos of compositional form changed to a vertical emphasis of the colour of sound. This research demonstrates how the sound of the Stuart piano has influenced my performance and compositional practices. In chapter six I demonstrate how the characteristics of the Stuart piano soundscape influences my composition and pianistic styles, in providing me with unique piano sounds for collaborations with Australian Aboriginal musicians.

\[^{40}\text{Good, 32-33.}\]
\[^{41}\text{Loesser, 24.}\]
Stuart Piano Recording 1996-2015

Since 1996 to the date of this writing in 2015, there have been over fifty recordings commercially released featuring the Stuart & Sons piano. In many of these recordings the Stuart piano sound portrays the sounds of Australian contemporary composition and improvisation, music that is fundamentally influenced by vertical musical concepts of the 20th century outlined above. The comment below by Australia’s leading contemporary music pianist Zubin Kanga importantly supports Wayne Stuart’s ethos to enhance the clarity of piano sound so complex harmonic layering is clearly realised throughout the frequency range.

The ability to layer different sounds, both in different registers and different colours in the same register is one of the most distinctive features of the Stuart [piano]. I find this feature is particularly useful in contemporary music, where definition of layers and maintenance of different layers of colour are vital to the works.

- Zubin Kanga, Australian Pianist

In the first five years of recording between 1996 and 2001, eight of the thirteen Stuart & Sons piano CD releases were produced by Belinda Webster and her Tall Poppies recording label.

The Stuart piano is one of the best things that has happened to Australian music for many years! It sounds great, looks great, and it is such a proud moment for Australia that an instrument which may change the face of piano sound, world wide, has originated from this country. As a recording instrument, the piano is to die for. It has such a magnificent range of colours and dynamics. A stunning sound! It is an instrument perfectly suited to the pianist who is open-minded, willing to believe that the impossible is possible, and who has the flexibility to learn from an instrument in order to extend his/her technique.

- Belinda Webster OAM. Tall Poppies Recordings.

The new sound of the Stuart piano was initially made accessible to the public through the Tall Poppies recordings. The new recordings were highly interesting for pianists as the piano itself was not easy to access. At the time the first CD was launched only two Stuart pianos had been made. Production of handcrafted pianos is never fast and Stuart pianos have had some difficulty in being a ‘piano of choice’

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42 see Appendix 1, for the list of Stuart & Sons recordings, composers and pianists.
46 Ward, 227.
for major concert venues in Sydney, but for two exceptions. The Albert family’s first commissioned Stuart piano, christened ‘The Albert’, was the resident piano in the Clancy auditorium in Kensington, Sydney for many years. And the Independent Theatre in North Sydney housed three Stuart pianos from the late 1990s until very recently.

From 1996 to 2007, a large proportion of the music recorded on the Stuart piano was composed by the most highly regarded Australian contemporary composers. The *Mere Bagatelles* (1996) CD a solo piano recording, presented bagatelles from a large cast of contemporary Australian composers including the pianist/composer Ian Munro. In this recording, many of Munro’s performances exhibited the new qualities of the Stuart sound. For example, the enhanced qualities of sustain in the middle and treble registers was clearly exhibited in first section of Carl Vine’s *Five Bagatelles III*.

The recording *A Garden Of Earthly Delights* (1997) featured the piano concerto by Australia’s eminent composer Peter Sculthorpe, played on the Stuart piano also by Ian Munro.

**Australian Compositional Subjects : Indigenous and Environmental.**

Two compositions *Earth-Flowering –Time* (1987) by Colin Bright and *Etymalong* (1984) by Ross Edwards are played on the Stuart piano in the recordings *Mere Bagatelles* (1996) and *Alternating Currents* (2010). Both compositions exemplify the oblique connection between Australian contemporary music and Australian Aboriginal culture. These compositions reflect the growing swell of interest in Aboriginal culture experienced in the 1980s across non-Indigenous sectors of Australian society, especially in the Arts. The compositions by Peter Sculthorpe with Australian Indigenous imagery, *Djilile, Kakadu, Earth Cry, Jabiru Dreaming* and the *Irkanda series* were composed in the 1980s. It was the decade which led up to the landmark decision of the high court of Australia in 1992 to recognise native title.

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47 Ward, 7–9.
48 Ward, 227.
Native title is a property right which reflects a relationship to land which is the very foundation of Indigenous religion, culture and well-being. The non-discriminatory protection of native title is a recognised human right.51

Both *Earth-Flowering –Time* and *Etymalon* depict colours and sounds of natural Australian environments. The abstract characteristics of the music enable the listener to focus on the aspects of sound suggesting elements of land and place. The tonal spectra of the Stuart piano soundscape is on show in both these pieces. The bright attack tone and clarity of tone, the tonal balance within dissonant harmonic layers, and the steady sustain in the higher registers are qualities heard in both the recordings.

*Earth-Flowering –Time* (1987) track 31 on the *Mere Bagatelles* CD is composer Colin Bright’s adaptation of his musical ideas to the Australian Aboriginal word *Tya*, which means ‘earth’ and/or ‘flowering time’.52 Bright’s composed sounds depict the intricate patterns created by small Australian wildflowers as they grow out of an aged earth.

The picture these words paint seemed to suit the ideas in this piece.
It is one of what I think of as ‘1-2-3’ pieces, that is, the minimal musical materials (harmonic, melodic, rhythmic and tessital) are derived from relationships between these numbers. The essence, consequently, is STASIS. The piece belongs to the ‘psyche of place’ bag. That is, where we live and how it affects the way that we think. Even if you live on the more densely populated east coast of Australia, you are nevertheless still aware of the vast distances involved in travelling towards the centre (center), the north and west.53

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52 *Mere Bagatelles*
Bright’s music has an improvised feel about it. As a jazz pianist I interpret the repetitive rhythmic motif in the left hand as a ‘riff’, over which a jazz pianist would create improvised variations with the right hand. Bright describes the technique of his piece as STASIS, by which I understand he is referring to the stationary or static repetition of the low motif, and its conversation with the right hand motifs, which depict the colourful patterns and growth of the small desert wildflowers, coming up out of an aged and dark earth. The dark elements of the Phrygian mode are repeatedly apparent in the low motif, and the bright harmonic element of the mode are portrayed in the right hand gestures. This mode was used by European musicians in the late 18th century in their transcriptions of two Aboriginal chants of the Sydney region, see Barrabul-la in chapter six. I use the Sydney chants as a primary source for my collaborative music projects with Aboriginal musicians and the soundscape of the Stuart piano.

_Etymalong_ (1984) by Ross Edwards is track 4 on the _Alternating Currents_ CD recording by Bernadette Harvey. Eminent Australian composer Ross Edwards described his piece in an address to the Conference On Belonging⁵⁵, recounting the musical transformation he experienced at Etymalong. This was a time for collecting his new musical language. He thanks the sounds of the nature-scape of the place,

> …these ancient voices, whose near-symmetries and inconsistently varied repetitions often seem close to our inherited musical syntax. I don’t doubt that, over the millennia, such voices have generated much of the world’s music and it’s not hard to detect their presence in various surviving folk and religious traditions.⁵⁶

_Etymalong_ is an Aboriginal word meaning watering place and is at the same time the name given to the mountain overlooking the village of Pearl Beach, NSW. In this once sacred place I lived with my family … and composed, amongst other music, a series of static, evanescent works much influenced by the sounds of the natural environment.⁵⁷

The enhanced stability of sustain in the Stuart sound is apparent in the sonorous after – sound⁵⁸ of the dissonant bird call gestures in _Etymalong_. The first three composed gestures of _Etymalong_ are notated in the table 0.1 below. Gesture 1 is repeated intermittently. The attack of the sound is abrupt and dissonant, followed by sonorous after-sound sustain. Eventually the motive moves to include gesture 3, which stretches over the wide spectra of the Stuart soundscape. Each gesture is interpreted and listened to vertically, statically and minimally, each as a complete entity, gesture, or colour.

⁵⁶ Ross Edwards.
⁵⁷ ² Hannan, _Etymalong for Piano_,
⁵⁸ A technical term used to describe the sound of the piano note that lingers, or sustains, after the initial attack of the note. see ⁷Weinreich. _The Coupled Motion Of Piano Strings_.

In *Etymalong* and *Earth-Flowering-Time* each composer has musically depicted visual and sonic details that portray closeness with the natural Australian environment. The Stuart piano soundscape portrays these images very clearly. In the titles, the composers’ words and in the abstract openness of the music, there is also an oblique acknowledgement of Australian Aboriginal cultures. From the perspective of this research, these recordings set the beginning of an artistic association between the sound of the Stuart piano and the initiatives of non-Indigenous Australian artists to interact with Australian Indigenous artists and art forms. In chapter six I describe my use of the Stuart piano sound as my sound to collaborate musically with Aboriginal musicians in their music practises.

The First Stuart & Sons Pianos.

In 1995, the first Stuart & Sons concert grand pianos, Nos 1 & 2, were built by Wayne Stuart, in a productive research partnership with Robert Constable and the Newcastle University, New South Wales. In 2001, a partnership between Albert Investments Pty Ltd and Stuart and Sons Terra Australis Pty Ltd, was created. This unique arrangement has enabled the construction of over fifty, 2.9m concert grand pianos, the most pianos ever handcrafted by an individual Australian maker. The Alberts group is a vibrant publishing, recording and philanthropic organisation, with a long history of support for artistic initiatives in the Australian music industry.

In the latter half of the 1990s, the local media frequently described the Stuart & Sons piano as ‘Australia’s new piano’. The back sleeve of the first CD release of the Stuart piano sound *Mere Bagatelles*, featuring the pianist-composer Ian Munro, revealed to the public the first detailed written description about its design:

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59 Hannan.
61 *Stuart & Sons Handcrafted Pianos*, accessed 18th Feb 2013.
The cabinet is veneered in rare birds eye Huon pine and the legs covered in gold plated brass. The veneer was cut from an ancient Huon pine log salvaged from a creek bed in South West Tasmania. The Surface emulated the oxidised golden appearance this timber adopts when exposed to the air. These materials were chosen for the first Stuart & Sons piano to portray an image of light and time. Stuart & Sons pianos are designed and individually hand crafted in Australia. They incorporate innovative design principles that enhance dynamic range and sustaining qualities. A unique string coupling system produces exceptional clarity of tone, opening new horizons in piano making and performance technique. Stuart believes that the current limited choice of differing aesthetic qualities in modern musical instruments disadvantages musicians and ultimately leads to a decline in performance standards. The great tradition of western musical instrument making requires constant change to remain vital and relevant. 

The visually appealing appearance of the Stuart piano and the localised fascination of an Australian piano, made of Australian woods with extra notes and a new sound, created the subject of many arts media stories soon following the launch of the Stuart piano. This public interest in an Australian piano is well founded on the historic successes of Octavius Beale’s piano manufacturing operations, sourcing his timber from the forests of Dorrigo in NSW, early in the twentieth century. The Beale and Wertheim names hold a special place in Australian social history, having manufactured many thousands of Australian made pianos for households and schools in the years of the piano popularity boom, early in the twentieth century.

Unlike the Beale and Wertheim instruments made early last century, and indeed most pianos manufactured today, the Stuart & Sons piano is not manufactured by mechanised machines to an economy of scale. Its use of the finest contemporary materials and technologies, and its handcrafting at high expense means that an average of three pianos are made a year. Without a large market demand, the Stuart piano is produced without the requirement to standardize its manufacturing process, enabling

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the experimental and developmental piano building process to continue. The ongoing developments in steel tensile by Stephen Paulello for instance, can be instantly adopted in the next instrument Wayne Stuart.

This research examines how the new developments in the Stuart piano design interact and perhaps catalyse, the production of new and improvised music. Although *Mere Bagatelles* featured relatively new music by contemporary classical Australian composers, the works were not specifically composed for the Stuart piano. It is interesting that since this recording, the Stuart piano is commonly regarded as an instrument that is suited to contemporary classical music and less suited to the classical and romantic piano repertoire. Associations can be formed quickly when a new instrument arrives on the music scene.

Public Acclaim: Beethoven, Willems and the Stuart & Sons Piano.

In 2000 a series of recordings of the complete Beethoven piano sonatas and concertos, played exclusively on the Stuart & Sons piano, was initiated by producer Brendan Ward and pianist Gerard Willems, achieving a high level of promotion and social recognition.

Two years before the release of these recordings, a sense of anticipation was portrayed successfully in reporting the progress of this recording project, featuring the new Australian piano.

Already the recordings have been acclaimed not least for the fact that they’re played on a revolutionary new Australian-made piano, known as “the Stuart”….. “The secret of his piano lies in a unique string coupling system that ensures greater tonal clarity. It also has 97 keys instead of the traditional 88. The timbers used in the Stuart include rare Tasmanian Huon pine, King William pine and Queensland Hoop instead of traditional maple, spruce or mahogany. This unique CD project has been described as climbing music’s Mt Everest – on your own”.64

The series of Beethoven recordings featuring the Willems and the Stuart piano was expanded several times. In 2013 a box set of 15 discs entitled *the Beethoven-Willems Collection*, was commercially released containing Beethoven’s complete sonatas, concertos and variations for keyboard.

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Brendan Ward’s book ‘The Beethoven Obsession’ also launched in 2013, is a narrative that dramatically depicts the enterprising undertakings and achievements of Willems, Ward and Wayne Stuart, in producing this exhaustive body of recorded work. Interestingly, Ward clearly documents Wayne Stuart’s dual episodic engagements with both the commercial world of the necessary financial support, and the artistic piano design world, describing the reality and tensions of making decisions that have influenced the evolution of Stuart & Sons piano from the 1990s in Melbourne, through to 2012 in Newcastle.

Ward’s narrative positions Beethoven’s music as the central object, and Willems and the Stuart & Sons piano as the actors, interacting and producing an outcome of new perspectives on Beethoven’s monumental music, challenging established views on one of the corner stones of classical music repertoire for the past 200 years. Ward’s prose attaches plenty of colloquial ‘under dog’ national cultural characteristics of an Australian made contemporary instrument ‘taking on’ the traditional European-American clandestine Steinway concert piano traditions, at the Sydney Opera House, at the time when Sydney was host of the Olympic Games. It is the interactions of a nationally unrecognised musical identity of low socio-economic European refugee background, with an unknown Australian piano claiming to be the contemporary alternative to the 120 year convention of European and American modern piano design, manifesting a new interpretation of the musical language of Beethoven that creates the story. At the outset, these disparate ‘actors’ seemed unlikely characters to achieve a successful new interpretation, yet their unison and separate interactions with the music culminate in unique, award winning recordings that enhanced the pianist’s career and initiated a positive public perception of Australia’s new piano. Ward’s literal ‘snapshot’ reveals the interactive collective energies that generated a positive community awareness of the new piano, and with it a unique perspective and sound of Beethoven’s music.

This multi-layered model of activity relates closely to the structure of this research program, which examines the interaction of the Stuart & Sons piano with the ‘actors’ of my piano music style, the recomposition of historic Aboriginal music and the traditional modern piano.
Since the Willems recording projects began, interest both publicly and artistically in the Stuart & Sons piano has gradually increased, as more pianos are produced at an average of three each year. It is a traditional characteristic of new design, especially one that involves changing an established form such as the modern piano, that it takes a long gradual period of time for the changes to be accepted. It took over thirty years for the traditional piano makers Erard and Broadwood, to completely accept the use of iron frames in their pianos.65

There are significant challenges in changing traditional musical instruments because the ear is the organ of fear…and any difference in a previously learned preconditioning of that organ will be met with suspicion, and the only way to overcome differences is through education, familiarization, and a gradual re-programming of how the mind relates to and interprets the new sound experience. It could be said that new acoustic experiences are initially, simply not recognised beyond the obvious difference.66

Discovering Instrumental Tonal Colour Through Improvisation.

The first exploration, experimentation and composition of music primarily influenced by the Stuart piano soundscape was produced by the improvisations of jazz pianists.

Jazz pianists are involved in a music practice of adaptability. The improvising pianist can adapt to and explore a new instrumental soundscape as soon as they begin to play, because they are free to make sounds with the sound, in the moments it is heard. Jazz keyboard style is also intrinsically linked to contemporary technological developments of new instrumental soundscapes. This was especially evident in the 1960s, with the emergence of electronically enhanced keyboard instruments. Jazz keyboard players created playing techniques and styles of jazz for the new tonal soundscapes of the Hammond B3 Organ of the 1950s, the Moog synthesizer of 1964, the Hohner Clavinet 1968, the Fender Rhodes of 1969, and the Arp synthesizer of 1969. Jazz keyboardist today are creating new styles of improvisation with the use of 21st Century sampling and virtual instrument computer technology.

The exploratory Stuart & Sons jazz piano improvisations were recorded at the Stuart & Sons piano studio ‘the White Room’, in Newcastle. These sessions were informative to the piano maker, the pianists and the audio engineers. In 2007, Stuart & Sons released the first of their CDs, A New Voice. The improvisations on this recording are arguably the first compositions specifically created for the 97

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65 Good, chpt.6.
keys Stuart piano. In over 115 years of stylistic development, Jazz piano style had not experienced a fundamental change in the acoustic soundscape of the piano, until now.

In 2010 a second CD entitled *A New Voice II* was released by Stuart & Sons to coincide with the launch of its expanded keyboard compass of 102 notes. The expanded frequency range of C₀ 16Hz to F₈ 5587.65 Hz made this the largest piano ever to be made in the 300 year history of the piano. Five lower notes were added to the bass register. The lowest note of the 97 note compass is F₀ 21.82 Hz, and the lowest note of the 102 compass is C₀ 16Hz. The highest note F₈ 5587.65 Hz is the same in both the 97 a 102 compasses.

Pianist Bill Risby produced improvisations in these Stuart & Sons sessions that profoundly influenced my approaches to playing the Stuart piano. His improvisations reveal a superb understanding of the Stuart sound. He produced a distinct tone and played with intricate attention to the complex inner harmonic balances as the sounds sustain. In the audio excerpt link below, Risby creates a sound effect with the extreme bass registers, with a deep sound that is created by the palm of his left hand, gently striking the bass strings. These particular bass strings are being sustained by the selective sustain of the sostenuto pedal. The deep low sound maintains its harmonic and dynamic quality whilst the treble sounds are activated by the hammer strikes, played by the right hand. In this sound, several contrasting harmonic layers sustain simultaneously. As stated previously by Zubin Kanga, these layers are clearly defined in the Stuart piano soundscape.

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![CD covers](Fig0.4_A_New_Voice_CD_cover_2007_A_New_Voice_II_CD_cover_2010)

I have found an extraordinary amount of sustain in the sound of Wayne Stuart’s piano, which has opened up a whole palette of sounds- when I studied Debussy, the score instructed you to hold down a bass note, without sounding it, and let the harmonics of the held note sound sympathetically with the played notes in the treble, … doing this on a Stuart piano is a completely different sound. - not only can all the harmony be heard completely clearly in that single held note, but they sustain for a very long time… and you can use that sustained effect to play with… selecting its sustain with the sostenuto pedal and continue playing to then reharmonise the sound that you’ve sustained. 68

The Stuart piano was the featured instrument of the Kinetic Jazz Festivals in Sydney, in 2010 & 2011. At these festivals over twenty Australian jazz pianists improvised on the extended frequency ranges of 97 keys, higher and lower than the standard 88 keys of the traditional modern piano. The performances at the Kinetic Jazz Festivals were recorded and are available as commercial CD releases. On the 2011 Kinetic Jazz CD release, pianist Roger Dean comprehensively explores the Stuart piano soundscape in his performance improvisation of ‘Cloudspotting’. His performance begins with a portrayal of the very low frequencies of the Stuart range.

In *Cloudspotting*, Dean combines the Stuart sound with the sound of a sampled and treated piano sound. The sustain transient in the sampled sound has been extended beyond the capability of an acoustic piano, nevertheless the Stuart sound has tonal qualities that are compatible with the enhanced electronic sound. The sustained quality of sound of the sampled piano is not dissimilar to the Stuart sound.

We are at the point monumental scientific, technological and intellectual changes. The post Mechanical Age presents particular challenges for historically focused cultural pursuits deeply rooted in the mechano-crafts of antiquity. Electricity is central to most contemporary technological operations and the vast majority of music related experiences uses electricity as its energy source.

I sense that Wayne Stuart envisages an acoustic piano sound that could be regarded in the 21st century as contemporary as the digital sampler, or computer.

Wayne Stuart maintains a position that his piano design is a reaction to significant changes in Western artistic aesthetics that date back to the Impressionist movement from around the mid 1860s. By increasing the importance of the harmonic and dynamic aspects of the sound envelope (vertical) to the time and ethos focused tradition (horizontal), enabled an explosion in radical new ways of expression. The old narrow European tradition expanded to embrace a ‘world music’ that reflects not one particular idea of sound but has potential to integrate with many traditions where vertical or ‘colour’ based sound has been the cultural preference. Stuart’s vision is for a multi dimensional orchestral approach to piano tone building where both the vertical and horizontal elements of the attack and decay transients of the sound envelope are integrated and explored. The clarity of sound attainable in his designs is due to low levels of inharmonicity. Non masking and harmonic integration with other musical instruments and sound types is an important outcome of this approach. This achievement sets Stuart’s work apart in the modern music forum. The sound fashion adopted for the acoustic piano of the 20th century is fundamentally an American ideology and aesthetic. It is not culturally nor universally representative but rather, reigns as a consequence of political and economic dominance. This last statement is clearly stated on the Steinway web site with President Bush congratulating them for spreading the American way around the world!

69 Kinetic Jazz Festival 2011, info@kineticjazz.com, Sydney: 2011, compact disc.
71 Wayne Stuart, speaking on “Innovations In Piano” Know Your Music.
72 Wayne Stuart, email interview with author, Monday, 18 April, 2011.
Early Piano Design Associated with a Musical Style.

A piano is a machine of interactive systems connected by three main mechanisms, i) vibrating strings, ii) hammer action, iii) resonating soundboard. The hammer action that strikes the strings is activated by the pianist’s touch on the keys. The resonating soundboard is forced by the strings’ vibrations to vibrate by energy transmitted through the wooden bridges. The soundboard subsequently amplifies the piano sound via the vibrations of its larger mass.73

The modification of the Italian harpsichord into a gravicembalo col piano e forte74 in 1700, by the Italian harpsichord builder Bartolomeo Cristofori, signified the invention of the piano. Cristofori’s invention of the hammer struck action, occurred at a time in history when a major shift was occurring in the perceptions of art music. The exclusive Baroque, church and aristocratic influence on the arts was experiencing a transition influenced by social trends towards a more centralised business-connected artistic community for both professional and amateur musicians. This shift in social practice subsequently coincided with more frequent staging of public concerts, and the establishment of associations between event entrepreneurs, publishing companies, instrument makers, agents of instrument makers, composers, professional and amateur performers and the general public. Political revolutions and wars were influencing the emergence of egalitarian influences on governments and the aristocracy. The migrations to London of many leading musicians and instrument builders escaping the wars and revolutions of Europe transformed London into the commercial and artistic capital of the world. The empire building colonisations, revolutions and wars of this time influenced the growth of world industry and trade. The colonisation of Australia is well connected in this archetype of empire expansion, trade and science.75

Chronology of Piano Design and Keyboard Compass Expansion.

The text of the following pages is accompanied with an illustrated chronology of the expansion of the piano keyboard compass over 313 years, from 1700 to 2013. Associated composers, pianists and technological developments are included with several of the illustrations. This illustration is important to this study as it displays how musical compositional style has traditionally been associated with instrumental design. A complete uninterrupted presentation of the piano compass development can be viewed in Appendix 1a.7

The keyboard notes in the illustrations are numbered in the ‘scientific’ system which accommodates a clearer presentation of the compass expansion from 1700 – 2014. The lowest note being C₀ 16Hz; middle C = C₄ 261.63 Hz; to the highest note F₈ = 5587.65 Hz. Both upper & lower casing is used to identify the same note for example: C0 and C₀ are the same note.

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73 Good, 2.
74 ‘harpsichord with soft and loud’ 14 Good,41-42. Source: Scipione Maffei Giornale deLetterati d’Italia 5 (1711):144-59
Resonating wood, vibrating wrought iron strings and a dynamically enabled keyboard action were the primary working mechanisms in early pianos between 1700 and the 1820s. The desire for a more musically expressive touch and sound for keyboard instruments was the impetus for modifying the harpsichord keyboard action mechanism. The popular styles of music in 1700 were the expressive forms of Italian opera and string music, signifying the beginning of a shift from the systemic Baroque, into a more individual sense of music making. It was the Florentine, harpsichord maker Bartolomeo Cristofori’s modification of the harpsichord’s keyboard action that initially enabled the keyboard player to implement dynamics, sustain and expression, that was previously not attainable on the harpsichord and clavichord.

The First Piano

On a visit to the Medici Court of Prince Ferdinando where Cristofori was employed as an instrument builder, Veronese intellectual Marquis Scipione Maffei, realised the importance of Cristofori’s invention and published detailed diagrams of the new instrument in a Venetian quarterly magazine Giornale de’ Letteratti d’Italia in 1711. Transcripts of the article are found in Loesser’s Men Women and Pianos, and E. Good’s Giraffes, Black Dragons and Other Pianos. Cristofori’s dynamic keyboard action with escapement set the piano building industry on its subsequent journey of design development. Escapement is a term that describes the bouncing of the hammer freely from its impact on the string, enabling a free vibration of the string, whilst the key is still depressed. This wasn’t a capability of the harpsichord or the clavichord. Cristofori’s hammer and string motion delivered to the music world a dynamic keyboard action and keyboard sound, that would respond to the desired dynamics and texture of the pianist or composer, without the need for tradition tone modifying hand stops. Dynamics and tone colour were previously controlled by stops on the harpsichord. Dynamics enabled through the keyboard itself meant the pianist could implement a change in dynamics, without stopping the music, i.e. with both hands still playing on the keys. George Handel and Domenico Scarlatti were in Florence at the Medici Court at this time, and it is assumed both composers played the new instrument at the place and time it was made. News of Cristofori’s invention would have spread quickly through Europe via Maffei’s article.

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76 Loesser, Men, Women and Pianos; 7 Good, Giraffes, Black Dragons.
77 ibid. 11 Good,36.
75 Ron Surace “CRISTOFORI, BAROLOMEO” in Palmieri, 102.
Hammer struck keyboard actions were being developed elsewhere throughout Europe, without prior knowledge of Cristofori’s invention. At approximately the same time the Saxon designer and musician, Gottlieb Schroter was developing a similar idea, to implement dynamics via the keyboard. Schroter’s design was different to Cristofori’s. Schroter’s model was not the harpsichord, but the lighter simpler action of the clavichord. Schroter’s design eventually became known as the ‘Viennese action’ and was development by piano builders Andreas Stein and Anton Walter.

German organ builder, Gottfried Silbermann developed Cristofori’s design further with some guidance from J.S. Bach and his son C.P.E Bach. Silbermann was the first to give the new instrument the title forte piano in 1733. CPE Bach was an influential authority on how to play the new keyboard instrument, providing a manual of techniques and a tutor on musical style advising harpsichord players how to adapt musically to the new forte piano. The Versuch über die wahre Art, das Clavier zu speilen, (Essay on the True Manner Of Playing Keyboard Instruments 1753), makes comments on accompanying, the undamped nature of the piano particularly in the higher registers, its colourful resonance, and details on improvisation, an essential ingredient of music practice in the eighteenth and early nineteenth centuries.

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82 Geoffrey Lancaster in *“Innovations in Piano”. Know Your Music.*
The art of improvisation, or extemporisation, has virtually vanished among serious musicians (in the twentieth century it popped up in jazz). C.P.E. Bach was involved in the new musical style that focussed on the performer’s interpretation, taste and expression with a homogeneous melodic style, the style gallant. The new musical expression had a sense of simplification, and attracted more amateur musicians to music performance than previously in the Baroque. As the piano progressively replaced the harpsichord as the preferred keyboard performance instrument, pianistic techniques, methods and ‘schools’ of playing began to be clearly illustrated by the leaders of the style in instructional volumes. The descriptions of piano tone, and articulations in these publications serve as an indication of which make of piano design was being favoured.

For nearly two centuries, piano designs changed as technical processes of steel drawing changed and the craft of pianist-composers in the late eighteenth and nineteenth centuries evolved.

The fact that instrument makers experimented so widely is evidence of new musical requirements which grew more insistent as the style of musical composition became increasingly homophonic, rather than contrapuntal.

The pianist-composers, J.S Bach, CPE Bach, JC Bach, Haydn, Mozart, Beethoven, Schubert, Brahms, Schumann, Chopin and Liszt, Rachmaninov, Debussy and Ravel were in frequent contact with piano builders, and the virtuoso pianists such as Hummel, Clementi, Cramer, Moscheles, Thalberg, Hans von Bulow, Rubenstein, and Paderewski, had business and artistic involvement with the design developments and experiments of the piano makers such as Silberman, Stein, Broadwood, Graf, Pape, Collard, Erard, Peyel, Bosendorfer, Bechstein, Bluthner and Steinway.
Viennese and Anglo/German piano design.

Historically, the influence of keyboard design and instrumental sound on music compositional style is demonstrated by the difference between the Viennese and Anglo/German piano designs in the later half of the eighteenth century. Both distinctly different piano sounds corresponded distinctively in the piano music of Wolfgang Amadeus Mozart and Muzio Clementi. Mozart was clearly the master of clarity, precision and improvisation. Living most of his life in Vienna, his pianos were designed in the Viennese style, characterised by silvery tone and feather light smooth flowing action.

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Music historian, pianist Robert Levin discusses the characteristics of Mozart’s Viennese piano in his program ‘The Instrument Of Choice’. Levin describes and demonstrates the associations of the Viennese instrument’s light and fast action, a rapid decay of the tone, and a very clear tonal spectrum, in parallel with the style of Mozart’s piano music. Clementi on the other hand lived in London, playing pianos derived from Silbermann’s model, larger in size, louder, longer sustain, heavier keyboard action, more strings per note and pedals. Schönberg tells us that Clementi is the first composer to

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89 ibid.

90 Mary L. Boehm, 'STEIN FAMILY,' in 4Palmieri, 372.

91 Robert Levin, “The Instrument Of Choice,” YouTube video , 7.48, September 14, 2007,  
[http://www.youtube.com/watch?v=r-DEhpPgtSY&feature=reImMu](http://www.youtube.com/watch?v=r-DEhpPgtSY&feature=reImMu)
exploit the dynamic extremes of the instrument.\textsuperscript{93}

The two different instrument designs produced two pianistic approaches to legato; pedalling; melodic, harmonic and dynamic density.\textsuperscript{94} A clearly illustrated difference and development in pianism is revealed in the writing of C.P.E Bach, Muzio Clementi and in the letters of Wolfgang Mozart. All three were innovators of performance style and composition.

\begin{tabular}{|c|c|c|c|c|c|c|c|}
\hline
Year & Maker & Pegs & Notes & Year & Maker & Pegs & Notes \\
\hline
1794 & Broadwood (Haydn) & $F_1$-$F_7$ & 6 octaves & 1803 & Walter & $F_1$-$F_6$ + $G_6$ & classic 5 octaves, Beethoven \\
\hline
1803 & Erard & $F_2$-$C_7$ & (5 octaves + 7) & Beethoven & 1807 & Erard's metal stud bridge, brass agraffe. & \\
\hline
1808 & Streicher & $F_1$-$F_7$ & (6 octaves) & Beethoven & & & \\
\hline
1810 & Clementi & 6 octave, a lighter English action than the heavier Broadwood action. & & & & & \\
\hline
1816 & Broadwood & $C_1$-$C_7$ & (6 octaves) & Beethoven & & & \\
\hline
1818 & Graf & $C_1$-$F_7$ & (6 octaves + 5) & Beethoven & & & \\
\hline
& Vienesse action, Combination of Vienesse and English compasses. & & & & & & \\
\hline
1819 & Steel Strings being to be used - William Brokendon's steel drawing invention. & & & & & & \\
\hline
1821 & Erard double escapement action.\textsuperscript{95} & & & & & & \\
\hline
1824 & Erard & $C_1$-$C_8$ & (Liszt - 13yrs old, performance) & 7 octaves\textsuperscript{96} & & & \\
\hline
1826 & Pape : Hammer Felt patent; & & & & & & \\
\hline
1828 & Pape : over-cross stringing patent with a separated bass bridge.\textsuperscript{97} & & & & & & \\
\hline
1839 & Pleyel pianos played by Schuman and Chopin & & & & & & \\
\hline
1839 & Graf & $C_1$-$G_7$; 6 octaves + 7 notes played by Schuman and Brahms & & & & & \\
\hline
1840s & Nuns and Clarke, $A_0$-$A_7$ (7 octaves) American large ornate square pianos, establishing the new common range.\textsuperscript{98} & & & & & & \\
\hline
\end{tabular}

\textsuperscript{93} Schonberg, 60. \\
\textsuperscript{94} Schonberg, 49. \\
\textsuperscript{95} David Grover. \textit{A History of the Piano from 1709 to 1980} \url{https://www.piano-tuners.org/history/d_grover.html} (accessed 14th May 2015). \\
\textsuperscript{96} Good, 111 \\
\textsuperscript{97} Good, 211 \\
\textsuperscript{98} Good, 200
1847, 97 Keys.

The important French piano builder Henri Pape (1789-1875) is regarded as an experimenter-designer. Pape pioneered the expansion of the piano’s frequency and dynamic ranges. Henri Pape had a profound influence on piano builders of his time and contributed greatly to the evolution of piano design. His most important innovations are the use of felt for hammers, made out of rabbits hair and lamb’s wool patented in 1826, cross stringing of his pianinos patented in 1828, the use of piano wire made of tempered steel patented in 1845. The expanded compass of eight chromatic spans, patented in 1842, was exhibited at the Paris Exposition in 1844. The Stuart & Sons piano compass of 97 notes was pioneered by Henri Pape’s patent of 1842, a design of 8 chromatic spans, F₀ – F₈.

Iron & Steel Developments.

Since the early 1700s, piano design has experienced both rapid and slow periods of development. Perhaps a most important development that defines the modern piano, occurred in the first half of the 19th Century, as the technological, acoustical and mechanised advancements in metallurgy made possible the production of iron frames and piano wire with high tensile capacity. These advancements were initially adopted by the American, Chickering (1823) and Steinway (1853) and the German, Bechstein (1853) and Bluthner(1853) piano makers. This industrial standard ‘change of the guard’,

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99 The term ‘chromatic span’ is interpreted in this instance as being a group of 11 semi-tones, 7 white- tones. Therefore the full 8 chromatic spans consist of 8 repeats of each of the 11 semi-tones.
101 Peggy Flanagan-Baird, 259. Also see, Loesser, Men, Women and Pianos, 407-409; and Good, 176-177.
102 Courtesy of Stephen Paulello email (19th June 2013) and Paul Corbin. Also see - Alexander Prince, “The Record of patent inventions, a monthly abstract of all specifications of patents of invention,” (U.K.: Oxford University 1842), 238-241.
from wood to iron in the 1860s brought about changes in manufacturing methods of pianos that achieved efficient mechanised production through economies of scale meeting the increasing demand for pianos at a lower retail cost. The piano companies promoted themselves as being both traditional and modern, producing a fashionable piano for everyone, with the latest unique advancements in technology and appearance whilst honouring the timeless traditions of piano building.103

**Popularity of the Piano.**
The piano’s popularity increased greatly in the nineteenth century, as an increasingly affluent urban middle class developed a hitherto unattainable preoccupation with artistic experiences and leisure time. In previous generations it was generally accepted that the pursuit of developing artistic skills and talent was the exclusive domain of the noble and aristocratic classes. A commercial industry rapidly grew, influenced by the popular Romantic piano compositions of Schuman, Chopin, and Liszt. Interest in the celebrity of concert performers such as Thalberg, Paderewski and Rubenstein influenced a widespread interest in music tuition, and the building of spectacular concert halls, all contributed to the popularity of the piano. 104 The success of the piano manufacturing industry since Johann Zumpe started making square pianos in London in 1766 105 is due historically, to sales of pianos for domestic, home and amateur use, and not sales of concert grand pianos to concert halls, professional venues and studios. The first major business success of Steinway in 1856 was their development of the American upright piano, 106 as the replacement for the American square piano, which had become expensive, larger and more ornate than the European squares, and cumbersome to manufacture on mass. Though many of the technological advances in piano design have largely been developed in vogue with the contemporary performance and composition of concert piano music, it is the domestic piano market which has financially supported the science.

1843 Chickering - one piece iron frame patent 107.
1845 Pape patent for tempered steel.
1853 Bechstein - associations begin with concert pianist Hans von Bulow
1857 Steinway A0-A7 108, Steel Strings now common.
1859 Henry Steinway patent for cross-stringing grand pianos.109
1867 Steinway 12 (a-g#) x 7 =84 + 4notes Standardised by 1880s: 7 chromatic octaves + 2 notes (88 keys); 7 chromatic spans for 4 notes a; a#; b; c110

---

103 Ehrlich, 49.
104 Ehrlich, 15-26, 52-58.
108 * Good, 184, 205.
109 10 Good, 212.
110 11 Good, 220.
The Modern Australian Piano

From the 1890s, for approximately forty years, the Australian piano industry grew to become one of the largest in the world. In 1925 the Australian piano manufacturer Octavius Beal claimed to be the largest manufacturer of pianos in the British Empire. The Australian piano manufacturers Wertheim (1908) and Beale (1893) began their businesses as importers of German pianos into Australia in the 1880s. The German piano makers, Ronisch (1845) and Lipp (1831) exported pianos to Australia in large numbers, offering an affordable alternative to the English makes of Broadwood and Collard. Both Ronisch and Lipp won medals in the Sydney and Melbourne international trade Exhibitions of 1879 and 1882. Australia enjoyed the advances in the worldwide piano industry initially as the colonised province of the United Kingdom, and then as the largest manufacturer of pianos in the southern hemisphere, between 1893 and 1930. Beale manufactured 95,000 pianos, and Wertheim 18,000 pianos. There are two piano makers of hadncrafted Australian pianos operating in the 21st Century. Ron Overs and Wayne Stuart are developing and modifying the modern piano with very different philoshosies of piano sound production. Both makers are changing the dimensions and materials for soundboards, implementing more stable string scales and producing key action with reduced friction and both makers are making pianos with an expanded frequency range. Overs continues to implement the standardised pinning of the piano string to the bridge and soundboard. Stuart has replaced the traditional piano string pinning with a bridge aggraffe which radically changes how the string vibrates, and fundamentally changes the sound of the piano, creating a very different sound from that of the traditional modern standardised piano.
1995 Stuart & Sons - 7 chromatic spans, of each note, 8 chromatic spans of 'f'.
12 semi tones (f-f) x 8 = 96 + 1 note

<table>
<thead>
<tr>
<th>C0</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>F8</th>
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21.82 Hz

2010 Stuart & Sons 102 notes (8 chromatic spans of c, c#, d, d#, e, f)
12 semi tones (c-c) x 8 = 96 + 6 notes

<table>
<thead>
<tr>
<th>C0</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>F8</th>
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16 Hz

2013 -16 Stuart & Sons proposed 8 chromatic spans of each note of the chromatic scale =108 notes.

<table>
<thead>
<tr>
<th>C0</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>B8</th>
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</table>

16 Hz


The Stuart & Sons bridge agraffe and the expanded keyboard compass design innovations implemented since 1995, have been employed by the French piano manufacturer Stephen Paulello to achieve his specialised Paulello piano soundscape. The Paulello SP 300 piano released in 2016, integrates the Stuart & Sons extended frequency, harmonic and dynamic ranges with Paulello’s concepts of piano sound quality. The Paulello soundboard is ribless, signifying an expansion of Stuart’s concept of increased soundboard flexibility. Paul Corbin suggests that the standard keyboard compass of the 21st century modern piano will change to 102 keys as more piano manufacturers creatively engage with Stuart's concepts.

1995-2013 Piano Keyboard Compass Evolution. Table 0.8

…given the advanced wire of Stephen Paulello, a French piano maker, it was inconceivable to limit these new generation pianos to 88 keys but rather, to aim for the ultimate goal of 9 octaves for the chromatic scale.

108 Keys, Omega 6 and Stuart & Sons.

In 2014, French piano technician & researcher Paul Corbin constructed a device that demonstrates the recent advancements by Stephen Paulello in steel wire drawing. Paulello’s new wire ‘XM’ grade will support the extension of the piano compass to B8, 7902Hz. Corbin gave his demonstration device the title ‘Omega 6’ -

Omega (Ω) is the last letter of the Greek alphabet, in contrast with Alpha. It is notably used to indicate an end or limits. Number 6 stands for the six remaining notes (F#, G, G#, A, A#, B).

---

117 7901 Hz is my calculation, and may be under. W Stuart states it's over 8,400Hz in the documentary “Opus Dissonus, “Artur Cimirro- The Documentary.”
118 4Paulello, “Pianos & Strings” www.stephenpaulello.com
121 6“Innovations”, Stuart & Sons Handcrafted Pianos.
123 8 Corbin, 11-19.
In his journal article *Why extend the range of the piano* Corbin outlines a history of the piano keyboard compass (ambitus). He denotes the expansion of the keyboard compass in the first half of the 19th Century as responses to the rapid advancements in steel technology from the 1820s. (The historic metallurgy advancements are noted in Appendix 1.2). Corbin also offers his insights in playing the extended ranges of 97 & 102 keyed pianos. He makes the observation that the Stuart tone of the low range C₀ to G♯₀ is more full and more bassy, not as ‘brassy’ as the Bosendorfer Imperial piano sound. This observation is linked to a combination of Stuart piano design elements, the improvements in tonal quality of the lower frequencies of the Paulello strings and the harmonic transient controls implemented by the Stuart bridge aggrafe. The vibrational changes imposed by the Stuart bridge aggrafe are discussed in detail and tested in chapter 2 of this research. Corbin observes in his article, that the very low frequencies in the Stuart piano soundscape provide a harmonic support to the soundscape particularly when played with *pianissimo*. At this softer dynamic, less upper partials are resonated and the fundamental is ‘sensed’ in the sound more clearly than if the very low note was played a *forte*. Wayne Stuart has directed me to this dynamic technique also. For me, the effect is like the gentle hit of the orchestral bass drum, subtly opening up the sound to a wider frequency range, without interfering in the internal tonal balance of the sound. Corbin also observes that the extended frequencies in the 102 key compass contribute to the tone of the whole compass *sympathetically*. He compares this application to the great organ high frequency stops of 12,000Hz. In chapter six of this paper, I have composed music where the pitches of highest notes of the 102 key compass are heard clearly in arpeggiated sequences.

Since the Omega 6 has been produced the Brazilian pianist-composer Artur Cimirro has composed music for 108 keys in anticipation that the Omega 6 will be implemented into a Stuart piano design soon. Cimirro had composed piano music for a higher and lower frequency range than the standardised 88 keys before he knew about the Stuart & Sons piano. Before the 102 keyed Stuart piano was

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124 Corbin, 11-19.
125 Opus Dissonus, “Artur Cimirro-The Documentary.”
designed, in 2006 his compositions included the contra C already established by the Bosendorfer Imperial, and the higher Eb₃, three notes above the 88 key range to C₈. In the music extract below from Artur Cimirro’s *Eccentric Preludes* Op.20, (2012), the highest note on the manuscript is B₈ 7901 Hz. ¹²⁷

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**Stuart Piano Design, Sound and Composition**

The Stuart & Sons piano produces a different sound to the standardised modern piano. The difference is due to the design changes particularly in how the piano strings vibrate. The effect this difference in sound has on my performance and composition are demonstrated in the music composed and presented in chapter six. In brief, the new piano sound has inspired me to focus on Australian elements, defining the sound as an Australian sound, and proceeding to use its characteristics in collaboration with Aboriginal musicians, playing re-composed Aboriginal chants of the local Sydney region.

Wayne Stuart’s philosophy of piano design is focused on an artistic interaction between the musician and the designer that supports a process of developmental change within the art of contemporary music making. Stuart is interested in emphasising an artistic challenge to the pianist and composer through his instrument design, to create new contemporary sound vocabularies, combining the traditions and complexities of design with the implementation of new technology and an impetus to present a malleable palate of sound colour for the contemporary musician. Stuart’s interest in design practice evolving with contemporary music performance and composition presents a philosophical contrast to the historic industrial events of the late eighteenth century, where a growing market place for pianos, implementation of mechanical manufacturing technology, and competitive international trade markets, led to an industrial standardization of piano design. The perception that piano design had evolved to its perfection occurred at this time. ¹²⁸ The notion of a standardised design and the subsequent fallout of

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¹²⁸ Paulello, “Concepts page.”
product obsolescence\textsuperscript{129} is a world away from the bespoke artistry of Stuart’s contemporary piano designs.

For over three hundred years, piano designers and pianist-composers have interacted to affect change in design, composition and performance style. How the arrival of the Stuart & Sons piano, in 1995, fits into this historic design paradigm described in the preceding pages, will be the focus of this research, examining whether the Stuart piano design influences composition and pianistic style.

\textsuperscript{129} \textsuperscript{15} Good, 207.
1. Pianos In Comparison: Design Dimensions and String Scale

The processes involved in investigating the distinctive characteristics of the Stuart piano sound are demonstrated and illustrated in the following three chapters. To thoroughly examine the Stuart sound, I have compared its tonal qualities to the tonal qualities of the modern piano. It was more beneficial for me to conduct the research as a comparison because of my extensive experience in playing and listening to modern pianos. So the new Stuart sound was compared to the familiar ‘control’ sound of the modern piano.

It is stated in the introduction that this research regards the Stuart piano as a different instrument to the modern piano. The research subjects below indicate the points of difference the Stuart piano has to the modern piano -

i) The tonal qualities of the sound  
ii) String coupling at the bridge and vertical string vibration  
iii) Movement of the thinner soundboard.  
iv) Australian wood used for the soundboard  
v) Extended keyboard compass of 97 and 102 keys  
vi) Extended length and thickness of the bass strings  
viii) Australian made  
ix) The soundscape of choice for composition and improvisation for a growing number of Australian musicians.

The modern piano sound is produced in this research by a Steinway Concert D piano made in Hamburg Germany in 2005, No 574500 and is identified throughout the paper by the acronym (STE). The Stuart sound is produced throughout this research by the 2.9m Stuart concert piano No19, made in Newcastle Australia in 2002, and given the acronym (M19,STU) throughout this paper. The ‘M’ in the Stuart acronym is the grade of Paulello strings used for the notes examined on this particular instrument.

The technical dimensions of both pianos are displayed in the following pages.
Compass, Frame, Structure.

<table>
<thead>
<tr>
<th></th>
<th><strong>Stuart &amp; Sons</strong> 2002, No 19</th>
<th><strong>Steinway &amp; Sons</strong> D 2005, No 574500</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Red Cedar veneer</strong></td>
<td>Toona australis</td>
<td><strong>Black Ebony veneer</strong></td>
</tr>
<tr>
<td><strong>Keyboard</strong></td>
<td>97 keys</td>
<td>88 keys</td>
</tr>
<tr>
<td><strong>Compass-Frequency</strong></td>
<td>$F_0 \ 21.82\text{Hz}$ $F_8 \ 5587.651\text{Hz}$.</td>
<td>$A_0 \ 27.5 \text{Hz} \ C_8 \ 4186.01$</td>
</tr>
<tr>
<td><strong>Length</strong></td>
<td>2.9 m</td>
<td>2.74 m</td>
</tr>
<tr>
<td><strong>Frame</strong></td>
<td>High quality Australian SG iron</td>
<td>Steinway has their own foundry to supply iron frames.</td>
</tr>
<tr>
<td><strong>Rim</strong></td>
<td>Multi laminations of Hoop Pine and Hard Maple. Thickness: 110mm</td>
<td>Hard Rock Maple- 17 laminations. Maple and Mahogany for German production. Thickness: 82.6mm</td>
</tr>
<tr>
<td><strong>Pin Block</strong></td>
<td>Selected sawn hard maple hexagonal laminated pin block.</td>
<td>Steinway hard maple Hexigrip tuning pin block</td>
</tr>
<tr>
<td><strong>Back Posts</strong></td>
<td>3 solid spruce/hoop pine in parallel and angular configuration</td>
<td>5 solid spruce in fan configuration</td>
</tr>
</tbody>
</table>

Compass, Frame, Structure Dimensions Table 1.1

**Bridge, Soundboard**

<table>
<thead>
<tr>
<th></th>
<th><strong>Stuart</strong> No. 19, (2002)</th>
<th><strong>Steinway</strong> No. 574500, (2005)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bridge</strong></td>
<td>Laminated maple with hard wood cap. Separated bass and treble bridges. Long bridge depth: 24 mm + 8mm agraffe Short (bass) bridge depth: 52mm + 8mm agraffe</td>
<td>Vertically-laminated continuous ring bridge hard maple with hard wood cap. Long bridge depth: 34 mm Short (bass) bridge depth: 60mm</td>
</tr>
<tr>
<td><strong>Bass bridge to rim</strong></td>
<td>16 cm</td>
<td>25.5 cm</td>
</tr>
<tr>
<td><strong>Soundboard</strong></td>
<td>King William Pine 5mm in the centre, with minimal tapering out to the edges. Compression crowned.</td>
<td>Close-grained, quarter-sawn Sitka spruce. 9 mm thick in the center and tapered to 6 mm as specified as the diaphragmatic design since 1936. Compression crowned</td>
</tr>
<tr>
<td><strong>approximate Soundboard sizes</strong></td>
<td>160cm wide kybd end 288 cm length</td>
<td>150 cm wide kybd end 269 cm length</td>
</tr>
<tr>
<td><strong>Soundboard Ribs</strong></td>
<td>19 ribs 22mmx 22mm</td>
<td>17 ribs 25mmx 25mm</td>
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Bridge, Soundboard Dimensions Table 1.2
Action, Pedals, Hammers.

<table>
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<tr>
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<tbody>
<tr>
<td>Action</td>
<td>Stuart &amp; Sons action Tokiwa made with addition of rare earth magnets between hammer shank and repetition lever. Stuart &amp; Sons balance rail bushings and pin system.</td>
<td>Steinway &amp; Sons action and tubular metallic action frame. Traditionally Steinway manufacture for US models and Renner for German models. Now Renner made for all models.</td>
</tr>
<tr>
<td>Pedals</td>
<td>4 Pedals: Dolce, Una Corda, Sostenuto &amp; Damper Dolce: reduction of lever motion/dynamics. See pg. chapter 6 for an illustration of the 4 pedals.</td>
<td>3 pedals: Una Corda, Sostenuto &amp; Damper</td>
</tr>
<tr>
<td>Hammer shanks</td>
<td>Abel, 5 configurations of stiffness, 2 hexagonal wound strings; 3 oval pure wire</td>
<td>Renner, 2 configurations of stiffness hexagonal wound strings and oval pure wire.</td>
</tr>
<tr>
<td></td>
<td>$C_2$ 5.25mm; $C_3$ 5.1mm; $C_4$ 4.5mm; $C_5$ 4mm,</td>
<td>$C_2$ 6mm; $C_3$ 4.7 mm; $C_4$ 4.7mm; $C_5$ 4.7mm;</td>
</tr>
<tr>
<td>Hammer felts</td>
<td>Abel to specific design</td>
<td>Renner</td>
</tr>
<tr>
<td>Hammer strike</td>
<td>angle strike</td>
<td>angle strike</td>
</tr>
</tbody>
</table>

Actions, Pedals, Hammers Table 1.3

String Scale – 4 notes

![String Scale Chart](chart.png)

The most significant difference in string scale was observed in the lowest frequency, $C_2$ 65.406Hz.
Music Wire Scaling for C2 65.406Hz

The audibly different sound of the Steinway and Stuart of the note C2 65.406 Hz can be understood initially by looking at the strings of both instruments. The Stuart piano uses 2 wound strings, a bichord, wound in stainless steel nickel-plated\(^{130}\), and the Steinway uses 3 wound strings, a trichord, wound in copper. The Steinway piano uses Roslau piano wire, made in Hamburg, which are wound in non-tinned copper\(^{131}\). Roslau piano wire is the music wire of choice of many piano manufacturers of concert grand pianos. The Stuart strings are manufactured in France, by Stephen Paulello, who implements slower drawing methods of steel string production, and new composite alloy mixtures in the steel, to achieve steel of a higher tensile strength. Paulello’s innovations have enabled Wayne Stuart to extend the frequency range of the piano compass.

Samuel Wolfenden writes about the excess weight of the copper wound string,

Naturally, such excess [of copper winding weight] whether partial or total, tends to aggravate the characteristic defect of bass piano tone, viz., the preponderance of the first over-tone, often so pronounced as to eclipse the pitch of the fundamental, particularly when the strings are very short.\(^{132}\)

In response to this problem, Wayne Stuart implemented changes to the standard piano design:

i) extended the piano scale of the long bridge, lower by two notes,

ii) bichord Paulello ‘M’ steel wire, stainless steel wound of greater thickness , length, and tensile strength with increased applied tension.

Pianos have to be designed around these limitations and most of the issues in traditional designs stem from music wire limitations. The 7 trichord bass string groupings of the model D Steinway is a classic example of music wire limitations.\(^{133}\)

The problem with thin wound strings is that they are unstable and often sound rather poor. In this region[tenor strings]the very thin core and covering combinations are also weak in sound and Steinway uses three instead of two. Wound strings are harmonically incompatible , ….. two are bearable, but three are often noisy and unbearable… a very poor compromise.\(^{134}\)

The contrasting dimensions of the Paulello and Roslau piano wires are illustrated in table 4.24a in the 4.2a appendix. The diameter of the Paulello/Stuart core wire is .125mm thicker than the Steinway/Roslau wire, the Paulello/Stuart cover wire is .47mm thicker and of Stainless Steel, whereas the Steinway/Roslau strings are wrapped in copper. Stainless steel is 1.9g per cubic cm lighter than copper in specific gravity\(^{135}\). The tensile strength of the Paulello/Stuart wire is 481 N/mm\(^2\) higher than the Steinway/Roslau. The Paulello/Stuart strings are 235mm longer, and are set at 65.3kg higher

\(^{130}\) Stephen Paulello, (accessed 21st February 2014).
\(^{132}\) 2 Samuel Wolfenden, Art of Pianoforte Construction,209.
\(^{133}\) Wayne Stuart, email interview with author, 23 Nov 2012
\(^{134}\) Wayne Stuart, email interview with author, 5th March 2014
tension. The higher tension imposed on the Paulello string is possible because its mass and length are greater, and Paulello's tensile strength is significantly greater than the Roslau, illustrated by the breaking point figures. The yield or capacity of the Paulello/Stuart. wire is 46% higher than Steinway/Roslau. The composite of materials used, and the proportion of the amount of tension to the breaking point of the string are a matter of tone and the taste/choice of the piano maker.

The Stuart strings are significantly longer, a factor which is known to reduce inharmonicity of wound strings \(^\text{136}\). A reduction of inharmonicity means reduced prominence of the inharmonic frequencies of the string, resulting in a more pure sonorous sound. A wire with a higher capacity of yield produces a more satisfactory sound. \(^\text{137}\)

<table>
<thead>
<tr>
<th>C2 65.406 Hz Stuart</th>
<th>M19,STU</th>
<th>C2 65.406 Hz Steinway</th>
<th>STE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAULELLO / M nickel-plated surface.</td>
<td>ROSLAU high-tensile Swedish steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M bichord (2 strings)</td>
<td>Trichord (3 strings)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length: 1836 mm</td>
<td>Length: 1601 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cor dia: 1.075mm</td>
<td>Cor dia: .950 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cover dia: Stainless Steel wrap 2.175mm</td>
<td>Cover dia: Copper Wrap 1.702mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrapping weight 7g per cubic cm</td>
<td>Wrapping weight 8.9 g per cubic cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension 134,099kg 1387.9 N</td>
<td>Tension 68,7272kg 673.9N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nominal breaking load 2097 N/mm²</td>
<td>Nominal breaking load 1616 N/mm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield 88.25%</td>
<td>Yield 42.8%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C2 String Scale Table 1.4

C3 Scaling

The scaling of the strings for C3 130.81Hz, of the Steinway and Stuart, present a different scenario to C2. The strings for C3, are set in trichords of steel music wire, Stuart using Paulello ‘M’ wire, and Steinway using Roslau wire, both of similar thickness 1.125mm. The Steinway strings are longer by 41.5mm, and the composite materials of the steel wires are different, with differing drawing methods producing contrasting yield and breaking points. The tensile strength and stress % of the yield point is greater in the Paulello string by 140 Newtons per square millimetre (N/mm²). The different rates of tension illustrated in table 1.5 above are part of the equation due to differing string lengths and string material stiffness. The contrasting ‘hardness-stiffness’ of the music wire is illustrated by the contrasting breaking point, the higher the breaking point potential, and the harder or stiffer the wire.

…..the string, considered in its length, diameter, tension and point of agitation, is the most important factor in the production of tone. \(^\text{138}\)

\(^\text{137}\) Fletcher & Rossing,362.
\(^\text{138}\) Wolfenden, Art of Pianoforte Construction,15.
The combinations of string length and string wire ‘hardness’ affect the amount of movement generated in the bridge and soundboard by the string vibration. This influences tonal colour. The piano maker therefore adjusts combinations of length and hardness in the string to achieve the required tonal colour.

Tonal balance and sustain are the main differences between Röslau wire and Paulello wire.¹⁹⁻¹⁹

This comparison of Roslau and Paulello music wires, at C₃ 130.81 Hz, is centred on the tonal differences, which are influenced by the hardness and tensile strength of the two wires, the ‘M’ Paulello string having the higher tensile strength.

**C₄ String Scaling**

The Paulello/Stuart string is 1.5mm longer the Roslau/Steinway, and is set at 3.5kg higher tension. The diameter of the Paulello/Stuart wire is 25mm thicker than the Roslau/Steinway wire. The tensile strength of the Paulello/Stuart wire is 177 N/mm² higher.

---

¹⁹ Stephen Paulello, email interview with author, 14th April, 2014.
C5 String Scaling

For the note C5, the diameter of the Paulello-Stuart wire is 35mm thicker, the tensile strength of the Paulello-Stuart wire is 138 N/mm² higher. The Paulello-Stuart wire for C5 is 4.5mm longer, and is set at 7kg higher tension. The yield or capacity of the Paulello-Stuart wire is approximately 10% higher than the Roslau-Steinway wire.

<table>
<thead>
<tr>
<th></th>
<th>C5 523.25Hz Stuart</th>
<th>C5 523.25Hz Steinway</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>M trichord</strong></td>
<td>M19, STU</td>
<td>STE</td>
</tr>
<tr>
<td><strong>Cor dia:</strong></td>
<td>347.0 mm</td>
<td>343.5 mm</td>
</tr>
<tr>
<td><strong>Length:</strong></td>
<td>.985 mm</td>
<td>.950 mm</td>
</tr>
<tr>
<td><strong>Tension</strong></td>
<td>80.3137 kg 787.6N</td>
<td>73.208 kg 717.9N</td>
</tr>
<tr>
<td><strong>Nominal breaking load</strong></td>
<td>1754 N/mm²</td>
<td>1616 N/mm²</td>
</tr>
<tr>
<td><strong>Yield</strong></td>
<td>60%</td>
<td>58.82%</td>
</tr>
</tbody>
</table>

The Significance Of Design On Sound.

The physical parameters and design attributes of the Stuart No.19 and the Steinway No.574500 pianos’ presented above have been found by this research to significantly affect the qualities of sound produced by each instrument. In chapter four I present a detailed analysis of the various qualities of tonal colour produced by each piano. Each piano sound is described and illustrated in the analysis with its associated string scale dimensions, and the amplitudes of its specific string and soundboard vibrations. Through this analytical process, I established the four tonal characteristics\(^{140}\) that define the unique tonal characteristics of the Stuart & Sons piano sound. In the following chapter, the Stuart Bridge Agraffe is tested, and found to affect a more vertical string vibration, which fundamentally contributes to the production of the distinctive tonal qualities in the Stuart piano sound. These findings have provided me with a platform of knowledge that describes the tonal qualities of the Stuart piano sound. I have used this knowledge base to enquire how audiences perceive the tonal qualities of the Stuart piano sound in survey questions, presented in chapter five. I have also used this knowledge base for the creation of compositions using the qualities of the Stuart piano sound, presented in chapter six.

\(^{140}\) See page 17.
2. String Vibration, corresponding to String Coupling.

The vibrations of the Stuart piano string and its effects on tonal colour are investigated in this chapter. Wayne Stuart claims the Stuart piano sound has an improved dynamic range and clarity of tone because the string vibrates in a more pronounced vertical plane than the modern piano string vibrations.141 These claims are discussed and tested in the following pages.

The strike of the hammer activates the vibrations in the piano string that produces the basic ingredients of piano sound. A musical sound is produced by the exact repetition of vibrations known as their frequency. Musical pitch is defined by the frequency at which the vibrational period repeats. Galileo’s measurements of frequencies with periodic motion142, set the science world on an investigation of the relationships of time and frequency. In the 1960s the Systeme Internationale standardized the measure for pitch as a hertz, named after Heinrich Hertz, the 19th century German physicist who discovered how to generate radio waves.143

Something which makes 1 complete vibration every second has a frequency of 1 hertz, (or 1 Hz)144

The frequencies and the qualities of tone of the Stuart & Sons piano sound are investigated in this study by understanding the behaviour of vibrations. The string vibrations of the modern piano, represented in this research by the Steinway piano are compared to the vibrations of the Stuart piano strings.

The quality of tone depends on the form of vibration...... every different quality of tone requires a different form of vibration. 145

The Stuart & Sons piano design differs significantly from the modern piano design with the implementation of the bridge agraffe146. Wayne Stuart makes the claim:

The innovation at the core of the Stuart & Sons design concept is the principle of vertical string coupling, by using a special device (agraffe) to anchor the strings to the bridge. The agraffe defines the strings’ speaking length (frequency) and contains the reaction forces produced by bending the strings as they pass through the agraffe. This allows the soundboard to be designed on a speaker cone principle and not as a load bearing structure as found in the standard piano. This liberates the dynamic range; increases sustain and creates great clarity of tone throughout the entire frequency range.147

143 Johnston, 35.
144 Johnston, 35.
147 5 Stuart & Sons Handcrafted Pianos. FAQs qu.2 (accessed 8th March 2014).
The Bridge Agraffe.

The agraffe, is a metal device originally designed by Sebastian Erard in 1807 to keep the strings equally spaced and held firmly in position to counter the blow of the hammer. The agraffe string retaining concept has been adapted and substantially modified to retain strings in a number of different configurations since the original Erard design. John Broadwood & Son applied a bridge agraffe to their pianos during the early part of the 20th century. Although the principle was similar to the Stuart design, the application differed in that the knife edges were placed in the opposite configuration. The Broadwood application used a standard load bearing soundboard design concept. There are no records of the sound of this particular Broadwood design. In the Stuart piano the bridge agraffe has been adapted to form a three point coupling device through which the strings pass.

Wayne Stuart writes,

My bridge agraffe application is not an adaptation to resolve the limitations of the pinned bridge but rather, to wilfully enhance the tonal and dynamic parameters of the acoustic piano. I make no claim to uphold the traditional piano as an aesthetic norm but rather, to offer a solution to how the instrument’s sound might be enhanced and further developed along new trajectories. I am of the opinion that earlier attempts to utilise vertical agraffe string coupling devices fell foul of prevailing and often entrenched sound fashions. Combinations were often technically inadequate and/or limited mostly posing as solutions to split pinned bridges. 148

At the heart of the Stuart piano’s sound production is a device designed by Wayne Stuart that couples149 the piano strings to the bridge and soundboard in a different way to all other pianos. The device is the bridge agraffe.

Vertical string coupling is at the core of the Stuart & Sons design concept. A special device (agraffe) is used to couple the strings to the bridge and soundboard structure. The agraffe defines the string's speaking length (frequency) and contains the reaction forces produced by bending the strings as they pass through it. This negates the need for string down bearing that is required in the traditional pinned bridge system. The soundboard can thus be designed on a speaker cone principle and not as a load bearing structure as is the case in the standard [modern] piano. This scientifically designed device encourages the strings to vibrate in a more controlled manner improving the dynamic range, increasing sustain and significantly improving tonal clarity sympathetic to the entire piano repertoire.150

Piano strings of all pianos are coupled to the bridge to enable the transmission of the relatively quiet tonal vibrations of the strings into the soundboard, which by the subsequent movement of its greater surface area, the soundboard amplifies and projects the sound. The Stuart bridge agraffe transfers the string vibration modes to the bridge and soundboard without a down-bearing force.

149 Term for attach, ‘couple’.
150 Wayne Stuart, email interview with author, 4th April, 2012.
The Stuart agraffe couples the strings in a unique vertical application that maintains its straight line, without twisting its directional plane. The agraffe also enables the elimination of the traditional down-bearing force. The diagrams and photos below illustrate the coupling of the string onto the bridge of both the Stuart piano (left) and the modern piano, (right).

The photos above show the top-down view of the horizontal zig-zag pinning of the modern piano (right) which twists the line of the string, and the bridge agraffe (left) which maintains the line of the string.

The ‘off set’ is the direction in which the stretched music wire is bent and anchored to the bridge/soundboard to determine the speaking length of a note.\textsuperscript{151}

\textsuperscript{151} Wayne Stuart, email interview with author, 1\textsuperscript{st} February 2012.
The ‘off set’ is indicated by the yellow arrows in the photos below.

The string of the modern piano is pinned to the bridge in a two pinned horizontal ‘zig zag’ ‘off set’ plane, and the Stuart piano string is attached to the bridge in a vertical ‘zig zag’ ‘off set’ plane by the Stuart bridge agraffe. The horizontally pinned string is twisted in two zig-zag directions enforced by the two pins. The Stuart piano string is bent vertically in an up-down direction by the bridge agraffe.

The coupling of the string to the bridge is the fundamental connection between the string and the soundboard. The Stuart bridge agraffe couples the strings to the bridge maintaining the straight longitudinal line of the string by implementing a vertical twist termination replacing the traditional horizontal twist string termination coupling of the pinned bridge. The Stuart bridge agraffe has a three point coupling device through which the strings pass. The strings are bent at approximately 12 degrees to define the speaking length of each frequency unit. The Stuart agraffe is secured to the surface of the bridge. The three knife edges of the agraffe bends the wire whilst retaining the reaction forces produced by the string tension within the agraffe’s mass. This effectively neutralises the transfer of twisting and bucking forces to the soundboard.

The numerous vibrational modes of the oscillating string are transmitted into the bridge and soundboard via the agraffe on the Stuart piano, or via pinning on the modern piano. Some vibrations are transferred directly off the vibrating string to the soundboard and other panels on the piano, though these more longitudinal vibrations are less prominent in the onset sound, which carries the large portion of harmonic characteristics that influence the tonal colour of the sound. In 1977 Gabriel Weinrich, the innovative researcher of piano string vibration and honoured doctor of physics and acoustics, defined piano string vibration as two separate vibrations, the initial vertical or onset vibration, and the
subsequent more stable after-sound vibration. He describes the initial vibration as the ‘prompt sound, vertical polarisation’ and the second ‘after sound horizontal polarisation’.

……the vertical polarization is the primary one excited by the hammer, and so begins its life at a much higher amplitude than the horizontal one. However, since the bridge, which is attached to the soundboard, "gives" much more easily in the vertical than in the horizontal direction, the decay of the vertical mode is also much more rapid. As a result, the relatively slight amount of horizontal vibration becomes, after a while, dominant. ¹⁵²

All piano strings vibrate in the vertical plane immediately after being struck by the hammer, and rapidly move into an elliptical circular pattern of vibration for the majority of a long note’s duration.

The drop in level [of the initial decay of a piano string] would appear as a straight line if the decay of the sound were of a type called exponential, which is what a physicist would expect from a linear system such as the string and the soundboard. Instead, it is clear that the curve breaks into two portions of quite different decay rates. The initial portion, called "prompt sound," drops (in this case) at a rate of about 8 dB/sec; the final one, called "aftersound," at less than one-quarter that rate. As we shall see, the prompt sound is simply related to the theoretical decay rate determined by the string's coupling to the soundboard; whereas the after sound, which gives the piano its perceived sustaining power, represents the "miracle." ¹⁵³

Agreeing with Weinrich’s definition of two vibration polarities, professor Robert Anderssen of the CSIRO produced mathematical evidence of the prominent vertical string vibration caused by the Stuart bridge agraffe. In his The Challenge For the Piano Maker ¹⁵⁴ Anderssen bases his research on the findings of Gabriel Weinreich ¹⁵⁵, Richard Dain ¹⁵⁶, and Fletcher and Rossing ¹⁵⁷, stating it is the non-linear component of piano string vibration which provides the evidence. Anderssen made the observation that immediately after the string is struck by the hammer, the transition of the string from its vertically coupled rest point of the Stuart agraffe into its vertical oscillation is more efficient with less energy loss than and the transition from the horizontal pinned coupling of the modern piano string to its vertical oscillation.

Since the horizontal zig-zag clamp induces an energy exchange into a polarization orthogonal to the original polarization of the initial disturbance, as well as back into the vertical polarization, we would anticipate that the sustain would be different from that of the vertical zig-zag clamping on the Stuart & Sons pianos. In fact, as is clear from the [non-linear string equation], this complex energy exchange will affect the spacing between the eigenfrequencies, but in different ways, depending on the nature of the clamping. This prediction is consistent with the perceived stronger sustain of the notes on the Stuart & Sons piano as compared with traditional grand pianos [the modern piano]. ¹⁵⁸

¹⁵² Weinreich. The Coupled Motion Of Piano Strings.
¹⁵³ Weinreich. The Coupled Motion Of Piano Strings.
¹⁵⁴ Anderssen, The Challenge For the Piano Maker, 73.
¹⁵⁵ Weinreich. The Coupled Motion Of Piano Strings.
¹⁵⁶ Dain, 22.
¹⁵⁷ Fletcher & Rossing
¹⁵⁸ Anderssen, The Challenge For the Piano Maker, 73.
The eigenfrequencies Professor Anderssen refers to are the composite resonant frequencies within a sound, that in combination, make up the tonal quality of the sound. Eigenfrequencies are simple tones, or harmonics, described as partial frequencies of piano sound, because of their inharmonic nature.

A vibrating piano string simultaneously oscillates multiple modes of vibration, known as partials or overtones, which combine to produce the composite tonal sound of one note. The result is a superposition of sound waves, blended together into one complex wave. The frequency of the 1st harmonic, known as the fundamental, represents the repetition rate of the resulting complex vibration.\(^{159}\)

Prof. Anderssen reports here that the behaviour of the Stuart string vibration is different to that of the modern piano string vibration, and this also tells us that the tonal colour of the two will be different, because the characteristics of the partial frequencies in each of the string vibrations sounds will be different.

The current sound trajectory for the acoustic piano was laid down in that latter half of the 19th century with standardisation, and is based on variable string vibration modes produced by the pinned bridge.

Stuart writes,

\[\text{Stuart’s observations of string vibration behaviour and music composition over the past 150 years reveals that the vertical mode of vibration in sound behaviour has developed as the dominant factor in current sound behaviour aesthetics. The old pinned bridge favours an elliptical vibration mode whereas the Stuart agraffe favours the vertical mode.}^{160}\]

Changes in the direction of string vibration mode produces damping and variable tuning characteristics. This affects sustain, clarity, harmonic strength and development. The initial strike of the hammer produces a vertical ‘up and down’ motion which then changes to a more horizontal circular motion in the horizontal pinned bridge model. The Stuart agraffe maintains the initial strike in the vertical mode. As mode change and distortion is minimal the vibration is held in the same plane in which it is struck. It is claimed that the attack, sustain and harmonic transients of the Stuart piano tone are different because of this more controlled, vertical vibration mode.\(^{161}\)

Combining the information discussed above with what we actually hear in the sounds of the Stuart and the modern pianos, had illustrated to me that in all probability the Stuart string does actually vibrate in a different manner to the modern piano, and that analysing the vibration would be a thorough way of illustrating the tonal qualities of the Stuart piano sound. The difference in the string coupling is clearly visible inside the pianos, and the sounds of the instruments are audibly different. My enquiry into understanding the vertical nature of the Stuart piano string vibration continued by interviewing piano technicians who had experience in tuning and maintaining Stuart pianos. Interestingly, when the above information about the probability of an enhanced vertical vibration in the Stuart string was discussed, a sense of frustration in a few of the technicians’ responses was noticeable, in that they didn’t actually believe the vibration of the Stuart string could be more vertical than that of the modern piano string vibrations, and thought that this information was possibly a publicity beat up! Each of the technicians


\(^{160}\) Wayne Stuart, Email interview with author, 4th April, 2012.

\(^{161}\) Wayne Stuart, “Innovations In Piano”. 
admired the highly refined craftsmanship of Wayne Stuart observed in the materials, design and appearance of his pianos, though it was noticeable that the technicians who didn’t agree that the string vibration could be more vertical also expressed a personal dislike for the tonal qualities of the Stuart sound. Each technician agreed that if we could visualize the vibrations of both the Stuart and the modern piano strings, then that would help inform their understanding of the nature of the Stuart string vibrations.

Filming the String Vibrations

I then proceeded to film the string vibrations using the Stuart & Sons (M19 STU) and Steinway (STE) pianos (STE), described in chapter one. The bass piano string of the note C₂ 65.406 Hz was chosen to be the compared string vibration, because at 65 Hz, the vibrations are almost visible by the naked eye, and the timbre of the two pianos seemed closely matched in that register. A white mark was placed at an identical position on both strings and at a good visible angle for the video camera. A strobe light was deployed at a frequency that visually slowed the activity of the string vibration into a clearly visible contour, with the room darkened. This first attempt of filming the string vibrations became a useful exercise for realizing several additional conditions needed to be set up for the comparison to be clearly demonstrated.

i) the hammer needed to strike each piano string with exactly the same force

ii) the string needed to be visually filmed out of the piano, because the visual angle inside the piano was not clear enough for the camera to capture details of the string vibration,

iii) the camera needed to have the capability of slowing down the footage.

Fortunately, a team of specialists combined to produce the needed equipment:

i) Electronic engineer Peter Phillips constructed an electronic striker that could be precisely calibrated to various velocity key strikes.
ii) Wayne Stuart constructed a frame apparatus that housed both string types, Roslau and Paulello, each with their respective agraffe and pinned coupling, at the precise height to be stuck from underneath in the upward direction by a moveable piano hammer action, activated by a piano key. The apparatus also enabled clear sight lines of the string vibrations for detailed filming. Wayne Stuart supplied the moveable key-hammer action.

iii) Hideki Isoda, head of the audio and visual technological department at the Sydney Conservatorium of Music filmed the strings on a Sony PMW EX1R XDCAM EX Full HD Memory Camcoder, with the capability of slowing the footage down.

The movie clip below was shot by the Sony PMW EX1R XDCAM EX Full HD Memory Camcoder camera, and slowed down in the replay. As we had only one striker, this video is cleverly edited to show both string reactions simultaneously. The footage illustrates the behaviour of the Roslau-Steinway, copper wound string on the left side, the Paulello-Stuart stainless steel wound string on the right side, as they are struck with the same force, at midi calibration 81 ff.

To watch the String Vibration Test movie clip double click on: String Vibration test .mov.

String Vibration Test – A.V. recording file: String Vibration test .mov  USB Audio 2: File1

String Vibration Footage :Hideki Isda A.V. table  2.1

Observations:
The Stuart-Paulello string moves in a more controlled manner than the Roslau-Steinway string. At the initial strike, or onset, the Stuart string does appear to move further and more frequently in the up-down
direction though it is not completely clear. After 12 seconds, the movements of the strings are distinctly different. The Stuart-Paulello string exhibits a more controlled movement with less variation of direction than the Roslau-Steinway string. The filming exercise was a great success in illustrating the contrasting string vibrations, and confirmed that the coupling affected the vibration. The Stuart agraffe does appear to be controlling the string vibration.

The precise behaviour of the string oscillation when struck by various levels of force was tested and measured by Peter Phillips. Using the same string apparatus and electronic striker, Phillips assembled electrical sensors and positioned the sensors very close to the strings to record the exact vertical and horizontal vibrational movement of both strings, as they oscillated after being struck by various levels of force, by the electric striker.

This research is influenced by Gabriel Weinreich’s study *Coupled Piano Strings*, which established evidence for the actuality of two polarizations in the piano string motion, vertical and horizontal, with respective decay rates. Weinreich constructed a vibration probe for piano strings which recorded the two independent projections of the string’s motion.\(^{162}\)

Peter Phillip’s sensor contacts, pictured above, are positioned so that they contact the string when the string reaches a certain distance in both vertical and horizontal directions. The sensors are connected to an oscilloscope, which is set to the periodic time frame of the fundamental… 65.406 Hz. Vertical lines are spaced at the period of the fundamental wave form on the oscilloscope, so when each the string vibration is recorded, the measurement of the vibration contour and the cyclic temporal segment of the waveform are lined up in the oscilloscope’s recording of the string movement.\(^{163}\)

**Four String Vibration Tests.**

Four tests were conducted to precisely measure the horizontal and vertical vibrations of both strings. As observed in the string vibration video on the previous page, the string oscillates in a predominantly vertical, up-down direction immediately after the hammer strike, the onset.

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\(^{162}\) Weinreich, *The Coupled Motion Of Piano Strings*.

\(^{163}\) See Appendix 2, for detailed illustrations of the oscilloscope illustrations of the string vibrations.
Phillip’s sensors recorded the magnitudes of the vertical and horizontal excursions of the string oscillations in four tests using varied velocity ranges of the electronic striker.

**Test 1. The magnitude of the vertical oscillation in each string-**
Result: the Stuart/Paulello string vertical excursions in the oscillation were 2mm larger.

**Test 2. The duration of the vertical oscillation in each string-**
Result: the duration period of the Stuart/Paulello vertical excursions was longer.
Approximately 160ms longer.

**Test 3. The magnitude of the horizontal oscillation in each string-**
Result: the horizontal excursion in the oscillation of the Steinway/Roslau string was larger.

**Test 4. The duration of the vertical oscillation from the onset, to the beginning of the predominantly horizontal oscillation.** With no horizontal oscillation.
Result: The vertical oscillation of the Stuart/Paulello string extended for 400ms longer than the Steinway/Roslau oscillation, before the occurrence of the predominantly horizontal oscillation ensued. The horizontal vibration began earlier in the Steinway string oscillations.

**Summary of the String Vibration tests**

The Stuart string has a greater tendency to oscillate vertically, and a lesser tendency to oscillate horizontally compared to the Steinway string. Its oscillations resolve into a narrow elliptical pattern, where the Steinway string resolves into a much wider elliptical pattern. Furthermore the Steinway string begins horizontal motion much sooner in the cycle than the Stuart string. 

Peter Phillip’s tests findings confirmed that the Stuart and Steinway bridge coupling each influenced distinctive string vibrations. In the initial stages of the oscillation, the onset period immediately after the hammer strikes the string, the Stuart-Paulello string was found to vibrate for a longer period in the vertical plane and with larger amplitudes than the Steinway-Roslau string. The Steinway-Roslau string was found to establish its elliptical vibration sooner than the Stuart string. In the after-sound oscillation period following the onset, the Stuart string did not oscillate in the horizontal elliptical direction as broadly as the Steinway string. Peter Phillip’s findings support the visual illustration of the slow motion video, where the Stuart string appears to maintain a tighter, more consistent vibration than the Steinway. The fourth test found that the Stuart-Paulello string produced a predominantly vertical oscillation for 400ms longer duration than the Steinway-Roslau string.

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164 Weinreich. The Coupled Motion Of Piano Strings.
165 Vibration Test – see Appendix 2. Peter Phillips details and procedures of the above tests are illustrated in Appendix 2
The research has found that the string vibration of the Stuart piano sound is significantly different to the modern piano. The overall research objective of understanding the tonal characteristics of the Stuart & Sons piano sound has been well served by these preliminary conclusions about the influenced of the Stuart bridge agraffe has on the oscillation of the string. In response to Wayne Stuart’s comments about the string vibration tests above\textsuperscript{166}, the characteristics of the attack, sustain and decay transients within the Stuart piano sound will be investigated in the following chapters 3 & 4, with the expectation to visually and aurally illustrate the effects of the longer more pronounced vertical vibration and reduced damping of the Stuart piano string vibration, with an audibly more stable inner tonal balance.

\textsuperscript{166} Appendix 2.- Wayne Stuart’s comments on the String Vibration tests.

Vibrations and Partial Tones

The distinctive and dynamic characteristics of the Stuart piano sound are identified in the following chapters by visualising and listening to the harmonic makeup its soundscape. The musical shapes and colours of piano sound are explored by examining the waveforms and vibrations that combine to create the sound. The elements of piano tone description, amplitude, attack, sustain and decay are described in terms of their transient levels over time, as piano sound is in a constant state of transition. The hammer strike excites the string into its full spectra of sound after which the string’s oscillation and sound spectra gradually diminishes.

No stationary state is created for the piano sound, since there is no uniform continuous excitation. Nevertheless, quasi-stationary conditions can be assumed as an approximation at least for short durations. As a result, spectra of partials can certainly be used for the tonal description of the sound during its initial phases, however the time structure, and above all the decay behavior play a much more important role than in string and wind instruments.\footnote{Jürgen Meyer, \textit{Acoustics and the Performance of Music}. (Frankfurt: Springer 2009) \textsuperscript{116}.}

In this chapter I explore definitions of tone quality and explain how I have identified tonal characteristics of the Stuart sound.

Throughout this research I compare the sounds of the Stuart concert piano (M19,STU) to the sounds of the Steinway concert D (STE)\footnote{The Pianos in Comparison - see chapter 1.} as a method for identifying the new and distinctive sounds of the Stuart soundscape. The Steinway D provides a ‘control’ of the tonal qualities produced by the modern piano.\footnote{see “Modern Piano,” p.17.} When the sounds of both pianos are heard in the same room, it is audibly clear that fundamental attributes of the Stuart soundscape are different to those produced by the Steinway. The audio samples below demonstrate the sounds of both pianos, of the note C\textsubscript{5} 523.23Hz.

The sounds of the Stuart and Steinway pianos were obtained for evaluation by recording the pianos in a controlled acoustic sound field. From a thorough examination of approximately 96 recorded tones, I identified four distinctive characteristics in the sound of the Stuart piano that differ to the sound of the modern piano:

i) A slower rate of decay in the fundamental partial frequency

ii) An earlier transition into the after-sound states of string oscillation.

\begin{tabular}{|c|c|}
\hline
Stuart 2.9m 2002 No 19 & Steinway D 2005 No 574500 \\
\hline
C5 523.25 Hz USB audio 3: trk 1 & C5 523.25Hz USB audio 3: trk.2 \\
C5 v54 STU _ MW_mxd array.wav & C5 v54 STE MW mxd array.wav \\
C5v54 MW mixed array. Sound table 3.1 & \\
\hline
\end{tabular}
iii) A wider harmonic spectrum in the onset state of the sound,
iv) A more comprehensive projection of sound to 6 metres.

Detailed descriptions of the four characteristics are presented and illustrated in chapter four, *Qualities of the Stuart Piano Sound*. The terminology, processes and methods used to identify the characteristics are discussed in this chapter.

Comparative data sets of Stuart and Steinway sounds were compiled and analysed to test Wayne Stuart’s claim that the Stuart sound has a greater clarity, sustain, and an expanded dynamic range. The evaluations of piano tone began by examining each sound in two entities, partial tones and composite tones.

**Partial Tones**

Partial tones are also described as partial frequencies, simple tones, pure tones, partials, upper partials, sinusoidal, eigenfrequencies, harmonics, overtones and modes of vibration. These tones are of a single frequency, not of strong individual audible sound, they combine to make up the harmonic structure and subsequent tonal colour of the composite tone, heard as the piano note sound. They are numbered as Fundamental, 2\textsuperscript{nd} partial, 3\textsuperscript{rd} partial, 4\textsuperscript{th} partial... etc. Sounds that are different in tonal colour are found to have different amplitudes of partial tones.

Tone quality, or timbre, is indicated by the spectrum of simple tones, harmonics or overtones, contained within one complex musical tone. Timbre [also] depends strongly on envelope: on how the sound varies over time.

The fundamental’s frequency determines the frequency of the complex tone. For this reason partial frequencies are proportionally related to their fundamental frequency.

\[
\text{for the largest portion of the piano sounds, the fundamentals of the partial spectra dominate. Only in the two lowest octaves of the tonal range, the intensity maximum is shifted to overtones in the frequency range of about 100–250 Hz.}\]

The relative proportion with which each overtone intervenes in the resulting vibration determines to a great extent the particular character, quality or timbre of the generated tone. The pitch of the string’s complex tone is determined by the fundamental frequency.

Aside from the fact that tone color naturally changes over the tonal range of an instrument, as determined by the location of the fundamental, it can be said in general, that a tonal impression is brighter, and possibly

---

170 See Wayne Stuart’s claims : pages 17 & 51.
174 2 Roederer,118.
sharper, as richness in overtones increases (in view of the frequency range and the intensity of the upper frequency components) (von Bismarck, 1974). For low tones, rich in overtones, the dense partial sequence in the upper frequency region leads to a rough character. This effect can occur for tones from the 3rd octave upward. While, for example, for G3, overtones above 2,000 Hz effect a roughness, the corresponding limit for G1 already lies at about 500 Hz (Terhardt, 1974). In contrast, overtone-poor sounds have a tendency for dark or soft timbre.

The harmonic series orders the particular series of partial frequencies of a composite tone. They are numbered similarly to the harmonic series though a composite tone does not necessarily contain each partial of a harmonic series. An illustration of the harmonic series starting at a fundamental frequency is therefore a useful model when analysing the interactions of particular upper partials (prt.) above the pitch of fundamental frequency (Fnd.) within a composite tone. The intervallic description i.e. P5-perfect 5th, M3-major 3rd denote the distance of pitch above the fundamental pitch. These intervallic descriptions are useful for identifying a particular partial tone aurally.

The partial frequencies in piano notes are not as perfectly harmonic as in figure 3.1, that is, not an exact whole-number frequency relationship to the fundamental frequency. Due to adjustments of temperament, the stiffness of high tension steel wire, the movement between horizontal and vertical vibrational plane of piano strings, and the impedance qualities of the wooden bridge, the inharmonicity of partial tones is an accepted ingredient of the piano tonal spectra. This was proven by Fletcher and Blackham in their well documented experiment conducted at Brigham University in the 1960s. The harmonic partial frequencies for each of the notes examined in this research are presented in table 3.1.  

---


Ernst Terhardt, *On the Perception of Periodic Sound fluctuations (Roughness)*, Acta Acustica united with Acustica, 30 (4), (April, 1974); 201-213.


The evidences of tonal difference which defined the characteristics of the Stuart piano sound were established in this research by evaluating the transient qualities found in the partial tones of each piano tone.

**Composite Tones**

Composite tones also described as complex tones, are the superposition of the partial tones related by the resonance and frequency of the fundamental tone. A composite tone is perceived as an instrumental tone, shaped in its composite complexity by the dimensions of the vibrating system or instrument.

A vibrating piano string simultaneously oscillates multiple modes of vibration, known as partials or overtones, which combine to produce the composite tonal sound of one note. The result is a superposition of sound waves, blended together into one complex wave. The frequency of the 1st harmonic, known as the fundamental, represents the repetition rate of the resulting complex vibration.\(^{180}\)

In his treatise, *On The Sensations of Tone*, acoustic physicist Herman Helmholtz described a musical tone as a complex periodic vibration which consists of a series of partial tones he names as ‘upper partials’, all governed by the same periodic vibration, that of the fundamental partial tone, or the *prime*. He surmises musical tones as being dependent on three elements, force, pitch and quality.

\[
\text{............... we found that difference in the quality of musical tones must depend on the the vibration of the air. The reasons for the assertion were only negative. We had seen that force depended on amplitude, and pitch on rapidity of vibration: nothing else was left to distinguish quality but vibrational form. We then preceded to show that the existence and force of upper partials tones which accompanied the prime depend also on the vibrational form, and hence we could not but conclude that musical tones of the same quality [timbre] would also exhibit the same combination of partials, seeing that the peculiar vibrational form which excites in the ear the sensation of a certain quality of tone, must always evoke the sensation of its corresponding upper partials.}^{181}\]

Helmholtz also suggests that it is not only the compound musical note we are hearing, but collectively with it the sympathetic resonant oscillations within the instrument which combine to produce the qualities of the sound. This is a relevant observation for piano sound, as many sections of the resonating system of the piano vibrate in sympathy. The sustain pedal is ‘on’ for the piano sounds tested in this study, so the sound is representative of the whole resonating system. This includes the vibrations of strings that are not struck by the hammer. These unstruck strings are said to vibrate in sympathy, in a syntonic vibration.

\[
\text{When one resonant object is caused to vibrate, any other resonant object in its vicinity which has the same natural frequency will also vibrate; two bodies need not be touching, since vibration is passed on through such media as air. For example, if a tuning fork is sounding in air and a second tuning fork of identical frequency is placed close to it; then the second fork will begin to vibrate ‘in sympathy’.}^{182}\]
Timbre, sound quality, tonal colour

The perception of tonal quality, or timbre of piano sound is a central focus of this research. The sonic elements that determine tone have been identified as partial tones in the previous pages. J. Meyer has deduced generally that a brighter tone will consist of prominent upper partials, and a darker tone will consist of less upper partials. A description of sound quality is also influenced by the subjective contexts and experiences of the describer. This research uses a comparison of two piano sounds to ‘control’ the boundaries of tonal description, for example, one piano sound could be described as sounding ‘brighter’ in tone than the other. In chapter five the discussion about the tonal characteristics of these two instruments is opened up to the perceptions of over 300 audience members.

I define timbre as a temporal collective sensation of sound that is formed by specific combinations of frequency, loudness and harmonic content.

Our ear has the inbuilt capacity to decipher the details of superpositions of simple tones that combine to produce the complex tone. The basilar membrane in the human ear has a designated “resonance region” for each pure tone of a given frequency.\textsuperscript{183}

Since a complex tone vibration is entirely equivalent to the summation of pure tones of harmonically related frequencies, then, depending on which overtones are present, more than one part of the basilar membrane will respond at the same time. The cochlea therefore performs a kind of harmonic analysis… The message it sends to the brain consists of a number of electrical signals along different fibres of the auditory nerve, one for each overtone.\textsuperscript{184}

The following definitions of the timbre, were influential in the tonal evaluations I have made in this research:

- Sound "quality" or "timbre" describes those characteristics of sound which allow the ear to distinguish sounds which have the same pitch and loudness. Timbre is mainly determined by the harmonic content of a sound and the dynamic characteristics of the sound such as vibrato and the attack-decay envelope of the sound.\textsuperscript{185}

- The relative proportion with which each overtone intervenes in the resulting vibration determines to a great extent the particular character, quality or timbre of the generated tone.\textsuperscript{186}

- Timbre depends strongly on envelope: on how the sound varies over time.\textsuperscript{187}

The temporal envelope of an instrumental sound, including attack, decay and modulation of the steady-state portion [sustain], influences the perceived timbre to such an extent that changes on any of them can make the sound of an instrument unrecognizable.\textsuperscript{188}

\textsuperscript{183} Roederer, 31.
\textsuperscript{184} Johnston, Measured Tones, 244.
\textsuperscript{186} Roederer, 118.
Visualising Modes of Vibration

In the early years of the 19th century, the French mathematician Jean-Baptiste-Joseph Fourier presented a realization about the composite nature of the partial tones, or modes of vibration in a composite sound.

Any periodic vibration however complicated can be represented as the superimposition of pure harmonic vibrations, whose fundamental frequency is given by the repetition rate of the periodic vibration.  

Fourier came to the conclusion that the vibrations of sound and their subsequent harmonics and overtones are mathematically related by the fundamental vibration or prime tone.

Fourier discovered that individual sinusoidal waves illustrated the qualities of each partial tone within the whole composite tone. This discovery established that it is the interaction between the fundamental tone and its upper harmonic partial tones that produces the quality and tonal colour of sound. The Fourier Theory of harmonic analysis has subsequently established a method for the analysis of how partial tones interact within a sound. ‘Fast Fourier Transform’ (FFT) is a computerized application of the Fourier Theory, which presents a visual illustration of the qualities of each partial frequency. The rates of decay are visually plotted in both loudness (dB) and duration (ms), dB/ms. This visualised graphic array illustrates the transient elements of the harmonic spectrum of the sound over time in spectrograms and decay curves. To visually display and examine the differences in the sound qualities of the Stuart and Steinway pianos, I have used the computer software ‘Fuzzmeasure Pro 3’ which implements F.F.T. to produce illustrations of the piano sounds.

The spectrograms below, Spectrogram 3.1 of the note C₂ 65.406 Hz is produced by Fuzzmeasure Pro 3.2. The Stuart piano sound (left) and the Steinway piano sound (right) are illustrated by the amplitudes, frequencies and decay rates of their partial frequencies. The notes C₂ were struck at velocity 81, ff by the calibrated key striker.
The dynamic transients of loudness (dB), are measured by the vertical axis, and the frequency (Hz) by the horizontal axis. The 3rd axis is a measure of time, milli seconds (ms). This 3rd axis provides a view of the transient nature of the sound as it decays from the rear of the graph to the front. Spectrogram 3.1 plots the sound for a duration of 58s or 58,000 ms, and shows that the Stuart sound decayed at a slower rate than the Steinway in the fundamental frequency (Fnd.), and the 3rd, 4th & 5th partial frequencies (prt.).

The decay rate dB/ms of the composite tone of the both piano sounds is analysed in decay graphs throughout this research. Decay Graph 3.1 below exhibits three plotted states of decay for each of the sounds. i) onset; ii) unsettled after-sound; iii) settled after-sound. This decay graph shows that the Stuart sound (red) has decayed at a slightly faster rate than Steinway (blue) in the onset state of .5s, and at a slower rate than Steinway in both the after-sound states. The significant difference in the sounds occurs in the 3s unsettled after-sound state between 2.2s– 5.2s. The Stuart sound appears to have arrived into its settled after-sound oscillation earlier than Steinway.

The earlier establishment of the settled oscillation state in the Stuart sound illustrated above, is a characteristic observed in many of the Stuart sounds, and is one of four characteristics listed in the opening pages of this chapter. These four qualities of the Stuart piano sound are examined in detail in the following chapter ‘Qualities of the Stuart & Sons Sound.’
Throughout chapter four the illustrated piano sounds are accompanied with audio .wav files, listed in the audio tables. The audio of these sounds is accessed from an accompanying USB drive. The specific sounds of C2v81 mic2, of the Stuart piano (STU) and the Steinway piano (STE) are found in the USB Audio folder: 4.1 , tracks No 15 & 16.

<table>
<thead>
<tr>
<th>Stuart</th>
<th>USB Audio 4.1: trk.15 C2v81 STU MW mic 2.wav</th>
<th>Steinway Audio 4.1: trk.16 C2v81 STE MW mic 2.wav</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound table 3.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Attack, Sustain and Decay - Transient Attributes of Piano Sound.**

The attack, sustain and decay transients are transitional measures of the attributes of sound. These attributes combine to form particular envelopes of sound which are described in terms of their transient level at particular time plots of the sound’s duration. The transient value, as opposed to the steady state of a sound, simply indicates that the value is not a fixed value, due to the continuing decay of the piano sound.

The typical order of events in the sound envelope sequence attack- sustain-decay is appropriated to piano sound description, though the plotted transient value of sustain is not explored in detail in this study. A sound that is described as having ‘more sustain’, in this study is a description of a sound with a slower rate of decay.

**Attack**

The hammer strike excitation makes the string vibrate in a vertical plane, creating a vertical vibrational force that is transmitted at its maximum amplitude through the bridge of the soundboard.

As the string is stuck, or excited by the hammer, the string vibration does not immediately oscillate at its maximum amplitude. The time it takes to reach the full oscillation, or the build-up is known as the onset transient or the attack transient, measured in milliseconds (ms). In most of the sounds examined in this study, the attack transient is audibly faster than in the Steinway sound.

The full spectrum of the piano sound is heard before any partial tones begin to decay. In many of the piano sounds examined, the full spectrum of the Stuart sound consistently arrived earlier than the full spectrum of the Steinway sound. This often seemed to produce a more percussive and bright sounding onset.

The onset of a tone is a most important attribute for timbre and tone identification. During this transient period, the processing mechanism in our brains seems able to lock in on certain characteristic features of each instrument’s vibration pattern and to keep track of these features even if they are garbled and blurred by the signal from the other instrument.
The piano sounds examined in this study have revealed a faster arrival to the maximum amplitude in the Stuart sound than the Steinway sound. In spectrograms 3.2 & 3.3, (below) the 2nd partial of the Stuart sound sounded at its maximum amplitude (dB) earlier in the time plot (3rd axis) than the 2nd prt. of the Steinway sound. The fundamental of C3v20 STE mic3 also peaked at its maximum amplitude (dB) later than the Fnd. in the Stuart piano sound.

A brighter tone colour is heard in the attack of the Stuart sound of C3v20STU MW mic3. There is also a deeper stable presence of the lower frequencies.

In the sound of C4v81 mic1 illustrated above in Spectrogram 3.3, the 2nd prt. is audibly clearer in the Stuart piano sound in the first 3s of the audio sample. Generally the sound of the Stuart is brighter in the onset-attack period.
We can say that the attack transient is faster in the Stuart sounds than the Steinway sounds in both the sounds illustrated above, and that it is the onset transient of the 2\textsuperscript{nd} partial that produces the distinctive quality in the Stuart tone.

The attack transient is significantly distinctive in the Stuart piano sound. As previously mentioned, it is in the onset time period of the sound where the most distinctive difference in the piano tones occurs. Because of the vertically positioned rest point of the Stuart string\footnote{see chapter 2.} the onset sound of the Stuart is very different to the Steinway onset sound, and beckons a detailed study of its attack transients. A study of the action speed, and the hammer densities, and hammer shank densities in comparison to the modern piano would be interesting. This study has not produced clear evidence of the Stuart keyboard action speed and hammer densities. Hopefully this will be completed in the near future. As Benade’s description below makes clear, the attack of a sound is extremely complex, containing frequencies that do not belong to the periodic musical category of sound.

When one starts to drive a system of springs and masses at any frequency, there is an initial transient which is enormously complicated, since it is made up of the already complex transient motions belonging to each separate mode of oscillation. We therefore have present in the vibrational recipe not only the driving frequency but also the (decaying) complete collection of characteristic frequencies, exactly as in the case of impulsive excitation. Once the [attack] transient has died out, all parts of the system will settle down into a steady oscillation at exactly the driving frequency.\footnote{Arthur Benade, \textit{Fundamentals of Musical Acoustics}, (New York: Dover Publications INC., 1976), \textsection165.}

Wayne Stuart suggests the correct measure of sustain in piano sound is the measure of duration from the first maximum amplitude peak to the last maximum amplitude peak, before the decay of the sound begins. My efforts in obtaining this value using Pro Tools software did not produce clear results.

The sustain portion of the sound, is the steady state [rate] to which the sound decays after a time determined by the decay parameters.\footnote{William Sethares, \textit{Tuning, Timbre, Spectrum, Scale}. (Heidelberg, New York Springer-Verlag,1998), 30.}

A period during which the loudness varies little, called the sustain.\footnote{\textquoteleft\textquoteleftWolfe, J. "Timbre and envelope," (Accessed 10 April 2015)}

A sound that is described as having ‘more sustain’ in this study is a description of a sound that is decaying at a significantly slower rate than the sound it is being compared to. An example of a piano sound with ‘more sustain’ was observed in the sound C5v54 mic 1.
The spectrogram of this sound is graphically illustrated in chapter 4, Spectrogram 4.9, C5v54 MW mic1. The partial frequencies in the Stuart sound of the note C5v54 appear to have decayed at a slower rate than the Steinway sound. The 2\textsuperscript{nd} partial of the Stuart sound has a greater amplitude than the 2\textsuperscript{nd} part. of the Steinway sound.

It is audibly clear when listening to the comparison of the tones, that the Stuart sound is sustained more than the Steinway particularly at 5s, when the Steinway sound is decaying at a faster rate. The Stuart sound is observed here to be in a comparatively steady state in the after-sound.

Decay

Decay is the rate of decrease in the amplitude or size of the vibration. Decay of a piano string is a compound decay of two distinct transient measures. The onset decay is the initial and a faster decay which occurs within the first second of the sound as a reaction to the hammer strike. When the hammer strikes, the string vibrates in a vertical plane, creating a vertical vibrational force that is transmitted at its maximum amplitude through the bridge of the soundboard. This onset oscillation decays at a rapid rate till the oscillation settles into its elliptical oscillation, usually within the first second of time, which establishes the second considerably slower rate of decay that Gabriel Weinreich describes as ‘after-sound.’\textsuperscript{200} Multiple strings vibrating in-phase are characteristic of the onset decay and strings vibrating out-of-phase are associated with the slower after-sound decay.\textsuperscript{201} The low impedance of the bridge wood is associated with the fast travel of the onset decay, and the high impedance of the soundboard is associated with the slower travel of the after sound decay.\textsuperscript{202}

The findings of this enquiry presented in chapter four, establish four distinguishing characteristics of the Stuart sound. Each of these characteristics are found in the onset and after-sound states of oscillation of the piano string vibration. The after-sound is the state of the sound that follows or continues from the initial attack or onset of the sound. Piano sound physicians, Gabriel Weinreich,\textsuperscript{203} A.Benade\textsuperscript{204} and Greated & Campbell,\textsuperscript{205} agree that piano sound is characterised by two distinct rates of decay which coincide with two states of string oscillation. The first oscillation state the onset, is characterised by the initial faster decay of the attack transient, which is a measure of three elements combined, the frequency of the driving force, the frequency of the oscillation and the abrupt disturbance of the hammer strike. The second state of oscillation, the after-sound, has a slower rate of

\begin{tabular}{|c|c|}
\hline
Stuart & USB Audio 3: trk 9 C5v54 STU MW Mic1.wav \\
\hline
Steinway & USB Audio 3: trk 10 C5v54 STE MW mic1.wav \\
\hline
\end{tabular}
decay and reduced amplitudes of partials. In the after-sound state, the string oscillates in a more settled steady vibration, a steady state.

This study found that in many sounds, there appeared to be other transitional states of decay between the onset attack and the steady settled after-sound, which defined significant differences in the Stuart and Steinway rates of decay. This state has been named, ‘after-sound unsettled’, as it occurs after the onset attack, though shows a higher rate of decay than its steady oscillation which follows. So three transitional states of oscillation and rates of decay are identified throughout the findings in chapter 4: i) Initial Onset; ii) After-sound unsettled; iii) After-sound settled. The three states of oscillation are indicated by three rates of decay illustrated in the decay curve 3.2 below.

The volume of the Steinway in this sound is 3 dB louder than the Stuart sound. Often the partial frequencies with larger amplitudes in the onset state will decay faster in that period, as the Steinway does here. The Stuart sound arrives at its settled after-sound oscillation (iii) earlier than Steinway (iii).

Other terminologies used to describe these rates of decay are, ‘Initial Transient’ and ‘Steady Oscillation’ and dual decay rates - ‘Initial rapid, and decreased’ and ‘prompt’ and ‘after-sound.’

Damped Oscillation

The vibrating piano string oscillates in damped oscillation. How the piano is designed establishes the elements of damping. String coupling and the impedance ratios of the strings to soundboard are elements of damping that restrict or control the amplitude and tonal colour of the periodic vibrations over time. Almost immediately after the initial disturbance or excitation of the hammer strike, within .5s, the maximum oscillation amplitude is reached. Subsequently a rapid decrease in amplitude follows, which is associated with the impetus of the vibrating string and soundboard to return back to their rest positions. The rates of decay of each partial tone in both the wood of the bridge, the soundboard and the steel wire of the piano string collectively influences the tonal colour of piano sound.

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206 Weinreich.
207 Campbell & Greated.
208 Weinreich.
209 Roederer, 79.
210 Roederer, 118.
Although the hammer is meant to impart only vertical motion in the string of a grand piano, eventually horizontal motion also occurs. Horizontal motion is less damped over time because its motion is less coupled to the piano bridge and, ergo, soundboard.\textsuperscript{211}The coupling of the Stuart piano string by the bridge agraffe fastens the string in an up-down vertical plane. When the hammer strikes the string in the vertical up direction, the Stuart string oscillates reduced levels of damping in comparison to the Steinway string. This is because the Steinway string is pinned to the bridge in a horizontal plane, and will not enter into its vertical oscillation as easily as the Stuart string.

A vibrating system whose amplitude decreases in this way is said to be damped, and the rate of decrease is the damping constant.\textsuperscript{212} If the oscillator is heavily damped, the transient motion decays rapidly, and the oscillator quickly settles into its steady-state motion. If the damping is small, however, the transient behaviour may continue for many cycles of oscillation.\textsuperscript{213}

Onset - reduced damping

In the tests conducted in chapter two on the influences of coupling on vibration, the initial vertical oscillation of the Stuart string was found to be significantly larger than the Steinway’s. In this instance we established proof that the Stuart string was vibrating in a mode of reduced damping. The decay curves and spectrograms illustrated in chapter four, reveal that the majority of Stuart oscillations examined lose more energy than the Steinway oscillations in the initial .5s onset state, shown by steeper decay and amplitude curves. The majority of Stuart sounds produced higher amplitudes in this onset period. Given that each sound is struck with the same calibrated force, this also provides evidence of reduced damping in the Stuart coupling set up, the bridge agraffe.

After-sound – reduced damping

The decay curves and spectrograms illustrated in chapter four show the majority of Stuart sounds arrive at the settled after-sound period of oscillation earlier than Steinway. The string vibration tests in chapter 2, confirmed that the Stuart string maintained less of a horizontal vibration in its after-sound oscillation than Steinway. This shows the Stuart string vibration experienced less change in its overall vibration contour than Steinway. At the change of vibration mode from the vertical oscillation to its less-horizontal\textsuperscript{214} elliptical oscillation, it was found that the Stuart string lost less energy than the Steinway string. Subsequently the rate of decay of the Stuart sound in its after-sound state, is observed to be slower and the audible perception is one of a sound with more sustain.


\textsuperscript{212} Thomas Rossing, Moore, R. Wheeler, P. *The Science of Sound*, 3rd Ed. (USA: Addison-Wesley, 2001), 25.

\textsuperscript{213} 'Fletcher & Rossing', 21.

\textsuperscript{214} ‘less horizontal’ in comparison to the Steinway string oscillation
The complimentary objectives and outcomes produced by the unconnected tests in chapter two and chapter four supports the following statement by Wayne Stuart regarding the reduced amount of energy loss, or damping in the Stuart string vibration.

No change can contribute to a greater motion and quicker loss [as you indicate but] the lack of subsequent changes in mode ultimately reduces the overall loss in comparison to the ever changing back and forth motions of the pinned bridge scenario.\(^{215}\)

**Recording Stuart and Steinway Piano Tones**

The amplitudes or maximum value of oscillatory disturbance\(^{216}\) of the vibrations of piano tone were measured in three locations of sound activity:

i) the room, as radiated sound via a microphone array,

ii) the instrument as the power source: a sound level meter (SLM) microphone positioned 10cm above the hammer strike of the string.

iii) the soundboard – the oscillating muscle, via four piezo electric disk probes, positioned on the soundboard.

The design differences of the Stuart and Steinway pianos, which are associated with these tests:

i) Piano string attachment coupling to the soundboard, which affects the string vibration contour,

ii) String mass, length and tension.

iii) Sound board stiffness, mass and thickness.

**Qualities of tone linked with elements of design.**

The components of piano design that were observed to have influenced the qualities of tone were:

- soundboard stiffness;
- string material;
- string tension;
- string length;
- down bearing;
- horizontal pinned string coupling at the bridge;
- vertical agraffe coupling at the bridge.

See chapter 1 for the detailed dimensions of the specific Stuart and Steinway pianos examined by this research.

\(^{215}\) Wayne Stuart, “Decay and Damping” email interview with author, 22\(^{nd}\) June ,2014.

\(^{216}\) Benade,174.
Measuring Sound Pressure Radiation: Microphone Arrays

The Stuart and Steinway pianos described in chapter 1 were recorded in a controlled sound field created by an array of eight microphones.

Describing a sound field by specifying sound pressure levels for a number of points in a room represents a viewpoint oriented toward the listeners, or recording devices at those points.\(^{217}\)

The microphone positions in a 180° array defined the sound field, see fig. 3.2 below. It was found that the direction in which the sound radiated from the pianos affected the qualities of its tone and it loudness. For example, the tonal quality and sound pressure level of a piano note recorded at microphone 6 (mic6) could be found to be different to the same recorded note at microphone 2 (mic2). The evaluation of the amplitude levels and the direction of its strongest (loudest) and weakest (softest) radiated qualities was also made possible in the 180° microphone array. The direction and projection of the radiated sounds of each piano was found to be noticeably different and therefore was considered to be a consequence of piano design.

\(^{217}\) Meyer, 3.
Microphone Array (MW) Music Workshop Theatre, Stuart piano pictured.

Microphone Array MW (Music Workshop Theatre) Stuart piano pictured. Photos 3.1 Kevin Hunt
The sounds of four notes struck at 3 velocity strikes, was produced by the calibrated electronic striker used in the string vibration tests in chapter 2. The table below illustrates how each sound is coded, denoting the durations in seconds (s). The notes were sounded undamped till the sound died out, so their durations (s) were measured by the longest sounding of the note. The faster the velocity strike (v), results in a louder and longer note and notes with a lower frequency (Hz), will have a longer duration. Start times of the each sound were equalised using Pro Tools 10, for an equal measure of rates of decay and attack. 20 Hz and below was filtered out by a high pass filter in Pro Tools 10, to help eliminate extra low frequency room noise. The key numbers are different because the STU pianos have 97 keys and the STE piano has 88 keys.

<table>
<thead>
<tr>
<th>Note name</th>
<th>Abr. Piano Name</th>
<th>Key No</th>
<th>Hz frequency</th>
<th>3 velocity strikes</th>
<th>Note label example</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₂</td>
<td>C2 STE</td>
<td>16</td>
<td>65.406 Hz</td>
<td>v20;v54;v81</td>
<td>C2 STE v81 58s</td>
</tr>
<tr>
<td></td>
<td>C2 M19 (STU)</td>
<td>20</td>
<td>65.406 Hz</td>
<td>v20;v54;v81</td>
<td>C2 M19 (STU) v54 58s</td>
</tr>
<tr>
<td>C₃</td>
<td>C3 STE</td>
<td>28</td>
<td>130.81 Hz</td>
<td>v20;v54;v81</td>
<td>C3 STE v2032s</td>
</tr>
<tr>
<td></td>
<td>C3 M19 (STU)</td>
<td>32</td>
<td>130.81 Hz</td>
<td>v20;v54;v81</td>
<td>C3 M19 (STU) v81 46s</td>
</tr>
<tr>
<td>C₄</td>
<td>C4 STE</td>
<td>40</td>
<td>261.63 Hz</td>
<td>v20;v54;v81</td>
<td>C4 STE v54 28s</td>
</tr>
<tr>
<td></td>
<td>C4 M19 (STU)</td>
<td>44</td>
<td>261.63 Hz</td>
<td>v20;v54;v81</td>
<td>C4 M19 (STU) v20 35s</td>
</tr>
<tr>
<td>C₅</td>
<td>C5 STE</td>
<td>52</td>
<td>523.25 Hz</td>
<td>v20;v54;v81</td>
<td>C5 STE v81 40s</td>
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<td></td>
<td>C5 M19 (STU)</td>
<td>56</td>
<td>523.25 Hz</td>
<td>v20;v54;v81</td>
<td>C5 M19 (STU)</td>
</tr>
</tbody>
</table>

Note Coding Table 3.2

DPA 406 omni microphones, each calibrated at 94dB, were positioned around the pianos at equal angles and distance of 3 or 6 metres from a designated point on each piano frame and cabinet, to create the sound fields. The microphone arrays were used to pinpoint the directivity of the piano sound. The direction of the radiated sound from the piano was noticeably different in the two pianos and therefore was considered to be a consequence of design differences, such as string coupling, soundboard thickness and rib shape, soundboard wood type, length, mass and tension of the strings. A sound level metre, Virtual Sound Level Meter (VSLM) was used to measure the peak amplitude sound level (volume) at the beginning of the note, and an averaged amplitude sound level over the complete duration of the note. Software using FFT technology, Fuzzmeasure 3 Pro was used to filter the whole note duration into smaller duration periods, to examined the attack and decay transients of the sound.

The recording equipment and the audio engineer were the same for the recording of each piano sound. A Focusrite preamp was calibrated at -10 Omni pre amp calibration and a Fire Face UFX interface was used with recording software Pro Tools 10, designating one microphone to one channel, i.e. track 1 corresponding to microphone 1. Each microphone (mic) was positioned at a height of 1.5metres. A sound level meter (SLM) microphone was positioned in the piano to record the sound level of the hammer strike 10cm above the striking point of the string.

219 FuzzMeasure software: http://supermegaultragroovy.com/products/fuzzmeasure/
The directivity of sound projection is the direction in which the sound is radiated out from the instrument. The directional passage of travelling sound waves influences how the sound is humanly perceived.

When we hear music, the perceived tonal impression is caused by sound carried to our ears by the air. Relevant in this context are the minute pressure variations which are superimposed on the stationary pressure of the air surrounding us. The pressure variations propagate as waves in space. These more or less periodic deviations from the stationary mean value, comprise the so called sound pressure variations, for which in practice the shorter term ‘sound pressure’ is used.\(^{220}\)

Sound pressure is measured by decibels, (dB) which is an algorithmic scale that measures sound pressure with the vast and intricate range of human hearing, 16Hz- 20,000Hz. Sound pressures converted to the decibel scale are called sound pressure levels, abbreviated Lp.

The levels of loudness recorded by microphones in the arrays were calculated by the VSLM in two categories-

i) \(L_p\) : the measure which describes the peak pressure levels in dB, to register how the sound power of the source is radiated within the array.

ii) \(\text{leq}_A\) - Equivalent Continuous A-weighted sound pressure, which gives a reasonable approximation of the human perception of loudness, averaged periodically over the designated duration of the note, measured in dB\(_A\).

Inside the piano, a sound level microphone is positioned to record the sound pressure level of the instrument in Leq, equivalent continuous sound pressure level [dB] a calculation performed on time domain data, to provide a level of the instrument’s volume.

\(^{220}\) Meyer, 1.
Naturally the measured sound level depends on the strength of the sound source.
It is therefore also of interest to determine a characterization of the sound source,
which describes its strength independently of spatial considerations and the distance
from the listener. This relates exclusively to the sound source itself. Such a quantity
represents the sound energy radiated by a source in all directions during a unit of
time. This quantity is designated as the sound power of the source.221

A comparison of the amplitude output and directivity of both pianos is thoroughly illustrated in the data
below, which illustrate the sound pressure levels that reached each microphone of the same sound. This
data illustrates the Stuart piano’s highest signal of $\text{leq}_A$ was recorded by the microphone No 6, at a level
of 66 dB$_A$ and the Steinway’s highest $\text{leq}_A$ was recorded by microphone No 2 establishing distinctive
radiation directivities, in opposite directions! The sound level volume of the instruments is recorded by
mic7, and we see here that the Steinway is 4dB louder in $L_p$ peak, and an average of 4dB$_A$ louder than
the Stuart piano, averaged over the 50s duration of the note. The general sound pressure that was
radiated into the space is higher in the Stuart piano sound.

<table>
<thead>
<tr>
<th>MW Microphone Array</th>
<th>1 3m 180° (behind pianist)</th>
<th>2 3m 45°</th>
<th>3 3m 90°</th>
<th>4 3m 120°</th>
<th>5 3m 150°</th>
<th>6 3m 180° (behind bass bridge)</th>
<th>7 SLM 10cm over hammer</th>
<th>8 6m 90° cardioid</th>
</tr>
</thead>
<tbody>
<tr>
<td>STE 58s Steinway Piano</td>
<td>88(3) 86</td>
<td>88(2)</td>
<td>83.8 84</td>
<td>84(3)</td>
<td>85</td>
<td>86.9 87</td>
<td>95.9 96</td>
<td>71.6 72</td>
</tr>
<tr>
<td>L$_p$</td>
<td>64.9 65 62</td>
<td>64.6 65</td>
<td>61.9 62</td>
<td>62</td>
<td>63</td>
<td>64(3) 63</td>
<td>69.5 70</td>
<td>50.5 51</td>
</tr>
<tr>
<td>Leq$_A$</td>
<td>67(2) 86</td>
<td>88(4)</td>
<td>86(3)</td>
<td>85.9 86</td>
<td>88</td>
<td>91.9 92 94</td>
<td>92.0</td>
<td>79(4)</td>
</tr>
<tr>
<td>M19 (STU) Stuart Piano</td>
<td>61.9 62</td>
<td>64</td>
<td>62.8 63</td>
<td>63.6 64</td>
<td>63</td>
<td>65(4) 66</td>
<td>65.7 66</td>
<td>56.7 57</td>
</tr>
</tbody>
</table>

Sound pressure level $C2v81$ Table 3.3

221 Meyer, 3.
Sound Board Vibration

The rate of decay is an important measure, as it depicts how fast energy is being ‘spent’, or lost. If energy is released more slowly then it is contained within the mass, which in turn produces a slower rate of decay, or a higher perception of sustain. The amplitude is usually lower when the lost of energy is slow, and higher when the loss of energy is faster. Piano designers are interested in how the mass of the soundboard affects amplitude and decay. The impedance, or resistance to flow of energy through the wood is associated with the capacity of energy to be stored or contained in the vibrating wood of the soundboard, which affects the amount or amplitude of movement, and how much movement occurs over a time which affects perceived sustain.

Soundboard Amplitude:

To maximize loudness, we need to maximize the amplitude of the vibrational response of the soundboard for a given force, a quantity that is described by the frequency response function.\(^{222}\)

That [Stuart] sound board is about 5mm in the centre and tapering out thinner at the edges. Steinway is around 8mm in the centre tapering out to 5mm at the edges in some places. Generally, a tapered board is better and all makers employ variations on this concept. Steinway ribs are massive compared to Stuart so the actual board thickness is only a small part of the soundboard design… Overall mass reduction with high elasticity can increase the dynamic range. Increased stiffness can reduce dynamic range and increase metallic sound.\(^{223}\)

Stuart Soundboard- King William Pine

This species is widely used by Australian luthiers for the construction of sounding boards in musical instruments, for example pianos and violins. King William pine transmits sound at 5,500 metres per second the same as spruce which is renowned as producing the best soundboards for pianos and violins.\(^{224}\)

<table>
<thead>
<tr>
<th>Wood type</th>
<th>Thickness</th>
<th>Length</th>
<th>Width kydb</th>
<th>Width</th>
<th>Bass Bridge to rim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steinway Spruce</td>
<td>9-6 mm</td>
<td>2.69m</td>
<td>1.52m</td>
<td>950cm</td>
<td>25.5 cm</td>
</tr>
<tr>
<td>Stuart King William Pine</td>
<td>7-5 mm</td>
<td>2.88m</td>
<td>1.63m</td>
<td>960cm</td>
<td>16 cm</td>
</tr>
</tbody>
</table>

Soundboard Dimensions Table 3.4


\(^{223}\) Wayne Stuart email interview with author, 4th April, 2012.

How and in which direction the piano sound is projected or radiated from the instrument is an indication of how the soundboard is responding to the vibrations from the string and bridge.

The soundboard transforms the mechanical vibrations into radiated sound. As a first approximation, the soundboard acts like a large diaphragm clamped around its edge. Like all diaphragms, the soundboard exhibits a series of resonances, the individual intensities being determined by the point of excitation.225

The soundboard transforms the mechanical vibrations into radiated sound. As a first approximation, the soundboard acts like a large diaphragm clamped around its edge. Like all diaphragms, the soundboard exhibits a series of resonances, the individual intensities being determined by the point of excitation.226

Many instruments have an additional resonator whose function is to convert more efficiently the oscillation of the primary vibrating element into sound vibrations of the surrounding air and to give the tone its final timbre.227

The resonating system of a piano transforms the energy of the vibrating string into a composite sound wave that radiates the qualities of tone into the atmosphere. The treble and bass bridges transmit the initial string vibrations to the plate and the ribs disperse the vibrational energy throughout the broader area which radiates the sound out of the instrument. The impedance of the wood in the bridges, plate and ribs influences the efficiency and quality of the transmission of vibrational energy.

The soundboard is formed in such a way that the grain follows the general direction of the treble bridge. Sound travels about twice as fast with the grain as against it, and the modulus of elasticity of spruce is twenty times greater with the grain than against it. This results in the sound not being delivered uniformly to the entire soundboard and to compensate for the even delivery ribs of the same material are attached at fixed intervals to the underside of the soundboard.228

The sound radiation pattern of a piano is largely determined by the shape of the soundboard and the modal shapes of the various modes in which it vibrates.229

String vibration and the soundboard.

….. the initial impact on the string occurs in a direction perpendicular to the soundboard; in this direction the sound board is in a position to extract energy from the string in relatively strong measure…..

In addition, string vibrations parallel to the sound board are formed, though much weaker. Since the sound board presents a much higher impedance for transmitting such vibrations, this energy transmission process is much slower. The radiated sound field includes a superposition of these two different forms of vibration.230

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226 Klaus Wogram, 2.
We have only to think of each tiny moving patch of the soundboard as a small pump to realise that the complete board acts as a vast multitude of simple sources that run not necessarily in step and have many different amplitudes.\textsuperscript{231}

This research investigated the vibrational characteristics of the soundboards of each piano playing the same sound.

Measuring Soundboard Vibrations

Modal Analysis\textsuperscript{232} is implemented to produce amplitude spectrums of the soundboard modes of vibration. Associate professor of physics at the University of Sydney, Rod Cross attached four piezoelectric disks, 20 mm diameter and 0.3 mm thick, to each soundboard. The disks were connected, via a 10 MegOhm voltage probe, to an ADC-212 analogue to digital convertor. The signal was monitored by PicoScope software that effectively turned the PC into a digital storage oscilloscope. The data was also analysed by Kaleidagraph software in order to plot graphs and to perform an FFT (Fast Fourier Transform) to obtain the frequency spectrum.

Modal Analysis may be described as the process of describing the dynamic properties of an elastic structure in terms of its normal modes of vibration. In experimental modal testing, one excites the structure at one or more points, and determines the response at one or more points. From these sets of data, the natural frequencies (eigenfrequencies), mode shapes (eigenfunctions) and damping parameters are determined often by the use of multidimensional curve-fitting routines on a digital computer.\textsuperscript{233}

The piezoelectric disks were positioned in four areas of the soundboard. Four soundboard positions were monitored for each sound. Two positions remained fixed, P1 & P2, and two positions were varied for each note, A & B. The probe positions were specific to each of the soundboards.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Soundboard_spectra.png}
\caption{Soundboard spectrums C2v20 Fig 3.4}
\end{figure}

\textsuperscript{231} Fletcher & Rossing Modal analysis may be defined as the process of describing the dynamic properties of an elastic structure in terms of its normal modes of vibration. Fletcher & Rossing

\textsuperscript{232} Fletcher & Rossing, Modal Analysis

\textsuperscript{233} Fletcher & Rossing, 128-129.
Placement of Soundboard Probes.

The positions of probes P1 and P2 were different for each piano, and the same for each note (frequency). Probes A & B varied positions for each frequency on each piano. Probes A & B were moved to the sections of most movement on each soundboard, for each note. S probes P1 & P2 were comparing the effect of the vibration at a particular position for different notes, And probes A & B were measuring the most soundboard movement per note. It was expected that each soundboard would vibrate differently because of the difference in string material, string coupling, and because each soundboard is different in width, length, thickness and wood type, see figure 3.3 above.

Soundboard Frequency Maps

Central positions were decided on after plotting frequency maps for C3, C4, and C5, by touching lightly the boards from under the pianos whilst the note was sounded.

Similar to the vibrations in a piano string, the vibrations in the soundboard are classified by their modes of vibration, which are identified by the frequency at which they vibrate (Hz). As with the vibrations in a stretched string, the lower frequency produces a slower, larger vibration, and as the frequency rises the vibration is smaller and faster. The diagrams below (fig 3.3, 3.4) taken from two research investigations, illustrate the vibrational modes of several modern 9ft grand pianos, with an approximate soundboard thickness of 9-10mm, tapering off to the edges. Both diagrams illustrate the size of the vibrations relative to their frequency mode, and shows that as the frequency Hz rises, vibrations reduce in size and occur in many areas of the soundboard.

Stuart P1 & P2 positions of the soundboard frequency map of vibrations, for C3, C4, C5:
P1 STU piezo probe 1: positioned 10cm towards the curved side from the treble bridge, between ribs 5 & 6, 84 cm from the rear, 196 cm from the keyboard, 57cm from the front curved side.

P2 STU piezo probe 2: positioned directly over the treble bridge, between ribs 7 & 8, 135 cm from the rear, 165cm from the keyboard, 53cm from the back side, 55cm from the front curved side, 8cm towards to the straight rear side from the treble bridge.

Steinway piano soundboard frequency map of vibrations, for C3, C4, C5:

![Steinway soundboard frequency vibration locations. P1 & P2 Fig 3.6](image)

P1 STE piezo probe 1: positioned directly over the treble bridge between ribs 5&6, 96cm from the rear, 173cms from the keyboard, 46cm from the straight rear side, 556cm from the curved side.

P2 STE piezo probe 2: positioned 21.5cm towards the straight side from the treble bridge, between ribs 7 & 8, 131 cm from rear, 136 cm from the keyboard, 42 cm from the straight rear side, 66 cm from the front curved side.

Two soundboard probe points ‘A’ & ‘B’ were changed for each frequency. ‘A’ was positioned close to or on the position of where the string is coupled to the bridge. ‘B’ was positioned close to the bridge, though in a position of strong movement in the board.
<table>
<thead>
<tr>
<th></th>
<th>STU  C2 65.406 Hz</th>
<th>STE  C2 65.406 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td><strong>STU</strong> for C2:</td>
<td><strong>STE</strong> for C2:</td>
</tr>
<tr>
<td></td>
<td>positioned where the C2</td>
<td>positioned where the C2</td>
</tr>
<tr>
<td></td>
<td>bichord wound strings are coupled to the bass</td>
<td>trichord wound strings are coupled to the bass</td>
</tr>
<tr>
<td></td>
<td>bridge, 64.5 cm from the rear, 36 cm from the</td>
<td>bridge, 63 cm from the straight rear side, 72 cm from the</td>
</tr>
<tr>
<td></td>
<td>curved front side, 68.5 cm from the straight</td>
<td>rear end.</td>
</tr>
<tr>
<td></td>
<td>rear side,</td>
<td><strong>B</strong></td>
</tr>
<tr>
<td></td>
<td><strong>B</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>STU</strong> for C2: 86 cm from the straight rear</td>
<td><strong>STE</strong> for C2: 72 cm from the rear end, 37 cm from the</td>
</tr>
<tr>
<td></td>
<td>side, 23 cm from the front curved side, 123 cm</td>
<td>straight rear side, 63 cm from the curved side.</td>
</tr>
<tr>
<td></td>
<td>from the rear end.</td>
<td></td>
</tr>
</tbody>
</table>

STU length: 290cm. 19 ribs

STE length: 273cm. 17 ribs

<table>
<thead>
<tr>
<th></th>
<th>STU  C3 130.81 Hz</th>
<th>STE  C3 130.81 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td><strong>STU</strong> for C3:</td>
<td><strong>STE</strong> for C3:</td>
</tr>
<tr>
<td></td>
<td>positioned where the C3</td>
<td>positioned where the C3</td>
</tr>
<tr>
<td></td>
<td>trichord strings are coupled to the treble</td>
<td>trichord strings are coupled to the treble</td>
</tr>
<tr>
<td></td>
<td>bridge, 117 cm from the rear, 57 cm from the</td>
<td>bridge, 42 cm</td>
</tr>
<tr>
<td></td>
<td>curved front side, 53 cm from the straight</td>
<td>from the straight rear side, 57 from the</td>
</tr>
<tr>
<td></td>
<td>rear side,</td>
<td>curved front side, 83 cm from the rear end.</td>
</tr>
<tr>
<td></td>
<td><strong>B</strong></td>
<td><strong>B</strong></td>
</tr>
<tr>
<td></td>
<td><strong>STU</strong> for C3: 18 cm from the straight</td>
<td>end, 37 cm from the straight rear side, 63 cm from the</td>
</tr>
<tr>
<td></td>
<td>rear side and 126 cm from the rear end.</td>
<td>curved side.</td>
</tr>
</tbody>
</table>

STU length: 290cm. 19 ribs

STE length: 273cm. 17 ribs

C2 A & B Probe Positions Stuart and Steinway Soundboard Fig 3.7

C3 A & B Probe Positions Stuart and Steinway Soundboard Fig 3.8
Perceptions of the Stuart & Sons Piano Sound, Part I – Kevin Hunt

<table>
<thead>
<tr>
<th>STU C4 262.63 Hz</th>
<th>STE C4 262.63 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="STU_C4.png" alt="" /></td>
<td><img src="STE_C4.png" alt="" /></td>
</tr>
<tr>
<td>STU length: 290cm. 19 ribs</td>
<td>STE length: 273cm. 17 ribs</td>
</tr>
<tr>
<td>A STU for C4: positioned where the C4 trichord strings are coupled to the treble bridge, 164 cm from the rear, 45 cm from the curved front side, 74.5 cm from the straight rear side,</td>
<td>A STE for C2: positioned where the C4 trichord strings are coupled to the treble bridge, 70 cm from the straight rear side, 153 cm from the rear end.</td>
</tr>
<tr>
<td>B STU for C4: 38 cm from the straight rear side, 170 cm from the rear end.</td>
<td>B STE for C2: 80 cm from the straight rear side, 25 cm from the curved side, 110 cm from the keyboard.</td>
</tr>
</tbody>
</table>

C4 A & B Probe Positions Stuart and Steinway Soundboard Fig 3.9

<table>
<thead>
<tr>
<th>STU C5 523.25 Hz</th>
<th>STE C5 523.25 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="STU_C5.png" alt="" /></td>
<td><img src="STE_C5.png" alt="" /></td>
</tr>
<tr>
<td>STU length: 290 cm. 19 ribs Not done</td>
<td>STE length: 273 cm. 17 ribs</td>
</tr>
<tr>
<td>A STU for C5: positioned where the C5 trichord strings are coupled to the treble bridge, 89 cm from the keyboard, 58 cm from the curved front side, 95.5 cm from the straight rear side,</td>
<td>A STE for C5 positioned where the C5 trichord strings are coupled to the treble bridge, 85 cm from the keyboard, 59 cm from the curved front side, 88 cm from the straight rear side,</td>
</tr>
<tr>
<td>B STU for C5: 59 cm from the straight rear side, 124.5 cm from keyboard.</td>
<td>B STE for C5: 104 cm from the straight rear side. 40 cm from the front curved side, between ribs 11-12.</td>
</tr>
</tbody>
</table>

C5 A & B Probe Positions Stuart and Steinway Fig 3.10
When the note C2 was struck at v20, the following soundboard vibrations were monitored in each of the four positions:

![C2 v20 Soundboard Vibration Amplitude](image)

See Appendix 3 for the actual amplitude spectra graphs for C2v20. The probe positions provide information on the size or amplitude of the soundboard vibrations. Although four positions cannot reveal all of the soundboard’s vibrational characteristics, the size of the vibration is indicated, remembering that the soundboard vibrates as one whole unit as well as in its segregated modes of vibration. The four probes collectively established a 58% difference in the amplitude of the vibrations in the Stuart and Steinway soundboards.
Summary of Measuring Techniques

For a summary of chapter three, and an introduction to chapter four, the following pages briefly illustrate how the sound of note C2v81 is analysed,

<table>
<thead>
<tr>
<th>Venue</th>
<th>Array</th>
<th>Pianos</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW</td>
<td>6 mics 3m 1-6</td>
<td>STU &amp; STE</td>
</tr>
<tr>
<td></td>
<td>1 mic 10 cm above</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 mic 6m 8</td>
<td></td>
</tr>
</tbody>
</table>

Music Workshop (MW) Array:

The table and graph below illustrate the amplitudes of $L_p$ and $L_{eq}$ of pianos STE and STU, captured in the 8 microphone array in the Music Workshop (MW), of note C2 65.406 Hz, struck at velocity 81 (v81).

### Sound Pressure Levels for the note C2v81:

<table>
<thead>
<tr>
<th>MW Microphone Array</th>
<th>C2 v81</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STE 58s</strong></td>
<td></td>
</tr>
<tr>
<td>$L_p$</td>
<td>88,(3) 86</td>
</tr>
<tr>
<td>$L_{eq}$</td>
<td>64.9 65 62</td>
</tr>
<tr>
<td><strong>STU</strong></td>
<td></td>
</tr>
<tr>
<td>$L_p$</td>
<td>87,(2) 86</td>
</tr>
<tr>
<td>$L_{eq}$</td>
<td>61.9 62</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MW Microphone Array</th>
<th>C2 v81</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STE 58s</strong></td>
<td></td>
</tr>
<tr>
<td>$L_p$</td>
<td>88,(2) 86</td>
</tr>
<tr>
<td>$L_{eq}$</td>
<td>64.6 65</td>
</tr>
<tr>
<td><strong>STU</strong></td>
<td></td>
</tr>
<tr>
<td>$L_p$</td>
<td>86,(3) 86</td>
</tr>
<tr>
<td>$L_{eq}$</td>
<td>56.7 66</td>
</tr>
</tbody>
</table>

Sound Pressure Level C2v81. 8 microphones. Table 3.7
A comparison of the amplitude output and directivity of both pianos is thoroughly illustrated in the data above. This data shows for example, that the Stuart piano’s highest signal of leq_A was recorded by the microphone No 6, at a level of 66 dB_A, and the Steinway’s highest leq_A was recorded by microphone No 2 establishing distinctive radiation directivities, in opposite directions! The sound level volume of the instruments is recorded by mic7, and we see here that the Steinway is 4dB louder in Lp peak, and an average of 4dB_A louder than the Stuart piano, averaged over the 50s duration of the note.

C2 v81 MW mic8 Decay curve, 50s duration.

The decay curve for mic 8 positioned at 90° and 6 metres from the pianos, shows an interesting area of difference in the rates of decay starting at 5s.

The decay curves below, show the Stuart (i) to be decaying faster in the onset, and to be settling into its after-sound oscillation (ii), approximately 5s earlier than Steinway (ii).
4. Qualities of the Stuart & Sons Piano Sound

Introduction.

The characteristics of tone colour found in the sounds of the Stuart & Sons piano No 19 in the Music Workshop performance venue are identified, examined and defined in this chapter. The tonal descriptions of the Stuart piano sound were realised by comparing its sound with the sound of the Hamburg Steinway concert D piano, No574500, in the controlled acoustic environment of an eight microphone array set in a curve of 180°, 3 meters and 6 metres from the same measuring point of each piano.

The descriptions of tone colour are based on the understanding that the tonal colour or timbre, is determined by how proportions of the partial frequencies intervene within the whole tonal composite vibration of the sound, at specific time periods of the sound’s duration, understanding that piano sound is in a state of transient decay, over the time of the note’s sound. Piano sounds in the lower registers with long wound steel wire strings can sound for 60 seconds duration, whilst shorter durations occur for the higher tones of shorter thinner steel wire strings. Tonal colour therefore needs to be described in terms of the manner in which the transient qualities change over the time of the sound’s duration. The individual partial frequencies and the composite collective of partial frequencies are described in terms of their volume SPL, dB, amplitude, and the rate or speed at which they decay, as both dimensions influence tonal colour.

The sounds of both the Steinway and Stuart pianos were activated by a calibrated electronic key striker, which eliminated the variable of ‘human’ pianistic touch. Leaving pianistic expression out of this examination of tone colour, narrows the enquiry to one of tone production of the actual instruments and how their sounds interact within the acoustic of the specific performance hall.

A reference point of standard traditional piano tone was provided by the sound created by the Hamburg Steinway concert D piano, in the same acoustic space. The recorded samples were all created on the same recording date with each piano in identical positions in the space, using the same data microphone positions, as discussed in chapter three, ‘Vibrations and Tone’. The aim of creating the descriptions of the Stuart piano tone, is to establish knowledge on how and why the Stuart sound is different to that of the traditional modern piano, in this case the Steinway D. Realising these tonal characteristics informs musical choices for composition and performance.

Analysis of the sounds recorded in the MW performance space, on the 9th December, 2013, of four notes, C2 65.406Hz, C3 130.81Hz, C4 261.63Hz, and C5 523.25Hz, established four descriptive factors

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234 Roederer,118.
236 Sound Pressure Level
of piano tone which distinguished the sound of the Stuart piano M19 (STU) piano from the sound of the Steinway piano (STE).

i. A slower rate of decay of the fundamental partial frequency.

ii. Earlier transition into the after-sound (a-s) oscillation state.

iii. Wider harmonic spectrum at the onset of the sound.

iv. A more comprehensive tonal projection to 6 metres.

A slowly decaying fundamental frequency, greater amplitudes of the 2\textsuperscript{nd} or 3\textsuperscript{rd} partial, and the transfer to the after-sound oscillation phase within 1s, describes the qualities in piano sound that distinguish the M19(STU) piano from the Steinway STE 574500 piano.

The direction of radiation of each piano sound within the 180° array, was realised by monitoring the SPL levels of each microphone in the array. For each sound, the radiated harmonic characteristics were tested to see if they correspond to the harmonic vibrations produced by the soundboard. In many instances, the Stuart piano was found to produce larger harmonic sound board vibrations, which corresponded to a fuller harmonic spectrum being radiated over a longer distance.

The sound qualities of the Stuart and Steinway are visually presented in spectrograms, which display the SPL levels of the onset attack, and the amplitudes and rates of decay of the individual partial frequencies. The decay curves display and the rate of decay of the composite note. Tonal qualities were consistently observed in the Stuart piano sounds that contained, a larger fundamental, a larger 2\textsuperscript{nd} or 3\textsuperscript{rd} partial, a faster onset rate of decay usually within .5s, and a slower after-sound decay, often in the 2\textsuperscript{nd} phase of oscillation, immediately after the onset period.

The audible characteristics that distinguished the Stuart sound from the Steinway sound, as heard in the recorded sounds were:

i. A more stable sound, with less movement or change of harmonic balance within the sound.

ii. A more balanced sustain established in the first .5s of the sound

iii. More bass fullness, or sustain of lower frequencies in the lower notes, C\textsubscript{2} and C\textsubscript{3}

iv. A more immediate sounding of the SPL peak in the onset, with a more percussive attack.
Familiarity of the sound

This research assumes that the Steinway sound is ingrained in the consciousness of many musicians and listeners as the sound of the modern piano. There is a familiarity associated with the ‘sound’ of the Steinway most probably because since the 1880s countless of performances and recordings have used the Steinway piano. As well as this, most other piano designers have implemented the elements of its standardised design for over 100 years. The 88 key compass, down-bearing pressure of the strings onto the soundboard, the zig-zag pinned string terminations on the bridge, and copper wound bass strings. A simple indication of this familiarity was observed in the audience surveys, when a higher number of the participants answered the question, “how do you describe the sound of the Steinway piano” with ‘just as I’d expect a piano to sound’.

Wayne Stuart doesn’t agree that the standardised pinned bridge traditional piano in particular the Steinway, should be presented as the ‘standard’, but rather a piano design of…

‘ ……a specific era and ethnic origin. Whereas, contemporary music has a non-specific ethnicity and therefore, must embrace not only different music scales but different harmonic and aesthetic parameters.

237

Throughout my career as a pianist, my experience in assessing piano sound quality has been only in regards to the modern piano. So conducting a comparison of the sounds of the modern piano in this case the Steinway, with the sounds of the Stuart piano provided me with a practical method for acquiring a sense of the qualities of both piano sounds. To understand what is different about the Stuart sound, the ‘familiar’ modern piano sound was compared with the ‘unfamiliar’ Stuart piano sound. Conscious listening, graphical analysis and memory were employed throughout the analysis process where the ‘familiar’ is also scrutinised.

I immersed myself in the specific palette of tonal colours of one particular Stuart piano, No 19, to enable my performances and compositions of music that demonstrated an understanding of its sound qualities. The palette of Stuart sound qualities illustrated in the following pages is intended to be used for reference points of tonal descriptions, as well as to establish evidence of how the Stuart piano sound is different to that of the modern piano sound.

This enquiry is centred on the sound of one instrument, the Stuart & Sons piano identified throughout this research as M19 (STU). This piano was made in 2002, it is Stuart No 19, 2.9m long, with a keyboard compass of 97 keys, F_0 22.2337Hz to F_6 5587.6518 Hz. The tones of the M19(STU) piano were consistently compared to the tones of one Hamburg Steinway concert D grand piano, (STE) No 574500, made in 2005, with a keyboard compass of 88 keys, A_0 227.50 Hz to C_8 4186.0091Hz . The Steinway is affectionately named the ‘Olley’, in honour of the Australian artist and benefactor, Margaret Olley. See chapter one for the detailed descriptions of both instruments. The methods and

processes of recording, microphone placements and sound analysis, are described in detail in chapter three, ‘Vibrations and Tone’. The sounds of both these specific pianos were used to produce all the comparative data in this chapter and for the following chapters on jazz trio tone comparison and audience surveys. Compositions based on Aboriginal music collaborations were created using the particular sounds of the M19(STU) Stuart piano, as described in in Chapter 6.

In the first section of this chapter, (4.1) eight sounds of the M19 (STU) and STE are presented in brief one page analyses, as an introductory summary of the four qualities found which distinguished the Stuart sound from the Steinway sound, listed on page 2. To keep the overall analysis to one page, the text is in a condensed font. It is necessary to read the decay graphs in colour. The graphs can be viewed in colour using the files on the USB drive with a computer.

The direction in which the sounds were radiated within the MW space, and their qualities of sound projection are added to the three descriptive categories, to make five descriptive subjects in section 4.2, with twenty eight piano sounds presented overall.

The transient presence, balance and activity of the partial simple tones within the composite complex tone sound of a note, is examined to describe piano tone in the following pages, because the loudness and amplitude of the fundamental, 2nd and 3rd partial frequencies are indicators of tonal colour.

The relative proportion with which each overtone intervenes in the resulting vibration determines to a great extent the particular character, quality, or timbre of the generated tone.238

The coupling apparatus on the Stuart piano bridge, the bridge agraffe, was shown to change the vibrational modes of the string, in chapter 2. The vibration modes in the string are harmonic, and therefore influence the tone colour.

**Directivity and Timbre.**

The contrasts in perspectives and perceptions of what an audience ‘hears’, and what the pianist ‘hears’ are assessed by examining the radiations of piano sound to different positions and distances within the performance space. The tones are ‘captured’ by the microphone array of 180°, at distances of 3 metres and 6 metres, from the pianos

*Sound is not radiated uniformly in all directions by an instrument; the pattern of directionality is likely to be different for different harmonics*239

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238 Roederer, 118.
The sound files in sound table 4.1 below, illustrate the range of tonal colour of one sound defined by its various directivity. The variation in timbre belongs to the single sound of C2v20, captured by eight microphones as it radiated within the 180° MW sound field. Each row of eight sounds is from the Stuart M19(STU) and Steinway STE pianos. The velocity strike of the key is of the slowest (softest) force, v20.

<table>
<thead>
<tr>
<th>C2v20 47s MW</th>
<th>Mic1 180° (3m)</th>
<th>Mic2 60° (3m)</th>
<th>Mic3 90° (3m)</th>
<th>Mic4 120° (3m)</th>
<th>Mic5 150° (3m)</th>
<th>Mic6 180° (3m)</th>
<th>Mic7 hammer strike (10cm)</th>
<th>Mic8 90° (6m)</th>
</tr>
</thead>
</table>

Individual microphone sounds, C2v20 MW Sound table 4.1 USB Audio 4.0 : Trks 1-16

The collective array sound of the above note, C2v20:

<table>
<thead>
<tr>
<th>Stuart C2v20 MW mixed array USB Audio 4.0: trk 18</th>
<th>Steinway C2v20 MW mixed array USB Audio 4.0: trk 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2v20 MW Mixed Array(2) Sound table 4.2 USB Audio 4: Trks 17-18</td>
<td></td>
</tr>
</tbody>
</table>

The Stuart sound of the note C2 65.406 Hz was found to have a more extensive harmonic and dynamic spectrum across all the partial frequencies. The string scale dimensions and harmonic vibrations in the soundboard correspond to the radiated sound to 3 metres and 6 metres. The dimensions of string density and the soundboard vibrations, combine to form the resonating system of the piano.

The string cannot radiate a sound wave itself, its motion has to be transferred to a much larger object which can serve as a much more efficient radiator of sound.240

In the bass section of the piano compass, where C3 is situated, the Stuart piano has significantly longer strings of higher yield capacity and lower inharmonicity, set at significantly higher tension. The Stuart soundboard was found to vibrate harmonic frequencies of C3, at 57% higher amplitude than the Steinway soundboard. Of the four notes tested, the sounds of the Stuart piano note C3, at each velocity strike, produced the most extreme tonal comparisons to Steinway.

The volume level of piano sound radiated to each microphone is described as Sound Pressure Level, (SPL). The information for the description of STE and M19(STU) piano tone quality was derived from the recordings conducted in the MW performance space, in a 180° array of 6 microphones at 3 metres, mics 1-6, one microphone at 6 metres, mic 8, and a close microphone positioned 10 cm above the hammer strike of the string, mic 7.

The MW array:

Overall Sound Pressure Level of Each Piano

The SPLs of all four notes, of both the Steinway and Stuart pianos in the MW space, across 8 microphones, and three velocity strikes, were found to be surprisingly similar when processed by the General Linear Model (GLM). The boxgraphs below, show the (GLM) reading of the SPL (dB) of all 96 piano sounds recorded, per piano, in the MW. Marginal differences show the Steinway to be louder and softer in the extreme ranges of loudness, r1 and r4. The Stuart is marginally louder in the lower three ranges of loudness, r1-3. The smaller range of the Stuart reveals a higher consistency of volume was produced by the fixed and calibrated velocity key strikes.

Total SPL : MW lp & leqA v20, v54, v81 boxgraph:

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241 Generalized Linear Models Faá Di Bruno’s Formula to Graduation, Whittaker–Henderson J. A. Nelder, R. J. Baker Published Online: 15 AUG 2006 DOI: 10.1002/0471667196.ess0866.pub2 John Wiley & Sons, Inc.
The SPL values of one note C₂, struck at three velocities, recorded in the MW space by 8 microphones, comprised a total of 24 recorded values of SPL for each piano. To summarise the range of these values, the 24 values are categorised into four SPL range groups of 6 notes each, from the quietest notes, range (r1) to the loudest notes, range (r4). Characteristics of each piano’s SPL are informed by comparing both the ranges of each 25% segment (r1-r4) and the total SPL range.

C2 MW Boxgraph

A higher proportion of the Stuart notes were sounded in higher dB ranges than Steinway, revealing that the Stuart produced more louder notes than the Steinway. The Steinway sounded a wider range by 13dB, with the loudest and the softest notes of C₂. This could also mean that the Stuart was outputting more consistently accurate volumes per calibrated velocity strike. The fact that the r1 range of the Stuart is significantly louder than the r1 range of the Steinway suggests that the Stuart is capable of producing softer sounds than the Steinway. This could be tested by striking the key at the slower velocities of v10, and v5.

The piano sounds recorded in the MW space, are presented in the following pages, firstly in section 4.1 as an introductory summary of the range of tonal characteristics found in the 4 notes, struck at 3 velocities.

In section 4.2 sounds are presented in categorised groupings of tonal characteristic:

i) Fundamental partial – slower decay
ii) Earlier transition into the after-sound oscillation phase.
iii) Wider harmonic spectrum
iv) Directivity of the maximum SPL radiations
v) Projections to 6 metres, mic 8
The appendices A-E of this chapter contains data for: A. String scales; B. Soundboard vibrations; C. SPL; D. decay curve calculations, E. audio sounds index.

Stuart Design Concepts - relating to tonal colour outcomes

- The faster rate of decay in the onset of the Stuart string vibration was found to occur because of less resistance to the vertical plane of the hammer strike, due to its vertical coupling. The larger amplitudes of the Stuart Fnd, 2\textsuperscript{nd} and 3\textsuperscript{rd} partials, subsequently causes a faster inverse decay reaction in the onset of the sound.

- The Stuart’s earlier change into the slower decay rate (after-sound) is due to a proportionally smaller change in the vibrational mode from vertical to elliptical, ie less damping, which is heard in the stability of the tonal balance of the after-sound.

> Changes in [vibration] mode = damping. No change [in vibrational mode] can contribute to a greater motion and quicker loss as your figures indicate but the lack of subsequent changes in mode ultimately reduces the overall [energy] loss in comparison to the ever changing back and forth motions of the pinned bridge scenario.\textsuperscript{242}

- The higher degree of stress on the horizontally pinned string of the Steinway, when forced into the vertical plane by the hammer strike, causes a higher amount of damping, resulting in a longer inverse decay rate at the onset, of smaller gradations, subsequently losing more energy over a longer period, before settling into its after-sound.

\textsuperscript{242} Wayne Stuart, email interview with author, 22\textsuperscript{nd} June, 2015.
Stuart Piano - Tonal Distinctions
Eight Introductory Sounds of Stuart Piano Tone Distinction.

1. C5v54 MW mic3  Onset Tonal Stability; Slower Fnd a-s; Earlier a-s transition.

The Stuart sound is brighter, with more sustain of the onset tonal balance. The Steinway decays immediately and has a rounder tone. The Stuart’s larger Fundamental, 2nd and 3rd partials, contribute to the brighter tone colour.

MW array sound:
The brightness of the Stuart tone at mic3, is enhanced in the room sound of the 8 microphones.

Decay:
The Stuart sound decayed more rapidly in the onset (i), for a shorter time, losing less energy in the onset, with an earlier transition into the 1st phase to the slower settled oscillation (ii), a phase which wasn’t part of the Steinway decay, in this instance.

Both pianos radiated waves of similar SPL to mic M19 (STU) lp 83 leqA 62; STE lp 82 leqA. At velocity 54, Stuart radiated waves of its maximum SPL to mic2, and Steinway radiated waves of its maximum SPL to mics 1 & 6. The Stuart sound radiated marginally higher SPL of C5 to mics 2,3,5,7 and significantly higher SPL to mic 8. Soundboard: The magnitude of the movement of the Steinway soundboard was found to be 46% higher than the Stuart soundboard for C5v54.

For the note C5, the diameter of the Paulello-Stuart wire is .35mm thicker, the tensile strength of the Paulello/Stuart wire is 138 N/mm² higher. The Paulello-Stuart wire for C5 is 4.5mm longer, and is set at 7kg higher tension. The yield or capacity of the Paulello-Stuart wire is approximately 10% higher than the Roslau-Steinway wire.
2. C4v20 MW mic2. Slower Fnd, a-s; 2nd prt. ; Earlier a-s transition.

The brightness of the Stuart tone, and the roundness of the Steinway tone is illustrated at mic2, and in the mixed array sound. The 2nd partial is featured more prominently in the Stuart sound. The Steinway sound decays quickly within the first second of the sound, the later appearance of STE the 3rd partial is distinctive. The 3rd partial dominates the Steinway sound more than the Stuart sound. The Stuart sound sustains a consistent level till 7s, whereas the Steinway has sharp decays at 1s and 4s.

Decay: The Stuart moves into the 2nd phase of oscillation earlier, than Steinway by approximately .5s, losing less energy and maintaining a higher SPL and sustain.
3. C3v81MW mic5  Slower after-sound Fnd., 2\textsuperscript{nd} & 3\textsuperscript{rd} prt. STE bass ‘swell’
Earlier transition to the after-sound oscillation.

The Steinway sound produces a bass ‘boom’ at approximately .5s. We can see in the spectrogram that the Steinway Fnd. 2\textsuperscript{nd} & 3\textsuperscript{rd} prts are decaying at a slower rate than Stuart at .5s. Here we can hear the advantage of a faster decay in the onset, the Stuart has no bass ‘swell’.

MW array sound:

Both Stuart and Steinway radiated waves of maximum SPL to mics5 and 1. Both piano sounds produced similar levels of SPL lp, and STE had higher leq\textsubscript{A} by 3dB.
C3v81 MW mic5 SPL:M19(STU)\ lp 90 leq\textsubscript{A} 64  // STE \ lp 90 leq\textsubscript{A} 67
Soundboard: At the 4 probe positions, the Stuart soundboard vibrated at 19% greater magnitude than the Steinway soundboard for C3v81.
For the note C3, the diameter of both wires is identical at 1.125mm. The tensile strength of the Paulello/Stuart wire is 140.5 N/mm\textsuperscript{2} higher, the Roslau/Steinway is 41mm longer, and is set at 6.7kg higher tension. The yield or capacity of the Paulello/Stuart wire is 8% higher than Roslau/Steinway.
A wider spectrum.

4. C2v54 MW mic 6

The Stuart sound consists ofpartials with larger amplitudes, a more varied spectrum array and with slower rates of decay than in the Steinway sound. The fundamental, 5th and 6th partials are more clearly identified in the Stuart sound. The general tone of the Stuart note is more harmonious, emphasising the 6th partial, whereas the Steinway tone is more dissonant emphasising the 7th partial. The 6th partial was more resonant in the Stuart soundboard than in the Steinway soundboard.

MW array sound:

<table>
<thead>
<tr>
<th>Stuart USB Audio 4.0 trk.31 C2v54 M19(STU) MW mic6.wav</th>
<th>Steinway USB Audio 4.0 trk.32 C2v81 STE MW mic6.wav</th>
</tr>
</thead>
</table>

There is more bass frequency in the Steinway array sound than solely at mic6.

The bass frequency of the Stuart sound in the array is quite large. The Stuart bichord sound is clearer, than the ‘whizz’ sound of the Steinway trichord.

Decay: The Stuart decays faster than Steinway in its onset (i) and the 1st settled phase (ii). Slower than Steinway 3-4s.

<table>
<thead>
<tr>
<th>Stuart USB Audio 4.0 trk.33 C2v54 M19(STU) MW mxd.wav</th>
<th>Steinway USB Audio 4.0 trk.34 C2v54 STE MW mxd.wav</th>
</tr>
</thead>
</table>

Stuart radiated waves of maximum SPL to mic6, and Steinway radiated waves of maximum SPL to mic 2. At mic 6, Stuart was 8dB louder than Steinway.

C2v54 MW mic6 SPL:M19(STU) lp 90 leq, 62 // STE lp 82 leq, 56.

Soundboard: At the 4 probe positions, the Stuart soundboard vibrated at 44% greater magnitude than the Steinway soundboard for C2v54. The STE S.board vibrated a larger fundamental than M19(STU).

For the note C2, the diameter of the Paulello/Stuart core wire is .125mm thicker, the cover wire is .47mm thicker and Stainless Steel, the tensile strength of the Paulello/Stuart wire is 481 N/mm² higher, the Paulello/Stuart is 235mm longer, and is set at 65.3kg higher tension. The yield or capacity of the Paulello/Stuart wire is 46% higher than Steinway/Roslau.

C2 65. Hz Scaling. Soundboard table 4.4
5. **C5v81 MW mic8** - Projection to 6 metres.

   - Slower Fundamental decay, Wider spectrum, Earlier a-s transition.

Radiating a distance of 6 metres both piano sounds are brighter in tone colour. The Stuart sound is brighter and louder. The partial movement in both sounds is fast and erratic.

The Stuart was 7dB louder than Steinway at mic 8, at the velocity strike of v81. The attack sound is more present in the Stuart sound. After 1s the Steinway sound is heard to diminish in volume, far more rapidly than the Stuart sound.

**MW array sound:**

<table>
<thead>
<tr>
<th>Stuart</th>
<th>USB Audio 4.0 trk.35</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5v81 M19 (STU) MW mic8.wav</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Steinway</th>
<th>USB Audio 4.0 trk.36</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5v81 STE MW mic8.wav</td>
<td></td>
</tr>
</tbody>
</table>

The onset of the Stuart sound (i) decayed slightly faster than Steinway in the onset of C5v81. The Steinway (ii) transfers earlier than Stuart into its slower after-sound oscillation. The Stuart’s initial period of the after sound oscillation (ii) decays at a slower rate than Steinway. The Steinway settles into its 2nd phase of after sound (iii) oscillation 1s earlier than Stuart.

**Soundboard:** The Steinway soundboard vibrated larger magnitudes of the fundamental, 3rd, 4th, 5th & 6th partial frequencies than Stuart. The Stuart soundboard vibrated a larger 2nd partial frequency. The magnitude of the total movement of the Steinway soundboard was found to be 44% higher than the Stuart soundboard for C5v81.

**String Scale:** For the note C5, the diameter of the Paulello-Stuart wire is .35mm thicker, the tensile strength of the Paulello/Stuart wire is 138 N/mm² higher. The Paulello-Stuart wire for C5 is 4.5mm longer, and is set at 7kg higher tension. The yield or capacity of the Paulello-Stuart wire is approximately 10% higher than the Roslau-Steinway wire.
6. C4v20 MW mic4  Slower Fnd. after-sound; Earlier a-s transition

The Stuart sound has a faster attack, a louder fundamental. The Steinway sound diminishes momentarily in the first second.

Array sound:

<table>
<thead>
<tr>
<th>Stuart</th>
<th>USB Audio 4.0 trk.39</th>
<th>Steinway</th>
<th>USB Audio 4.0 trk.40</th>
</tr>
</thead>
</table>

Decay:
The Steinway note is louder at the onset, it peaks later then STU in the onset, and holds it’s peak for longer, to .3s. (i) it then decays more rapidly than Stuart in the 1st phase of after-sound (ii), The Stuart transfers to the 2nd phase of after-sound oscillation (iii) earlier, after losing less energy, hence the sense of a more stable sustain.

String Scale: The diameter of the Paulello/Stuart wire is .25mm thicker, the tensile strength of the Paulello/Stuart wire is 177 N/mm² higher, the Paulello/Stuart is 1.5mm longer, and is set at 3.5kg higher tension. The yield or capacity of the Roslau/Steinway wire is 3.6% higher than Paulello/Stuart.

A faster after-sound decay decrescendo is audible in the Steinway sound, from approximately 1s, immediately after the bass frequency ‘swell’ crescendo. The bass tone of the Stuart Fnd. is more evenly balanced throughout the duration, with longer sustain, i.e. slower decay. The 3rd partial (sounding a P12th) is more audible in the Stuart sound. The attack onset tone of the Stuart is more immediate. The Stuart sound begins with peak SPL of Fnd. 2nd & 3rd partials.
7. C3v20 MW mic1

Array sound:

The bass ‘swell’ is enhanced through the added microphones. The attack tone of the Stuart is more immediate, with the higher amplitudes of 2nd & 3rd partials.

Decay:

The Stuart sound decayed .5 dB/s slower than Steinway in the onset oscillation (i). The Steinway’s transition to its 3rd phase settled oscillation (iii) is approximately 1.5s earlier than Stuart.

Soundboard:

For C3v20, the Stuart was louder than Steinway at mics 1,2,5,6,7,& 8

At the 4 probe positions, the Stuart soundboard vibrated at 31% greater magnitude than the Steinway soundboard for C3v20.

For the note C3, the diameter of the Paulello/Stuart wire is 25mm thicker, the tensile strength of the Paulello/Stuart wire is 177 N/mm² higher, the Paulello/Stuart is 1.5mm longer, and is set at 3.5kg higher tension. The yield or capacity of the Roslau/Steinway wire is 3.6% higher than Paulello/Stuart.
The Steinway is 1 dB louder than Stuart at mic7. The Stuart sound contains a larger amount of bass frequency, i.e. more fundamental, and its more varied spectrum is ‘present’ from the beginning of the sound, whereas portions of the Steinway spectrum enter more gradually. The Steinway fundamental is decaying in a more fluctuating manner than the Stuart fundamental.

The Stuart is significantly louder than Steinway at each microphone of the 3 and 6 metre array. In the 1st second of the array sound, the Steinway sound diminishes, as it did at mic7.

Array Sound:

<table>
<thead>
<tr>
<th>Stuart</th>
<th>USB Audio 4.0 trk.49</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2v54 M19(STU) MWmxd.wav</td>
<td>C2v54 STE MW mxd.wav</td>
</tr>
</tbody>
</table>

Decay:

Steinway’s shorter trichord of thinner strings loses more energy faster, than the Stuart bichord of longer thicker strings, of significantly greater tensile.

For C2v54, the Stuart was louder than Steinway at mics 1,2,5,6,& 8.

Soundboard: At the 4 probe positions, the Stuart soundboard vibrated at 44% greater magnitude than the Steinway soundboard for C2v54. STE S.board vibrated a larger fundamental than STU.

For the note C2, the diameter of the bichord Paulello/Stuart core wire is .125mm thicker than the trichord Roslau/Steinway wire, the cover wire is .47mm thicker and Stainless Steel, the tensile strength of the Paulello/Stuart wire is 481 N/mm² higher, the Paulello/Stuart is 235mm longer, and is set at 65.3kg higher tension. The yield or capacity of the Paulello/Stuart. wire is 46% higher than Paulello/Stuart.
Tonal Distinction 1

A Slower Rate of Decay of the Stuart Fundamental Frequency.

Introduction:

A more stable harmonic balance was audibly present in the sound of the Stuart piano, when the decay rate of its fundamental frequency was found to be slower than Steinway’s after .5s. Sustained sound qualities were found to be enhanced in the Stuart sound at the same time period as the slower fundamental frequency decay.

Sustained sound in piano tone, is closely related to that rate (dB/s) at which it decays, because a vibrating coupled steel piano string is in a constant state of decay, restoring back to its rest position after the forced disturbance of the hammer strike. Therefore the size, or amplitude of the composite sound is constantly reducing, becoming quieter. When the rate of the reduction in amplitude is steady and slow, it can be referred to as sustain.

The sustain portion of the sound, is the steady state to which the sound decays after a time determined by the decay parameters. A period during which the loudness varies little, called the sustain. The fundamental frequency is the composite note’s primary pure tone, which vibrates periodically at a frequency rate by which the note is named, and by which multiple frequencies of superimposed upper partial frequencies vibrate. The fundamental is therefore the vibrational frequency that combines the upper partials into their composite group, and in that sense is a primary ‘driver’ of the composite tonal and decay characteristics of the sound.

In the following pages, the transient qualities of the Stuart fundamental frequency has been found to affect the nature of the sound of the upper partials and visa versa, in qualities which were not present in the Steinway fundamental frequency and partial tones.

Notes about Fundamental + Upper Partial Frequencies.

The partial tones are separated by multiples of the frequency of the fundamental frequency. 261.63Hz is the fundamental frequency of middle C or C₄. The 2nd partial of C₄ will therefore be vibrate at double the 261.63Hz frequency, which is an octave above at 523.2 Hz. The next partial frequency will vibrate at 3x the 261.63Hz fundamental frequency, at 784.8Hz, which sounds the 12th interval above the fundamental. Each frequency harmonically lines up with the harmonic series, so for the first 7 partials, nearly three octave of pitch range is covered, within one sound.

The spectrograms in the following pages illustrate the amplitudes of the fundamental and upper partials at their graphically spaced frequencies, measured in decibels dB on the ‘y’ axis. The combined dB of

243 7 Sethares, 30.
244 5 Wolfe, "Pyshclips." (Retrieved 10 April 2015).
the partials make up the volume of the composite dB level of the note, the composite note volume, or sound pressure level, (SPL). Importantly for piano sound, the waterfall spectrogram also plots time, in milli seconds (ms), to illustrate the exponential decay of the amplitude of each partial frequency, over the time period of the sound’s duration.

The stiffness, the set tension and the stretched expansion of the coupled piano wire (string) creates periodic changes in the strings length, when excited by the force of the hammer, and produces inharmonicity. This causes the partial tones to vibrate at exponentially sharper frequencies than the multiples of the fundamental frequency. As the strings are shortened and set at progressively higher tensions, as the pitch rises, the ratios of inharmonicity increase.

The following sounds recorded in the MW space, exhibited a slower rate of decay in the fundamental frequency of the M19 (STU) Stuart piano, and produced a sound with distinctly higher levels of sustain than the Steinway D (Olley) concert piano, STE No 574500.

**C5v54 MW mic1**

_Soundboard vibrations:_ The Steinway soundboard resonated a larger fundamental, and larger 4th & 5th partials than Stuart, and the Stuart soundboard vibrated with a larger 2nd partial frequency. Both these findings correspond with the peak dB comparisons of the fundamental and 2nd partial, illustrated in the spectrogram. Overall, the Steinway soundboard vibrated in amplitudes 46% larger than Stuart for C5v54.

_Instrument Volume Mic 7: STU 90 dB, STE 89 dB_

_Soundboard vibrations:_ The Stuart soundboard resonated larger amplitudes of the fundamental and 2nd partial frequencies. Overall, the Stuart soundboard vibrated at 71% greater magnitude than the Steinway soundboard for C4v54.

_Instrument Volume Mic 7: STU 89 dB, STE 86 dB_
C4v54 mic2 (cont)

**String Scale:** The diameter of the Paulello/Stuart wire is .25mm thicker, the tensile strength of the Paulello/Stuart wire is 177 N/mm² higher, the Paulello/Stuart is 1.5mm longer, and is set at 3.5kg higher tension. The yield or capacity of the Roslau/Steinway wire is 3.6% higher than Paulello/Stuart.

**C3v81 MW mic3**

**Soundboard vibrations:**
The Stuart soundboard vibrated larger amplitudes of the Fnd. 2nd, 6th and 9th harmonic partials, and the Steinway soundboard vibrated larger amplitudes of the 3rd, 4th, 6th, 7th 8th and 12th partials. Overall the Stuart soundboard resonated at 19% greater magnitude than the Steinway soundboard for C3v81.

**Instrument Volume Mic 7:** STU 98 dB, STE 97 dB

**String Scale:** For the note C3, the diameter of the Paulello/Stuart wire is 25mm thicker, the tensile strength of the Paulello/Stuart wire is 177 N/mm² higher, the Paulello/Stuart is 1.5mm longer, and is set at 3.5kg higher tension. The yield or capacity of the Roslau/Steinway wire is 3.6% higher than Paulello/Stuart.

**C2v20 MW mic7**

**Soundboard vibrations:** Both Stuart and Steinway resonated vibrations of the same magnitude of the fundamental frequency. The Stuart soundboard vibrated larger amplitudes of the 2nd, 3rd, 4th, 6th & 7th partial frequencies. Overall, the Stuart soundboard vibrations were 52% larger in amplitude than Steinway’s.

**Instrument Volume Mic 7:** STU 81 dB, STE 82 dB

**String Scale:** For the note C2, the diameter of the Paulello/Stuart core wire is .125mm thicker, the cover wire is .47mm thicker and Stainless Steel, the tensile strength of the Paulello/Stuart wire is 481 N/mm² higher, the Paulello/Stuart is 235mm longer, and is set at 65.3kg higher tension. The yield or capacity of the Paulello/Stuart wire is 46% higher than the Steinway/Roslau wire.

**Other Stuart piano sounds - with slower fundamental frequency decay, previously presented in in section 4.2:**

<table>
<thead>
<tr>
<th>C5v81 M19 (STU) MW mic6</th>
<th>C3v81 M19 (STU) MW mic5:4.0, 8 sounds intro</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5v54 M19 (STU) MW mic1: 4.0, 8 sounds intro</td>
<td>C3v20 M19 (STU) MW mic5: STU distinction No 2</td>
</tr>
<tr>
<td>C5v20 M19 (STU) MW mic2: STU distinction No 2</td>
<td>C3v20 M19 (STU) MW mic1: 4.0, 8 sounds intro</td>
</tr>
<tr>
<td>C4v54 M19 (STU) MW mic4: STU distinction No 2</td>
<td>C2v81 M19 (STU) MW mic2: STU distinction No 2</td>
</tr>
<tr>
<td>C4v20 M19 (STU) MW mic2: 4.0, 8 sounds intro</td>
<td>C2v54 M19 (STU) MW mic6: 4.0, 8 sounds intro</td>
</tr>
<tr>
<td>C4v20 M19 (STU) MW mic4: 4.0, 8 sounds intro</td>
<td>C2v54 M19 (STU) MW mic7: 4.0, 8 sounds intro</td>
</tr>
<tr>
<td>C2v54 M19 (STU) MW mic7: 4.0, 8 sounds intro</td>
<td>casos similari</td>
</tr>
</tbody>
</table>
1. C5v54 MW mic1.

The Stuart fundamental frequency of the note C₅ 523.25Hz was observed to decay at a slower rate than Steinway, at mic 1, at the velocity strike of v54 mf.

The Steinway sound is plotted by VSLM, to be 6dB louder than M19(STU), though audibly, the dB volume difference is not clear. The immediate brightness of the Stuart and the faster decay of the Steinway sound ii, is audibly distinctive, and illustrated in the energy curve and spectrogram below. Soon after the hammer strike, the SPL of the Steinway is heard to reduce, whereas the Stuart sound maintains more of a sustained tonal balance, with a slower steady-state reduction of SPL between .2 - .8s.

The fundamental frequency of the Steinway is illustrated in the spectrogram below to be decaying at a faster rate than Stuart, between .2-.8s, after the initial or attack onset phase. The 2nd partial of the Stuart sound is significantly more present in the Stuart sound, influencing the brightness of the tone.²⁴⁵

²⁴⁵ * Meyer,30.
2. **C3v81 MW mic3.** Slower fundamental after-sound, Stuart tonal distinction 1.

The Stuart piano produces a fuller bass frequency for a longer duration. The fundamental, 2\(^{\text{nd}}\) & 3\(^{\text{rd}}\) partials decay at a slower rate, after 4s. Both the 2\(^{\text{nd}}\) and 3\(^{\text{rd}}\) partials are also decaying at slower rates than Steinway. At mic3, the Steinway was 3dB louder than Stuart.

The Stuart’s faster decay rate in the onset (i), and slower decay in the after-sound, from .8s, (ii), illustrates the earlier establishment of steady-state decay (sustain) in the sound.
3. **C4v54 MW mic2.** Slower fundamental after-sound, Stuart tonal distinction 1.

A clearer brighter spectrum is heard in the Stuart sound. At approximately .5s, the sound of the Steinway diminishes in fullness suddenly, whereas there is no change to the fullness or balance of the Stuart sound at .5s. The Stuart and Steinway radiated identical \( \text{LP dB} \) to mic2, and STU radiated 3dB\( A \) higher \( \text{LEQ}_A \) than STE.

The Steinway sound continues to decay rapidly in the onset oscillation (i) for a longer period than Stuart.

---

Perceptions of the Stuart & Sons Piano Sound, Part I – Kevin Hunt
Slower fundamental after-sound

4. C2v20 MW mic7  Slower Onset Decay –
Fundamental, Stuart tonal distinction 1.

<table>
<thead>
<tr>
<th>Stuart</th>
<th>USB Audio 4.1: trk.7</th>
<th>C2v20 STU MW mic7.wav</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steinway</td>
<td>USB Audio 4.1: trk.8</td>
<td>C2v20 STE MW mic7.wav</td>
</tr>
<tr>
<td>Sound table 4.22</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The SPL of both pianos for C2v20 mic7 were close to identical, 1 dB lp higher for Steinway, 82 dB. The fundamental and the overall bass frequency was audibly more complete in the Stuart sound, from the onset, and sustained more prominently, than in the Steinway sound. The Stuart fundamental (FND) in the spectrogram below, is observed to decay at a more even steady rate then all the other partials of both sounds.

C2v20 M19(STU) MW mic 7  C2v20 STE MW mic 7

The composite note of the Stuart, is decaying at a slower rate than Steinway from .3s. The sudden increase in the Steinway’s decay rate at 2s, is also visualised in the above spectrogram.

C2v20 MW mic7 Decay Graph 4.12
Tonal Distinction 2

Earlier Transition to Slower Steady Modes of Oscillation.

The initial onset oscillation of the Stuart piano sound was found to transfer earlier to the after-sound oscillation than Steinway, especially when the Stuart fundamental frequency was of a larger amplitude. As a result of this transient characteristic, a heightened level of sustain was audibly and graphically presented in the Stuart sound.

The extended period of the vertical onset vibration of the Stuart piano string, tested in the chapter two of this research, enables a quicker release of the non-resonant frequencies, for a shorter period than Steinway, and is usually accompanied by a faster rapid decay. A smoother, quicker transition into the after-sound oscillation phase occurs, which establishes a heightened level of sustain in the sound. The Stuart piano design minimizes the production of non-resonant frequencies in its sound, with the implementation of Paulello wire materials, the reduced damping of the bridge agraffe coupling, the thinner more actively resonant soundboard, more detailed grading of hammer shanks thickness, and rare earth magnets in the keyboard action.

A piano string oscillates in the vertical plane at the onset, as a consequence of the vertical hammer strike. As the vertical oscillation is of a large amplitude, it has a more transferrable impedance to the narrow wooden bridge and the energy of the onset sound is transferred from the string to the soundboard at a faster rate, which causes the sound to decay at faster rate, the onset rate of decay. The onset vibrations contain non-resonant frequencies, which are expended quickly. As energy is reflected off the large plane of the soundboard of higher impedance, waves are returned to the oscillating string, and because certain amounts of resonant and non-resonant energy has been released, the string vibration transfers to a more settled, elliptical oscillation, with slower rates of decay, the after-sound (a-s) decay. The string vibrations test by Peter Phillips in chapter 2 found that the string coupling mechanism, the Stuart bridge agraffe, extended the time period of the vertical onset string oscillation. The extended period of the vertical vibration enables the faster transition to the after-sound oscillation.

The following pages will discuss four Stuart piano sounds, which illustrate the earlier transition to the after-sound oscillation:
C5v20 MW mic2

**Soundboard:** The Steinway soundboard vibrated 35% more actively than Stuart, for the note C5v20. The fundamental frequency vibration was of larger amplitude in the Steinway soundboard, and the Stuart soundboard vibrated a larger amplitude of the 2\(^{nd}\) partial frequency. Both these findings correspond with the radiated sounds to mic2, illustrated in the spectrogram.

**Instrument Volume Mic7:** M19 (STU) 83dB, STE 82dB

**String Scale:** For the note C5, the diameter of the Paulello-Stuart wire is .35mm thicker, the tensile strength of the Paulello/Stuart wire is 138 N/mm\(^2\) higher. The Paulello-Stuart wire for C5 is 4.5mm longer, and is set at 7kg higher tension. The yield or capacity of the Paulello-Stuart wire is approximately 10% higher than the Roslau-Steinway wire.

C4v54 MW mic4

**Soundboard:** The Stuart soundboard was 71% significantly more actively vibrating than the Steinway soundboard for the note C4v54. Both the fundamental and 2\(^{nd}\) partial frequency vibrations were of greater magnitude than Steinway. In contrast to this, the Steinway radiated a larger 2\(^{nd}\) partial than Sturt, to mic 4.

**Instrument Volume Mic7:** M19 (STU) 89 dB, STE 86 dB

**String Scale:** The diameter of the Paulello/Stuart wire is .25mm thicker, the tensile strength of the Paulello/Stuart wire is 177 N/mm\(^2\) higher, the Paulello/Stuart is 1.5mm longer, and is set at 3.5kg higher tension. The yield or capacity of the Roslau/Steinway wire is 3.6% higher than Paulello/Stuart.

C3v20 MW mic5

**Soundboard:** The Stuart soundboard vibrated larger amplitudes of the Fnd, 2\(^{nd}\) & 3\(^{rd}\) partial frequencies. Overall, the Stuart s-board harmonic vibrations were 31% larger in amplitude than Steinway’s. The Steinway s-board produced larger amplitudes of upper partials 4,5,6 & 7.

**Instrument Volume Mic7:** STU 86 dB, STE 85 dB

**String Scale:** For the note C3, the diameter of the Paulello/Stuart wire is 25mm thicker, the tensile strength of the Paulello/Stuart wire is 177 N/mm\(^2\) higher, the Paulello/Stuart is 1.5mm longer, and is set at 3.5kg higher tension. The yield or capacity of the Roslau/Steinway wire is 3.6% higher than Paulello/Stuart.
C2v81 MW mic2

Soundboard: The Steinway soundboard resonated a larger fundamental frequency than Stuart. The Stuart soundboard vibrations were larger in amplitude for all the upper partials 2nd - 11th. Overall, the Stuart soundboard vibrations were 32% larger than Steinway’s.

Instrument Volume Mic7: STU 92 dB, STE 96 dB

String Scale: For the note C2, the diameter of the Paulello/Stuart core wire is .125mm thicker, the cover wire is .47mm thicker and Stainless Steel, the tensile strength of the Paulello/Stuart wire is 481 N/mm² higher, the Paulello/Stuart is 235mm longer, and is set at 65.3kg higher tension. The yield or capacity of the Paulello/Stuart wire is 46% higher than Steinway/Roslau.

Other Sounds where the Stuart transitioned earlier to the after-sound oscillations.

<table>
<thead>
<tr>
<th>C5v54 M19 (STU) MW mic3</th>
<th>intro 4.0 8 sounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4v20 M19 (STU) MW mic2</td>
<td>intro 4.0 8 sounds</td>
</tr>
<tr>
<td>C3v81 M19 (STU) MW mic5</td>
<td>intro 4.0 8 sounds</td>
</tr>
<tr>
<td>C5v81 M19 (STU) MW mic8</td>
<td>intro 4.0 8 sounds</td>
</tr>
<tr>
<td>C4v20 M19 (STU) MW mic4</td>
<td>intro 4.0 8 sounds</td>
</tr>
<tr>
<td>C5v54 M19 (STU) MW mic1</td>
<td>STU distinction No1</td>
</tr>
<tr>
<td>C4v54 M19 (STU) MW mic2</td>
<td>STU distinction No1</td>
</tr>
<tr>
<td>C3v81 M19 (STU) MW mic3</td>
<td>STU distinction No1</td>
</tr>
<tr>
<td>C5v81 M19 (STU) MW mic1</td>
<td>STU distinction No3</td>
</tr>
<tr>
<td>C4v20 M19 (STU) MW mic2</td>
<td>STU distinction No 3</td>
</tr>
<tr>
<td>C3 v20 M19 (STU) MW mic3</td>
<td>STU distinction No 3</td>
</tr>
</tbody>
</table>
Earlier Transition to slower Oscillation, Stuart Tonal Distinction 2.

1. C5v20 MW mic2

The Stuart sound is marginally louder than Steinway at mic2 by 3dB, and audibly the Stuart sustains its brighter tonal quality for a longer period than Steinway. The longer sustain is illustrated in the spectrogram. The higher amplitude of the 2nd partial frequency in the Stuart sound, influences the brighter sounding tone. At approximately 5s, the Stuart sound is audibly more present than Steinway.

The rapid onset decay in the Steinway sound (i) continues for .45s longer than Stuart. The transition from the onset oscillation to the more steady after-sound oscillation occurs sooner in the Stuart sound, than in the Steinway sound. The larger amplitude of the Stuart fundamental (Fnd.) initially decays more rapidly to .2s, when the transition to the slower oscillation and slower decay occurs, approximately .2s before the transition occurs in the Steinway sound.

C5v20 MW mic2 Decay Graph 4.13 calculation p.323
Earlier Transition to slower Oscillation, Stuart tonal distinction 2.

Steinway radiated higher levels of SPL to mic 4 than Stuart by a significant 6dB. The tone of the Steinway is brighter than Stuart, as the STE 2\textsuperscript{nd} partial (523 Hz), is larger in amplitude, with longer sustain, influencing the envelope of the Steinway sound. The Stuart transfers to the settled oscillation .7s earlier, than Steinway.

The Stuart sound is heard to sustain marginally more than Steinway at approximately 6-7s, where the ridges appear in the STU fundamental wave, on the spectrogram and in the 10s composite decay curve.

The peak volume of the Stuart fundamental is louder than Steinway’s, and decaying faster than Steinway in the onset. The larger 2\textsuperscript{nd} partial of the Steinway sound influences the composite note, with the higher SPL and the longer, slower steady decay.
Earlier Transition to slower Oscillation Stuart tonal distinction 2.

The Stuart piano radiated its sound at 3dB louder than Steinway to mic5, at velocity 20(v20). The Stuart is louder at the onset, than Steinway. The Steinway bass frequency swells after 1s, and then decays rapidly after 4s. The Stuart sound is more constant from the onset. The 3rd prt. is more prominent in the Stuart after-sound. The 2nd prt. is more prominent in the after sound of the Steinway. The onset oscillation of the Stuart sound (i), decays at 8.6dB/s, almost twice the speed of Steinway. The Stuart oscillations transfers into the first stage of the after-sound oscillation (ii) after .5s, approximately 2s before the Steinway’s transition. In the first phase of the settled after-sound oscillation (ii), the Stuart sound decays at a slower rate than Steinway after .3s.

Energy loss: The rapid loss of energy at the onset of the Stuart sound could be due to several factors. The thinner soundboard of the Stuart, vibrated with larger harmonic magnitudes, 31% more than the Steinway soundboard, and therefore is expending 31% more energy, and the vertical coupling is enabling a larger movement of the string at the onset, producing a larger louder string vibration and wider spectra, which decays at a faster rate than a quieter vibration with a narrower spectra. The Stuart sound’s rapid restoration back to a settled oscillation at .5s, is the factor which establishes a more stable sense of sustain in the sound.

Spectrogram 4ii).7 below, illustrates distinctive qualities of the Stuart’s sound. The fundamental and 2nd partial frequencies are larger in amplitude than Steinway, with faster onset decay and slower after-sound rates of decay. Steinway 3rd partial is larger in amplitude, a higher SPL, and faster after-sound decay.
The Stuart onset tone is fuller with a greater production of bass frequencies than Steinway. Steinway is brighter from the onset. At velocity strike v81, the Stuart transferred to its after-sound settled oscillation approximately 2.5s earlier than Steinway.

A slower rate of decay of Fnd, 3rd, 4th, 5th and 6th partial frequencies in the Stuart sound is illustrated in the spectrogram 4i).3 below. The 24th partial, is also distinctive, sounding a sharpened P5th, 4 octaves above the Fnd. frequency. The Frequency Response graph below, shows the Steinway’s 2nd, 3rd, 10th and 13th partials had higher SPL than Stuart at v81. The Steinway line (blue) rises above the Stuart red line, in an interesting way between 600 Hz and 1k. These higher peaks of dB of the higher partials, 9-10-11-12 -13-14, influence the brighter, brassier tone of the Steinway.
**Tonal Distinction 3: Wider Harmonic Spectrum.**

Wider spectrums of upper partials were observed in the Stuart sound when either the fundamental, 2\textsuperscript{nd} or 3\textsuperscript{rd} partials decayed at a slower rate than the Steinway sound. The higher prevalence of upper partials was observed in the onset, and/or the after-sound periods of the Stuart sound. At each of the higher notes, C3, C4 & C5, the Stuart sounds with the wider partial spectra were also observed to transfer to the settled after-sound oscillation earlier than Steinway.

As discussed in chapter 3, tone quality is determined by the intervening characteristics of the upper partials within the composite sound, at particular duration periods of the sounds’ decay. The Stuart piano sounds discussed in this section, were observed to be influenced by the interventions of their upper partials, more so than Steinway.

**C5v81 MW mic1**

**Soundboard:** The sounds of C5v81, radiating 3metres to mic1, corresponded with the harmonic vibrations in each soundboard. STE: Fnd / STU: 2\textsuperscript{nd} prl./STE: 3\textsuperscript{rd} & 4\textsuperscript{th} & 5\textsuperscript{th} & 6\textsuperscript{th} prts.

Overall at v81, the Steinway soundboard vibrations were 44\% greater amplitude than Stuart for the note C5.

**Instrument Volume Mic7:** STU 96dB, STE 97dB

**String Scale:** For the note C5, the diameter of the Paulello-Stuart wire is .35mm thicker, the tensile strength of the Paulello/Stuart wire is 138 N/mm\(^2\) higher. The Paulello-Stuart wire for C5 is 4.5mm longer, and is set at 7kg higher tension. The yield or capacity of the Paulello-Stuart wire is approximately 10\% higher than the Roslau-Steinway wire.

**C4v81 MW mic1**

**Soundboard:** The Stuart soundboard vibrated higher amplitudes of the Fnd. and 2\textsuperscript{nd} partial frequencies. Overall the Stuart soundboard vibrations for C4v81 were 67\% larger than Steinway.

**String Scale:** The diameter of the Paulello/Stuart wire is .25mm thicker, the tensile strength of the Paulello/Stuart wire is 177 N/mm\(^2\) higher, the Paulello/Stuart is 1.5mm longer, and is set at 3.5kg higher tension. The yield or capacity of the Roslau/Steinway wire is 3.6\% higher than Paulello/Stuart.

**Instrument Volume Mic7:** STU 96dB, STE 92dB

**Soundboard:** Stuart soundboard vibrated 67\% larger amplitudes. STU: Fnd. & 2\textsuperscript{nd}
C3 v20 MW mic3

**Soundboard:** The Stuart Fnd and 2\textsuperscript{nd} prt. were resonated strongly in the Stuart soundboard. Steinway soundboard vibrated a wider spectrum of upper partials than Stuart. STU: Fnd.; 2\textsuperscript{nd}; 3\textsuperscript{rd}; 4\textsuperscript{th}, 5\textsuperscript{th}, 6\textsuperscript{th}, 7\textsuperscript{th}. Overall, at v20, the Stuart soundboard vibrations were 31\% larger in amplitude than Steinway, for the note C3.

**Instrument Volume Mic7:** STU 86dB, STE 85dB

**String Scale:** For the note C3, the diameter of the Paulello/Stuart wire is 25mm thicker, the tensile strength of the Paulello/Stuart wire is 177 N/mm\textsuperscript{2} higher, the Paulello/Stuart is 1.5mm longer, and is set at 3.5kg higher tension. The yield or capacity of the Roslau/Steinway wire is 3.6\% higher than Paulello/Stuart.

C2v20 MW mic 6

**Soundboard:** The wider spectrum radiated in the Stuart sound to mic2, corresponded to the spectrum which vibrated in the Stuart soundboard. Fnd: STU=STE/ STU: 2\textsuperscript{nd}; 3\textsuperscript{rd}; 4\textsuperscript{th}, 5\textsuperscript{th}, 6\textsuperscript{th}, 7\textsuperscript{th}. Overall, at v20, the Stuart soundboard vibrations were 52\% larger in amplitude than Steinway, for the note C2.

**Instrument Volume Mic7:** STU 81dB, STE 82dB

**String Scale:** For the note C2, the diameter of the Paulello/Stuart core wire is .125mm thicker, the cover wire is .47mm thicker and Stainless Steel, the tensile strength of the Paulello/Stuart wire is 481 N/mm\textsuperscript{2} higher, the Paulello/Stuart is 235mm longer, and is set at 65.3kg higher tension. The yield or capacity of the Paulello/Stuart wire is 46\% higher than Steinway/Roslau.

**Other Stuart piano sounds** previously discussed- with a wider spectrum than Steinway:

<table>
<thead>
<tr>
<th>C5v81 MW mic8 (4.0 intro)</th>
<th>C3v81 MW mic5 (4.0 intro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5v54 MW mic1 (Stu Dist 1)</td>
<td>C3v81 MW mic3 (Stu Dist 1)</td>
</tr>
<tr>
<td>C5v54 MW mic3 (4.0 intro)</td>
<td>C3v20 MW mic5 (Stu Dist 2)</td>
</tr>
<tr>
<td>C5v20 MW mic2 (Stu Dist 2)</td>
<td>C2v54 MW mic7 (4.0 intro)</td>
</tr>
<tr>
<td>C4v54 MW mic2 (Stu Dist 1)</td>
<td>C2v54 MW mic6 (4.0 intro)</td>
</tr>
<tr>
<td>C4v20 MW mic2 (4.0 intro)</td>
<td>C2v20 MW mic7 (Stu Dist 1)</td>
</tr>
<tr>
<td>C4v20 MW mic4 (4.0 intro)</td>
<td>C2v20 MW mic6 (Stu Dist 3)</td>
</tr>
</tbody>
</table>

Other sounds with wider spectras: C2v20, v81 MW mic7; // C3v54 mic7
Wider Harmonic Spectrum, Stuart tonal distinction 3.

1. C5v81 MW mic1.

The Stuart and Steinway radiated the sound of C5v81 at identical SPL of 86dB, to mic 1.

The Stuart tone is brighter, possibly due to the slower decay of the fundamental, enabling the wider spectra of the 2nd and 3rd partials, to be heard more openly, for a longer period. There is therefore a greater even sustain in the tonal balance in the onset and after-sound of the Stuart sound. In the 1st second of the Steinway sound, rapidly diminishing SPL output is heard, due to the more rapid decay of its fundamental frequency. This change in tonal and volume level is not heard in the Stuart sound. The 3rd partial is heard more prominently in the first 3 seconds of the Steinway sound, though is audibly more present for a longer period in the Stuart sound.

![C5v81 MW mic1 Spectrogram 4.48](image1)

The sustained tonal balance in the Stuart sound is supported by the stability of the slowly decay rate of its fundamental frequency.

![C5v81 MW mic1 Spectrogram 4.49](image2)

After a rapid decay and briefer onset oscillation period (i), the Stuart sound loses less energy, transferring to its 1st phase of settled steady-state oscillation (ii), .5s earlier than Steinway.

![C5v81 MW mic1 Decay Graph 4.22](image3)
Wider Harmonic Spectrum, Stuart tonal distinction 3.

2. C3v20 mic3.

Both Stuart and Steinway sound radiated C3v20 at 74dB to mic3.

The larger dynamic range of the Stuart is evident at the onset, with a percussive impact of sound, and a faster rise to its full sound. The Stuart Fnd, 2nd, 4th & 6th prt. are larger at the onset, as viewed in the spectrogram below. The Steinway spectrum evolves more gradually at the onset, whereas the wider and brighter Stuart spectra is clearly more immediately at the onset.

The rapid decay in the Steinway’s 2nd partial at 2s, influences a sudden softening of the composite SPL. The Stuart sound decayed at marginally slower rate than Steinway, after 4s.

The faster onset decay of the composite Stuart sound (i), transfers to the after-sound settled oscillation (ii) 2s earlier than the Steinway (ii) . The onset and after-sound amplitudes of each 2nd partial directly influences the loss of energy observed in the decay curve.
Wider Harmonic Spectrum, Stuart tonal distinction 3.


The Stuart piano strings and soundboard have produced a wider, louder spectrum. The Stuart sound is 9dB lp and 8 dB\textsubscript{A} louder than Steinway at mic 6. The Stuart has a more full-bodied round sound, with greater bass frequency tone, and more prominence of the 2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th}, 5\textsuperscript{th} & 6\textsuperscript{th} partials. With longer and thicker bi-chord strings, wrapped in stainless steel, higher higher yield capacity set at significantly higher tension, and with the soundboard vibrating 52% larger amplitudes of significantly the 2\textsuperscript{nd} prt.

The Steinway has a brighter thinner tone.

The Stuart piano sound, decayed at a faster than Steinway, in an exponential decay of amplitude 247, from a significantly louder onset. At 3s, the Stuart rate of decay slowed momentarily for 1s, similar to the Stuart decay curve at mic2.


The Stuart 90dB, and Steinway 91dB, both radiated similar strong SPL levels of C4v81, to mic1. The Stuart sounds brighter. The number of upper partials illustrated in the .5s spectrogram below, are also similar for each sound, except the Stuart partials are more clearly defined, and the 8th pt of the Stuart and the 7th of the Steinway are more prominent. The high b7 in the Steinway is prominent in the sound, as is the high P5th in the Stuart sound. Generally the Stuart sound is more harmonically balanced, and harmonious. The Steinway tonal spectra, changes more frequently than Stuart’s. The Stuart at 90dB, and Steinway 91dB, both radiated strong SPL levels of C4v81, to mic1. The Stuart sounds brighter. The number of upper partials illustrated in the .5s spectrogram below, are also similar for each sound, except the Stuart partials are more clearly defined, and the 8th pt. of the Stuart and the 7th of the Steinway are more prominent. The high b7 in the Steinway is prominent in the sound, as is the high P5th in the Stuart sound. Generally the Stuart sound is more harmonically balanced, and harmonious. The Steinway tonal spectra changed more frequently than Stuart’s.

The main difference in the spectrums is the slower decay rates in the after-sound of the Fnd. and 2nd pt. Both the Fnd. and 2nd partials of the Stuart piano sound decayed at a slower rate than Steinway, between .5 and 2s.
The composite Steinway sound is heard to diminish in volume at .5s, which creates more of an unbalanced movement within the sound of the note, as the 2nd prt. and Fnd. decay more rapidly.

The Steinway sound decayed faster than Stuart’s from .6 to 1.2s. The Stuart sound transferred to the settled after-sound oscillation .7s earlier than Steinway.
Tonal Distinction 4 - Directivity

C2 directivity
M19 (STU) C2 to mic 6; STE C2 to mic 2

In the MW 3 metre microphone array, across the three velocities, the Stuart piano radiated it’s maximum SPL of the note C2 to mic 6, away from the pianist, in the direction of 180°, and the Steinway radiated maximum SPL of the note to mic 2, 30° off centre, on the side of the pianist.

The Stuart piano was the louder instrument across the three velocity strikes, of C2 sounds which travelled 3 metres to mics 2 & 6. The volume levels of both pianos are closer together at mic2.

The factors of string scaling, length, tension, type, yield and coupling are major factors in why the Stuart was significantly louder, as well as a significant difference in the amplitudes of soundboard vibrations. For the note C2, the diameter of the Paulello/Stuart core wire is .125mm thicker, the cover wire is .47mm thicker and is stainless steel \(^{248}\), the tensile strength of the Paulello/Stuart wire is 481 N/mm\(^2\) higher, the Paulello/Stuart is 235mm longer, and is set at 65.3kg higher tension. The yield or capacity of the Paulello/Stuart wire is 46% higher than Steinway/Roslau.

Both instrumental volumes (mic7) were louder in the Steinway sound.

C2v81 MW mic6,
Instrument Volume Mic7: STU 92dB, STE 96dB
Soundboard: The Steinway soundboard vibrated a larger Fnd., and the Stuart board vibrated larger vibrations of the rest of the spectrum, 1-10 harmonic frequencies. Overall, the Stuart soundboard vibrated 47% more actively for C2v81.

C2v54 MW mic2.
Instrument Volume Mic7: STU 88dB, STE 89dB
Soundboard: The Steinway soundboard vibrated the Fnd and 3\(^{rd}\) prt. as strongly as the Stuart soundboard. Overall, the Stuart soundboard vibrated 44% more actively across the spectrum.

\(^{248}\) Stainless steel is 1.9g per cubic cm lighter than copper in specific gravity.  
The sounds of the note C2 of both pianos, at their strongest directivity SPL radiations, are examined in the following pages. Both sounds C2v81 mic6 and C2v54 mic2, have not previously been discussed. For cross checking levels, C2v81 mic2 was previously discussed on p.122, in the tonal distinction No. 2, ‘Earlier Transition to After-Sound Oscillation.’


The Stuart bass frequency is more prominent than Steinway's. A harmonious upper partial is prominently sounding, the P12th above, the Stuart Fnd. which corresponds with the 3rd partial frequency shown to be prominent in the Stuart sound. The Stuart Fnd. is shown below to have decayed at a marginally slower rate than the Steinway Fnd. at both the onset and after-sound oscillations. This slower decay in after-sound oscillation is illustrated in more detail (ii), in the decay curve table 4.26 below. The 3rd, 4th, 5th and 6th partials of the Stuart also decayed at a slower rate than Steinway.

Excluding the onset of the note C2 v81, in spectrogram 4.9 below, illustrates graphically what we hear in the more stable, clear, less cluttered beginning of the note, of the Stuart sound. The coloured ‘ridges’ of the partials in the spectrogram, are graphic displays of the SPL dB levels of each individual partial, decaying towards the front, from the peak of the onset on the rear axis. The ‘ridges’ of the Stuart Fnd, 2nd & 3rd partials, are more evenly displayed than the Steinway ridges of the same partials, and the higher ridge of the Stuart 3rd ppt. seems to be the strongest of all the partials, showing very little decay.
The Steinway sounded higher dB peaks of the 7th and 14th partials, than Stuart, both these partials produce the less than harmonious 7th interval, 1 & 2 octaves above the fundamental.

The higher dB peak and slower decay of the 24th partial of the Stuart, 1569.74Hz, (P5th pitch) is distinctive in this note C2v81mic6, below, as it was for C2v81mic2. The Stuart piano was 7dB louder than Steinway at mic6, and radiated higher SPL of Fnd., 3rd, 4th, 5th, 9th and 24th partial frequencies.

The Frequency Response graph above, shows the Steinway’s 2nd, 3rd, 10th and 13th partials had higher SPL than Stuart at v81. The Steinway line (blue) rises above the Stuart (red) line, in an interesting way between 600 Hz and 1k. These higher peaks of dB of the higher partials, 9-10-11-12-13, influence the brighter, brassier tone of the Steinway.

The onset rate of decay of the composite Stuart sound, was faster than the Steinway, the exponential decay being associated with its larger amplitude. At 3s, the Stuart rate of decay slowed for 1s, similar to the Stuart decay curve for the note C2v54 mic2. (See next page).

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249 Roederer, 122.
The slower rate of decay in the fundamental both in the onset and after-sound, has influenced a momentary slower after-sound decay rate at 3s. (ii). A wider spectrum was observed with longer durations of the $3^{rd}$, $4^{th}$, $5^{th}$ and $6^{th}$ partial frequencies. The wider spectrum was also observed in at the Stuart onset, with larger amplitudes of the $3^{rd}$, $4^{th}$, $5^{th}$ & $6^{th}$ partial frequencies.
2. **C2v54 MW mic 2. STE maximum SPL radiation**

Even though this is a maximum SPL radiation of Steinway’s C2, the Stuart sound is 3dB louder at mic2. The resonating upper partial frequencies heard in the audio, are distinctly harmonious 3rd, 5th in the Stuart sound and dissonant in the Steinway sound, 7th 14th 9th 18th. There is distinctly more partial movement in the Steinway sound after 3s, than Stuart. The partials are sustaining more in the Stuart sound. The spectrogram below illustrates the Stuart’s more clearly defined fundamental frequency, and longer durations of the 3rd, 4th 5th and 6th partials.

![C2v54 M19 (STU) MW mic 2](image1)

![C2v54 STE MW mic2](image2)

C2v54 MW mic 2 Spectrogram 4.57

After the initial onset period, the Stuart sound decayed at a slower rate than Steinway, establishing it’s after-sound settled oscillation, earlier than Steinway.

![C2v4 MW mic2 Decay Graph](image3)
Distinctions of the Stuart piano sound: C2, mics 2 & 6 MW.

The characteristics of the Stuart sound previously described in the introduction of chapter four, have been observed in the sounds C2v54 MW mic2, and C2v81 MW mic6.

i) The Stuart sounds consisted of a wider spectrum with larger amplitudes of the fundamental, 3rd, 5th, 6th and 24th partial frequencies.

ii) The Stuart sound had fuller bass frequencies, which sustained in a stable, slow steady rate of decay with an after-sound of M3rd and P5th intervals, i.e. 5th and 3rd partials. The Steinway sound was brighter, thinner, with a characteristic of 7th and 9th intervals in its after-sound, and characterised by more metallic buzz noise, Wolfenden’s ‘vizz’ of the trichord.250

iii) Stuart produced a faster onset rate of decay, plotted at .5s.

iv) The onset oscillation of the Stuart sound of C2v54 MWmic2, transferred earlier than Steinway to its settled after-sound oscillation, enhancing its transient sustain quality.

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250 Wolfenden,209.
C3 Directivity

C3v81 MW mic1.

The Stuart & Steinway pianos both radiated maximum SPL of the note C3 to mic 1 & 5 equally, in two opposite directions, mic1 180° to the pianist, and mic5 150° away from the pianist, indicated in by the dashed lines in the graph below. This section examines the C3 sounds radiated to mic1. C3 sounds at mic5 have been discussed in earlier sections of this chapter.

The Stuart sound was marginally louder at mic1 across the three velocity strikes. The Stuart piano was marginally louder than Steinway at mic1, by 1dB. A sudden rise ‘swelling’ in the bass frequency level of the Steinway sound occurs between .5s, - 1s. At this precise time, the Spectrogram below shows a sudden decay occurs in the STE Fnd, an the 2nd ptr is continuing a stable rate of decay. The 3rd & 4th STE prts are also decaying at steady rates. The sense of unstable tonal & harmonic movement in the onset, in the Steinway sound, is therefore due to the sudden change in the fundamental level. A high 7th or 14th ptr is also prominent in Steinway’s after-sound. The Stuart C3 produces a more balance sound, of increased clarity, without the changing level of the bass frequency. The spectrogram below shows the Stuart fundamental frequency sustains between .3s and 1s, producing a more stable bass frequency. The Stuart sound has a more percussive brighter tone in the onset, due to louder 2nd, 3rd & 4th partials. The 2nd ptr. an octave above Fnd., is also more audible in the sound Stuart sound. The 3rd, 4th and 5th partials are more prominent in the Steinway spectrogram below.
**String Scale:** For the note C3, the diameter of both wires is identical at 1.125mm. The tensile strength of the Paulello/Stuart wire is 140.5 N/mm² higher, the Roslau/Steinway is 41mm longer, and is set at 6.7kg higher tension. The yield or capacity of the Paulello/Stuart wire is 8% higher than Roslau/Steinway.

**Instrument Volume Mic7:** STU 98dB, STE 97dB

**Soundboard:** The Stuart soundboard vibrated strong amplitudes of the Fnd., 2nd, 6th & 9th prts. The Steinway’s board produced prominent vibrations of the 3rd, 4th & 7th prts.

The Stuart sound transfers to the slower settled rate of decay sooner than Steinway, at 1s, establishing a slower rate of decay 3dB/s (ii)

**Conclusion**

The stability of the first 1s of sound is a distinction of the Stuart piano sounds of the note C3. The Steinway was heard to change dramatically with the swelling of the bass frequency and the sudden decay of the fundamental. The slower decay of the Stuart fundamental frequency from .3s, and the earlier transition to the slower decay rate at 1s, are tonal characteristics which are observed in many of the Stuart sounds observed in chapter 4.
C4 Directivity

The Stuart and Steinway pianos radiated waves of maximum SPL of the note C4 in four directions within the 180° array, to mics 1, 2, 4, & 5. The sounds C4 v54 mic1, and C4 v54 mic5 will be discussed in this section, as C4 sounds to mics 2 & 4 were examined in preceding sections, of this chapter.

The Steinway piano sound radiated maximum SPL of C3 to mic 1, and the Stuart to mic 5:

The instrumental volume was similar, for both pianos:
C4 v54 mic7: STU 89 dB STE 86 dB

Soundboards: C4 v54:
The Stuart soundboard resonated larger amplitudes of the fundamental and 2\textsuperscript{nd} partial frequencies. Overall, the Stuart soundboard vibrated at 71% greater magnitude than the Steinway soundboard for C4 v54

C4 String scale:
The diameter of the Paulello/Stuart wire is .25mm thicker, the tensile strength of the Paulello/Stuart wire is 177 N/mm\textsuperscript{2} higher, the Paulello/Stuart is 1.5mm longer, and is set at 3.5kg higher tension.

The yield or capacity of the Roslau/Steinway wire is 3.6% higher than Paulello/Stuart.
The higher octave partial frequencies, 2\textsuperscript{nd} & 4\textsuperscript{th} are more audible in the onset of the Stuart sound, establishing a brighter tone. The 3\textsuperscript{rd} + 7\textsuperscript{th} or 14\textsuperscript{th} part. are more immediately prominent in the Steinway sound. The bright tone of the Stuart is sustained for longer than in the Steinway sound. The Steinway tonal colour balance changes dramatically at approximately 1s, becoming less bright and clear.

The spectrogram below shows the Steinway fundamental and 2\textsuperscript{nd} partial frequency decayed at a faster rates than Stuart after .5s

The decay curve below illustrates the earlier transition of the Stuart sound into its more settled after-sound oscillation (ii)

The Stuart sound has sustained its bright colour, in a more stable harmonic balance than Steinway.
The Stuart is 4dB louder, with a larger in amplitude onset harmonic spectrum, of the Fnd, 2nd, 3rd & 4th partial frequencies. The Steinway sound colour changes tonally and in amplitude at approximately .5s. The spectrogram below shows a moderate increase in Steinway’s 4th partial amplitude at approximately .2s. The onset attack is marginally slower in the Stuart sound, followed by a dramatic rapid decay of the fundamental and 2nd partials between .2-.6s.

The spectrogram plot of 3s below, shows the Fnd. and 2nd prts. to be sustaining and decaying at opposite periods. At .8s, the Stuart is in rapid decay, whereas the Steinway is steadily and at 1.5s, the Stuart Fnd & 2nd partials sustain their levels at 1.5s, whilst the Steinway decays more rapidly.

The decay curve shows a typical pattern of Stuart sound, a faster onset decay 0-.5s (i), and an earlier transition into the slower after-sound oscillation, signalled at 1.5s (ii)
C5 Directivity

The maximum SPL of the note C5, for each of the three velocity strikes, radiated from the Stuart piano to mic2, 45° from the pianist, and from the Steinway piano 180° away from the pianist, to mic 6.

The radiation pattern for C5 is exactly reversed from that of the note, C2, where the Steinway radiated maximum SPL to mic2, and the Stuart to mic6.

This section will discuss the qualities of the C5v81 radiations in both directions of mic2 and mic6.

The Steinway sound radiated maximum SPL to mic 6 and the Stuart to mic 2. The very marginal difference of volume of 1dB for C5v81, at mic2, was larger for the slower softer velocity strikes, the Stuart was 3dB louder at v20, and 4dB louder for v54. Mic 6 captured a much wider contrast in SPL. The Steinway piano was 10dB louder than Stuart at mic6 for both v20 and v81, and 8dB at v54.

The instrumental volume of C5v81 was similar, for both pianos. mic7: STU 96 dB , STE 97 dB

The Steinway soundboard vibrated a significantly larger amplitude of the fundamental frequency, than Stuart for the note C5v81. The Stuart soundboard vibrated a larger 2nd partial. Steinway s/board also produced larger 3rd, 4th, 5th & 6th partials. Overall the Steinway soundboard vibrated 44% more actively than the Stuart soundboard for C5v81.

For the note C5, the diameter of the Paulello-Stuart wire is .35mm thicker, the tensile strength of the Paulello/Stuart wire is 138 N/mm² higher. The Paulello-Stuart wire for C5 is 4.5mm longer, and is set at 7kg higher tension. The yield or capacity of the Paulello-Stuart wire is approximately 10% higher than the Roslau-Steinway wire.
The Stuart onset is brighter in tone than the Steinway. The spectrogram below shows the Stuart fundamental, 2nd and 3rd partial frequencies each have higher peak volume levels, at the onset. The onset of the Stuart fundamental is observed to be decaying faster in the onset to .5s, and then at .5s to transfer to a significantly slower decay.

The energy curve below, shows the earlier transition of the Stuart sound, from the onset oscillation (i) to the after-sound oscillation (ii), indicated by the change in the decay rate.

The Stuart sound also arrives at its 2nd phase after-sound oscillation (iii) earlier than Steinway (iii).

The Stuart sound sustains significantly more than the Steinway sound, between 4s- 8s.
The Steinway sound at mic6 is 10dB louder than Stuart, as shown in the spectrogram below, the fundamental of the Steinway is significantly louder and larger in amplitude. The Steinway has a fuller tone. Quite possibly, we are hearing the effect of the larger Fnd. sounded by the Steinway soundboard, and its 44% greater vibration of the harmonic spectrum. The Stuart sound is brighter in tone, at the onset. The spectrogram below shows the 2nd partial frequency of the Stuart sound was louder than the Steinway’s 2nd partial, at the onset, which also corresponds with the vibrations of the Stuart soundboard. The onset periods of Stuart Fnd., 2nd & 3rd partial frequencies are decaying are slower rates to .2s.

The decay curve below indicates that the Stuart onset oscillation is very rapid (i), transferring to the steady after-sound oscillation at .2s(ii). The rapid decay of the Steinway onset oscillation (i) continues to .5s in a longer duration than Stuart (i). The Stuart enters its steady oscillation (ii) at .2s, .4s earlier than Steinway, (ii).

Conclusion:

The larger amplitude of the 2nd prt. in the Stuart sound of C5v81 at mics 2& 6, has influenced the brighter tone, and indicates a larger spectrum of upper partials in the onset period of the Stuart sound. The steady oscillation of the Stuart’s after-sound period, occurred earlier in the notes’ durations, at both mics2 & 6. At both microphones, the Stuart fundamental decayed at a slower rate than Steinway before 1s, generating a greater sustain in the sound, especially at mic2, after 4s.
Tonal Distinction 5 - Projection Quality to 6 metres.

The qualities of tone radiated to microphone 8 were measured to examine the projected volume and spectra of both pianos, to a distance of 6 metres, in the direction of 90°. The amplitudes of soundboard vibrations of the same sounds were also examined to see if they corresponded to the projection levels at mic 8.

Microphone 8 was positioned at 90° and 6 metres from the same measuring point on both pianos, in the MW performance space. Each piano was moved to identical positions in the MW space.

It was found that the Stuart piano projected significantly larger harmonic spectra with larger amplitudes of the Fnd., 2nd, 3rd & 4th partial frequencies, of the notes C2, C3, & C5. Both pianos sounded more similar levels and spectra of note C4 261 Hz. The magnitudes of the soundboard vibrations for each of the notes, corresponded with the contrasting radiated SPL of C2, C3, & C5 as well as the similarity of SPL levels for C4.

The boxgraph illustrates the generalised contrasts in SPL radiated to microphone 8, of the four notes, across the three velocity strikes. The SPL of the sounds of 12 notes on each piano, are represented in this graph. Each range, r1 - 4, partitions the SPL (dB) range of 12 sounds, into 4 segments, each of 3 notes, in their order of loudness. The loudest two ranges, r3 + r4, and the softest range, r1, are larger in the Steinway sound. A larger range is telling us that the difference in the softest and loudest note of that particular range is greater.

The three loudest notes of the Stuart sound, r4, struck at v81, are closer together in SPL than the 3 loudest notes produced by the Steinway, r4. The 3 quietest notes, r1, struck at v20 velocity strike were at an average 10dB louder in the Stuart sound, than Steinway. Continuing this test, using slower velocity strikes than v20, may produce data demonstrating that a wider SPL range is radiated by the Stuart piano to 6 metres.

This contrast can be more closely examined in the box graphs of specific notes, in the flowing pages. The telling result of the box graph above, is the extent of the difference in SPL which radiated to mic 8. In every range, the Stuart sound is significantly louder than Steinway.
C2v81 MW mic8 Projection, Stuart tonal distinction 5.

<table>
<thead>
<tr>
<th>Stuart</th>
<th>USB Audio 4.1: trk.39</th>
<th>C2v81 M19(STU) MW mic8.wav</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steinway</td>
<td>USB Audio 4.1: trk.40</td>
<td>C2v81 STE MW mic8.wav</td>
</tr>
</tbody>
</table>

C2v81, sounded 9dB louder than Steinway at 6metres. The slower velocity strikes of C2 produced wider contrasts in SPL.12dB for v20 and 11dB for v54. Box graph _ shows the exact dB levels of the 6 notes.

Stuart produced a more complete harmonic spectrum , as illustrated in the spectrogram below, with a significantly larger fundamental, 2nd, 3rd, 4th, and 5th partial frequencies. The Stuart fundamental frequency rate of decay slowed significantly more than Steinway in it’s after-sound.

The decay curves below, show the Stuart (i) to be decaying faster in the onset, and to be settling into its after-sound oscillation (ii), approximately 5s earlier than Steinway (ii).

Soundboard: The Stuart soundboard vibrated larger harmonic vibrations than Steinway by 47% , for C2v81. The Spectrum of the Stuart s-board was wider, with strong vibrations of the Fundamental to the 13th partial frequency. The Steinway didn’t vibrate higher than the 9th partial, and vibrated a larger fundamental frequency than Stuart.

String scale: The C2 string diameter of the Paulello/Stuart core wire is .125mm thicker, the cover wire is .47mm thicker and Stainless Steel, the tensile strength of the Paulello/Stuart wire is 481 N/mm² higher, the Paulello/Stuart is 235mm longer, and is set at 65.3kg higher tension. The yield or capacity of the Paulello/Stuart. wire is 46% higher than Paulello/Stuart.

C2 v81 exhibited the three distinctive characteristics of the Stuart sound found in previous tests, slower decay in the fundamental, a wider spectrum and earlier entry into the after-sound oscillation.
Perceptions of the Stuart & Sons Piano – Kevin Hunt

C5v54 MW mic 8  Projection, Stuart tonal distinction 5.

<table>
<thead>
<tr>
<th>Stuart</th>
<th>USB Audio 4.1: trk.41</th>
<th>Steinway</th>
<th>USB Audio 4.1: trk.42</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5v54 M19(STU) Mic8.wav</td>
<td>C5v54 STE MW Mic8.wav</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sound table 4.39</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Stuart was 9 dB louder than Steinway at mic 8, at the velocity strike of v54. The attack sound is more present in the Stuart sound. After 1s of, the Steinway sound is heard to rapidly diminish in volume, and settle to a quieter level of sustain than the Stuart. The Stuart sound is not heard to diminish in volume, till approximately 3.5s. The Stuart tonal colour is brighter at the onset, and throughout the after-sound. The larger 2nd and 3rd partials with significantly slower rates of decay, are influencing the brighter tone. The Stuart soundboard also resonated larger amplitudes of the 2nd & 3rd partial frequencies. The Spectrogram below shows, the Stuart fundamental frequency is larger in amplitude, louder, and is decaying at a slower rate than Steinway, after .5s . After .5s, the Stuart sound is audibly heard to sustain more gradually and steadily, than Steinway.

<table>
<thead>
<tr>
<th>C5v54 M19 (STU)MW mic 8</th>
<th>C5v54 STE MW mic 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrogram 4.66</td>
<td></td>
</tr>
</tbody>
</table>

The onset of the Stuart sound (i) decayed at a slightly faster rate than Steinway in the onset of C5v54. The Steinway (ii) transfers earlier than Stuart into its slower after-sound oscillation. The Stuart’s initial period of the after sound oscillation (ii) decays at a slower rate than Steinway. The Steinway settles into its 2nd phase of after sound (iii) oscillation 1s earlier than Stuart.

<table>
<thead>
<tr>
<th>C5v54 MW mic 8 M19 (STU), STE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decay Graph 4.34 calculation p.324</td>
</tr>
</tbody>
</table>

Soundboard: The Steinway soundboard vibrated larger magnitudes of the fundamental, 4th, 5th & partial frequencies than Stuart. The Stuart soundboard vibrated a larger 2nd & 3rd partial frequency. The magnitude of the total movement of the Steinway soundboard was found to be 46% higher than the Stuart soundboard for C5v54

String Scale: For the note C5, the diameter of the Paulello-Stuart wire is .35mm thicker, the tensile strength of the Paulello/Stuart wire is 138 N/mm² higher. The Paulello-Stuart wire for C5 is 4.5mm longer, and is set at 7kg higher tension. The yield or capacity of the Paulello-Stuart wire is approximately 10% higher than the Roslau-Steinway wire.
**Perceptions of the Stuart & Sons Piano – Kevin Hunt**

Projection, Stuart tonal distinction 5.

<table>
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<tr>
<th>Stuart</th>
<th>USB Audio 4.1: trk.43</th>
<th>Steinway</th>
<th>USB Audio 4.1: trk.44</th>
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</thead>
<tbody>
<tr>
<td>C4v81 M19 (STU) MW mic8.wav</td>
<td>C4v81 STE MW mic8.wav</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SPL levels are very marginally different, 1 dB apart. The leq, filtering is more indicative of the Stuart’s brighter, louder onset. The 2nd partial is more distinctive in the Stuart sound. After 1s, the Steinway sound is heard to rapidly diminish in volume, which influences the rounder tonal colour, whereas the Stuart volume level doesn’t diminished till 2.5s, establishing a brighter tone, of a wider harmonic spectrum, for a longer period than Steinway, before any change occurs in the tonal colour. The Stuart therefore, sounds a more sustained tonal balance, with less change, from the onset.

The spectrogram below shows the Stuart fundamental and 2nd partial frequencies are larger in amplitude than the Steinway. The higher amplitudes of the 2nd, & 4th partials in the Stuart sound would influence the brightness of the tone.

After a slower onset (i), the Stuart sound transfers to its after-sound oscillation (ii), .7s earlier than Steinway, establishing a more prominent sustain, earlier in the duration of the sound.

Soundboard:
The Stuart soundboard vibrated larger fundamental and 2nd partial frequencies, than the Steinway soundboard. The overall vibration of the soundboard across the harmonic spectrum for C4v81, was 67% greater in the Stuart soundboard.

The string scale of C4:
The diameter of the Paulello/Stuart wire is .25mm thicker, the tensile strength of the Paulello/Stuart wire is 177 N/mm² higher, the Paulello/Stuart is 1.5mm longer, and is set at 3.5kg higher tension. The yield or capacity of the Roslau/Steinway wire is 3.6% higher than Paulello/Stuart.
The Stuart sound of C3v81 was 10 dB louder than Steinway at mic 8. The Steinway bass frequencies ‘swell’ at 1s, illustrated in the spectrogram below, Fnd. at 1s. The Stuart spectrum is more stable, with less change. Inner harmonic balance of the two sounds is a distinguishing factor in describing the sounds.

The Stuart sound of C3v81, was 10dB louder than Steinway at mic 8. The Steinway bass frequencies ‘swell’ at 1s, illustrated in the spectrogram below, Fnd. at 1s. The Stuart spectrum is more stable, with less change. Balance of the two sounds is a distinguishing factor in describing the sounds.

The Stuart piano sound produced a significantly wider and louder harmonic spectrum. The 2nd & 3rd partial frequencies of the Stuart sound, are larger in amplitude and have slower rates of decay, than in the Steinway sound. The Stuart tone is brighter, and has a significantly more stable harmonic balance than the Steinway tone. The Steinway sound is in a constant state of change, with a dramatic swelling of the bass frequency at 1s, another swell at 4s, and a rapid decay at 6s. The longer duration of the 2nd partial frequency of the Stuart, has produced a note with more sustain.

The energy decay curve shows later transition to the slower oscillation of the Stuart sound (ii), to be significantly slower than Steinway (ii) at 3.2s.
Perceptions of the Stuart & Sons Piano – Kevin Hunt

Soundboard: At the 4 probe positions, the Stuart soundboard vibrated at 19% greater magnitude than the Steinway soundboard for C3\textsubscript{v81}.

The string scale of C3: The diameter of both wires is identical at 1.125mm. The tensile strength of the Paulello/Stuart wire is 140.5 N/mm\textsuperscript{2} higher, the Roslau/Steinway is 41mm longer, and is set at 6.7kg higher tension. The yield or capacity of the Paulello/Stuart wire is 8% higher than Roslau/Steinway.

Conclusion - Chapter 4.

The analysis of tonal colour of 96 piano tones of the sounds of two pianos, the Stuart No 19 (M19 STU) and the Steinway D No574500 (STE), found that three distinct transient qualities consistently combined to influence the distinctive tonal colour of the Stuart piano sound, across a frequency range C\textsubscript{2} 65.406 Hz to C\textsubscript{5} 523.25Hz, in a 180° sound field of 6 calibrated microphones, each positioned at an equal distance of 3 metres from the pianos, in the Music Workshop performance space, and struck at three calibrated velocities.

i) A slower fundamental frequency rate of decay,

ii) An earlier transition to the slower oscillation,

iii) A wider harmonic spectrum.

A calibrated microphone positioned at 6 metres distance from the pianos at 90°, provided sound data to support the finding that the Stuart sounds radiated to 6 metres were significantly louder and harmonically more balanced than Steinway, for the notes C\textsubscript{2}, C\textsubscript{3}, and C\textsubscript{5} at each of the three calibrated velocity strikes.
Stuart Tonal Colour Outcomes; relating to Stuart Design Concepts

- The faster rate of decay in the onset of the Stuart string vibration was found to occur because of less resistance to the vertical plane of the hammer strike, due to its vertical coupling.

- The larger amplitudes of the Stuart Fnd. 2nd and 3rd partials, subsequently causes a faster inverse decay reaction in the onset of the sound, as well as a wider harmonic spectrum.

- The Stuart’s earlier change into the slower decay rate (after-sound) is due to a proportionally smaller change in the vibrational mode from vertical to elliptical, i.e. less damping, which is heard in the stability of the tonal balance of the after-sound.

  Changes in [vibration] mode = damping. No change [in vibrational mode] can contribute to a greater motion and quicker loss as your figures indicate but the lack of subsequent changes in mode ultimately reduces the overall [energy] loss in comparison to the ever changing back and forth motions of the pinned bridge scenario.²⁵¹

- The Steinway’s higher degree of stress on the horizontally pinned string which when forced into the vertical plane by the hammer strike, causes a higher amount of damping, resulting in a longer inverse decay rate at the onset, of smaller gradations, subsequently losing more energy over a longer period, before settling into its after-sound.

The comparison tests in tonal colour, conducted in chapter 4 have produced sufficient evidence which supports the claim that the Stuart piano produces a sound that is in distinct contrast to the standardised sound of the modern piano. It has been clear to many listeners that the Stuart sound was audibly different, the data presented in chapter 4 now illustrates the difference we are hearing.

The detailed examinations of the characteristics of loudness, pitch and timbre of the four notes in an identical acoustic environment, excited by an identical calibrated energy source, enabled the tonal differences of the four notes of both pianos to be described in purely technical terms. The transient components of piano sound, attack, sustain and decay have been measured in terms of their magnitude. Temporal measurements of both the composite complex sound, and its individual pure – simple sinusoidal tones or partials were also examined in a detailed investigation of tonal colour. The audio of each sound accompanied each tonal description, serving as a definite audible reference.

In order to achieve clear definitions of distinct tonal characteristic, the examinations conducted in chapter four were limited to the same four single notes, excited by the same mechanically measured velocities, with no damping of the sympathetically vibrating characteristics of the instruments. The pianos were positioned in precisely the same positions within the 180° sound field of 8 microphones. The microphones were positioned at 3 & 6 metres, identically for each piano.

²⁵¹ Wayne Stuart, email interview with author, 22nd June, 2015.
5. - Piano Contrasts, Audience Surveys.

Introduction

Six interactive concert events entitled ‘Piano Contrasts’ were produced at the Sydney Conservatorium of Music to examine the sounds of the Stuart and Steinway pianos in performance, and to conduct audience surveys on piano timbre identification. 331 audience members participated in the surveys.\textsuperscript{252} The series of concert-surveys presented the same pianos previously examined in chapter four, the Stuart M19 (STU) and Steinway (STE) No 574500, in concert. Repertoires of jazz, popular and classical music were performed in the concerts. Three concerts were performed by a piano duo, and three concerts by a jazz trio. The researcher Kevin Hunt, a jazz pianist, was the central performer of each concert, assisted by musical colleagues in his jazz trio and piano duo settings. The other pianist in the piano duo was Simon Tedeschi, a highly acclaimed concert pianist. The experience of performing on the Stuart piano M19 (STU) in the concert series provided the researcher with the opportunity to befriend the new instrument in performance, experimenting with the parameters of its tonal qualities and capabilities whilst familiarity grew with each performance.

The audience surveys were conducted using multiple-choice questions, printed on sheets for the audience to fill out during the performance. In each question on piano tone, the participant was prompted to select from a list of verbal attributes that describe piano tonal colour. Past experience in deciphering piano tone was not a prerequisite condition for participation in the surveys, so both experienced and inexperienced listeners participated in the surveys. It was understood that the audience members who participated in the survey were unified as a group by their interest in deciphering the sounds of the Stuart and Steinway pianos. Each question had a written ‘comments’ option, which provided the research with a resource of unanticipated answers, whereas the multiple-choice questions by their nature of prediction, set the tonal parameters of choice, anticipating the range of response and

\textsuperscript{252} See Appendix 5, p.327
differential characteristics, ‘bright & clear’ and ‘mellow & clear’ for example\(^{253}\). In many cases it was apparent in the responses of both experienced and inexperienced listeners, that this was the first time the Stuart piano had been heard played live in a concert performance. Three questions of the survey produced results at each concert that identified trends of audience perception. General perceptions were realized by tallying numbers of response types, and sometimes, as in the case of questions 4&5, the general perceptions in the responses to the multiple-choice questions were contradicted by the perceptions written in the comments. The quantity of multiple-choice responses far outnumbered the quantity of written responses, though the participants’ use of the attributes in the written comments was significant, in that in most cases participants used the same attributes that were listed in the corresponding multiple-choice question.

The audience responses demonstrated that over 50% of the audiences identified distinctive characteristics in the sounds of both pianos that corresponded to the findings for both these instruments in chapter four. 66% of the survey participants identified the Stuart sound as sounding ‘brighter’ than the Steinway sound and 71% identified the Steinway sound as sounding more ‘mellow’ than the Stuart sound. These results concur with the findings of chapter four which showed the Stuart piano sounds consisted of a greater number of prominent upper partials with larger amplitudes than the Steinway sounds, which accounts for the perceptual identification that the Stuart sound sounded ‘brighter’ than the Steinway sound. The ‘mellow’ attribute was an alternate attribute choice to ‘bright’ in survey questions 4 & 5, which attracted responses with a large differential result of 71% in the affirmative of the Steinway sound.

**Qu.4** How do you describe the sound of the Stuart Piano (Brown Piano)
A. Bright and Clear 61% responses.
B. Mellow and Clear 39% //

**Qu.5.** How do you describe the sound of the Steinway Piano (Black Piano)
A. Bright and Clear 29% responses
B. Mellow and Clear 71% //

Both the free comments and the multiple-choice responses were examined for patterns of similarity and compiled into majority or minority % differences. Other results showed that 60% of the participants identified the ‘clarity’ and ‘resonance’ of the Stuart piano as being more distinctive than the Steinway, and 90% of participants described the Steinway sound as ‘just as I’d expect a piano to sound’. 66% of participants responded with a preference for the Steinway sound in responses to a simplified multiple-choice in Qu.6&7, about an overall preference, Qu.6 not as good as Stuart ; Qu.7 not as good as Steinway. 63% of participants evaluated the Steinway sound as being ‘rich and full’ and 60% responded that the Steinway sound was more ‘powerful’. 58% survey participants responded that the Stuart sound was more ‘percussive’, and 61% chose the term ‘colourful’ to describe the Stuart sound. The survey findings are discussed in more detail from section 5.5 of this chapter, ‘Piano Contrasts-Audience Surveys.’

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In the final two concerts of the series, ‘behind the screens’ tests were conducted after an interval. In these tests the pianos were positioned behind screens, out of view of the audiences to test whether a majority of the audiences could identify the sounds of the Stuart and Steinway without the aid of visual and directional stimuli. The audience responses of the ‘behind the screens’ tests were not as conclusive as the responses whilst the pianos were in view. The manner in which the qualities of tone were affected by the screens will be examined later in this chapter. The inconclusive result could support A.Galembo’s research project\textsuperscript{254} that found experienced pianists had difficulty identifying the sounds of three, out of view, different makes of pianos whilst seated in the audience. The pianists had previously played each piano, and were confident they could identify the sounds without having visual contact with the instruments. The pianists did however identify each instrument through touch in a second test, whilst playing the pianos blindfolded.

The compiled tallies of the responses of the Piano Contrasts concerts indicated that how the pianists played each piano influenced the audience evaluations. 85% of participants responded that Simon Tedeschi’s pianistic style was more suited to the Steinway sound, and 83% of participants stated Kevin Hunt’s pianistic style was more suited to the Stuart sound. Due to the known stylistic backgrounds of each pianist the perception that Kevin Hunt’s pianism was more suited to the Stuart piano sound is associated with another audience perception, that 69% of the audiences reported that the Stuart sound suited jazz style more than the Steinway sound. Psychophysical elements are therefore recognized as being influentially associated with the pianists’ playing styles, how they react to the sounds of the pianos in the acoustics of the space and their subjective interpretations of repertoire style, which in turn influence the audience evaluations of the piano sounds.

In evaluating people’s perceptions of tone quality, the sound qualities of the instruments as well the human application and interpretation of sound are examined in this chapter, as combined elements of tone quality, based on the writing of timbre analysts W.Brent\textsuperscript{255} and J.Roederer\textsuperscript{256}. The results of the audience responses of the Piano Contrasts concert-surveys follow a review of terminology used in studies and articles of sound quality identification. The temporal and spectral qualities of the Stuart and Steinway tones established in chapter four serve to provide a platform of physical evidence about the sonic qualities of both instruments as the sounds are interpreted by pianists in performances and evaluated by audiences. This chapter examines sound quality in both its physical and psychophysical dimensions.

\textsuperscript{255} W.Brent, "Physical and Perceptual Aspects of Percussive Timbre"
\textsuperscript{256} J.Roederer, The Physics and Psychophysics of Music.
Complex Tones and Interpretation.

The physical quantifiable tonal qualities of the Stuart and Steinway sounds presented in chapter four are based on the spectral and temporal measurements of the time varying amplitudes of each partial frequency of single notes, sounded by calibrated levels of velocity key strike. The writers Wolfe and Meyer257 (see chapter 3), describe timbre as a combination of spectral and temporal elements of specific frequency and loudness, analysed at a point in time in the duration of the sound.258 The table below, supplied by the UNSW Physics department, shows the interactive elements that combine to produce timbre, based on the purely sonic components.

The piano sounds evaluated by the audiences in the Piano Contrasts concert-surveys are heard as multiples of the single-complex notes examined previously in chapter four, because in music performance practice piano notes are heard/played in combinations, vertically in chords and clusters or linearly in melodic phrases. The harmonic qualities of sounds produced in music performance are therefore produced by simultaneously sounding and pitch shifting fundamental tones, each sounding their particular series of harmonics, combined in varying magnitudes of resonance. In addition to this, the musical performance setting brings the psychophysical participation of the individual musicians and audiences to the evaluation of the multidimensional sonic elements.

The collective qualities of the sound of groups of musical notes was first discussed by Herman Helmholtz in his On The Sensations of Tone260, where he documented his discoveries of the derivations of instrumental tone in the resonances of combined tones. J. Roederer explains the phenomenon of Helmholtz’s discoveries -

When two complex tones of different pitch are superimposed, either of two situations may arise: The fundamental frequency of the higher tone is equal to one of the upper harmonics of the lower tone, or it is not. In the first case, the upper tone will reinforce certain upper harmonics of the lower tone, … in the second case, each of the tones produces its own multiplicity of resonances regions.261

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257 30 Meyer,30.
259 ibid
260 3 Helmholtz.
261 12 Roederer, 167.
The perceptual evaluations of piano tone made by the pianists and audiences include psychophysical influences that are not exclusively determined by the quantifiable sonic proportions and combinations of sounds. *How* the sounds resonate in the particular acoustic environment, the position in the space of the evaluator, *how* the pianists respond to the sound each piano makes in that space, *how* the pianists interpret the music repertoire, *how* the musicians accompany, and *how* the audience participant evaluates the sound, have an integral influence on the subjective evaluation documented as the participant’s response.

The timbre sensation is a multidimensional psychological magnitude related not to one but to a whole set of physical parameters of the original acoustic stimulus.\(^{262}\)

The many variables which influence the audience’s subjective evaluations are listed:

i) The pianos.
ii) The acoustical position of each piano, differing angles of sound radiation.
iii) Each pianistic style.
iv) Each piece of music.
v) The position of the seated participant, in the audience.
vi) The preferences or bias of the audience member for piano sound
vii) The preferences or bias of the audience member for styles and practices of piano music performance and musical style.

The music performed in the duo piano concerts was a mixture of classical and jazz styles by a team of pianists well known to audiences for their performances and recordings. For the trio concert, Kevin Hunt performed with his group, the Kevin Hunt trio, a group of musicians very familiar and experienced in jazz performance styles, a trio formed for this research project. The repertoire performed at each concert was a mixture of classical, jazz, and popular music which mixes both genres, for example West Side Story, or Rhapsody In Blue. The jazz trio played ‘jazz’ styled arrangements of classical pieces, Ravel’s 1\(^{st}\) movement of *Nobles et Sentimentales*, for example.

Perceptions of Pianistic Style and Music Style, associated with piano sound.

Two survey questions were presented to participants to examine how musical style and the pianistic style influenced the evaluations of the audiences, and if a particular piano tone quality may suit a style of pianism, and a style of music. The perceptual results to these questions revealed probable psychophysical influences imposed by the contrasting pianistic approaches, as well as the survey participants’ histories and tastes of musical listening. Although an interesting differential was achieved by these questions, it is apparent that follow up surveys could identify more closely the backgrounds and musical tastes of the participants, to see if a particular type of participant is more susceptible to associating a particular piano sound to a playing style or style of music.

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\(^{262}\) Roederer, 155-56.
Perceptions of the Stuart & Sons Piano – Kevin Hunt

Qu.12 Of three concert surveys asked:

Which piano sound is more suited to jazz style

The averaged responses result revealed that 81% perceived the Stuart sound to be more suited to Jazz style than the Steinway sound.

<table>
<thead>
<tr>
<th>Concert Participants Qu12</th>
<th>2 (LH) 11 p.</th>
<th>4 (SH) 22 p.</th>
<th>5 (SH) 17 p.</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stuart - Jazz</td>
<td>91%</td>
<td>86%</td>
<td>65%</td>
<td>81%</td>
</tr>
<tr>
<td>Steinway- Jazz</td>
<td>9%</td>
<td>14%</td>
<td>35%</td>
<td>19%</td>
</tr>
</tbody>
</table>

Comments written in each of the six concert surveys about the suitability of both pianos to jazz style and classical style provided more evidence with 85% of participants commenting that the Stuart sound was more suitable for jazz style than Steinway, and 89% commenting that Steinway sound was more suitable for classical style than Stuart.

<table>
<thead>
<tr>
<th>Jazz style/piano - comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stuart - jazz</td>
</tr>
<tr>
<td>Stuart - classical</td>
</tr>
<tr>
<td>Steinway - jazz</td>
</tr>
<tr>
<td>Steinway - classical</td>
</tr>
</tbody>
</table>

Participants’ comments revealed perceptual associations of the newness of the Stuart sound with a newness of jazz music, and the traditional Steinway sound with the traditions of classical music. The nature of the presentation by Kevin Hunt presenting the Stuart as the new alternative sound may have influenced this audience perception. Possibly less information in the spoken presentation about the research objectives, and a more succinct detailing of the participants’ musical taste and listening history would be useful for compiling the psychophysical perceptions of instrumental sound, musical style and pianistic style.

The Steinway piano produced a powerful & clear classical sound.
The Stuart produce a light, jazzy fun and dancing sound.  

Jazz is suited to innovative sounds, so the Stuart fits in better, whereas the classical traditional sphere is suited to the traditional instruments, horses for courses.

The Stuart’s sound is very clear and uncluttered not muffled, sometimes it can sound a bit confronting because the tone is so clear. It seems to suit confronting music-Jazz/Modern.

Combining the survey answers and comments to establish an overall perception finds that 86% of participants preferred the Stuart sound for jazz style, and 89% preferred the Steinway sound for classical music.

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263 comment response music genre/piano sound from concert No 6
264 comment response music genre/piano sound from concert No 2
265 comment response music genre/piano sound from concert No 3
Perceptions of the Stuart & Sons Piano – Kevin Hunt

Qu. 11& 13. The question, *is either pianist more suited to one of the pianos*, engaged a large number of participants to respond to establish significant differentials. Kevin Hunt was heard and seen to be suited more to the Stuart piano, and Simon Tedeschi was heard and seen to be more suited to the Steinway.

<table>
<thead>
<tr>
<th>Concert Participants</th>
<th>1 (LH).</th>
<th>3 (SH) 56 p.</th>
<th>6 (SH) 34 p.</th>
<th>Total %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tedeschi</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steinway piano</td>
<td>80%</td>
<td>89%</td>
<td>85%</td>
<td>85%</td>
</tr>
<tr>
<td>Stuart piano</td>
<td>20%</td>
<td>11%</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td><strong>Hunt</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stuart piano</td>
<td>70%</td>
<td>91%</td>
<td>88%</td>
<td>83%</td>
</tr>
<tr>
<td>Steinway piano</td>
<td>30%</td>
<td>9%</td>
<td>12%</td>
<td>17%</td>
</tr>
</tbody>
</table>

Survey Results Qu.11 /13 table 5.3

The overall result shows that 85% of participants found Simon Tedeschi’s pianistic style to be more suited to the Steinway sound, and 83% of participants found Kevin Hunt’s pianistic style to be more suited to the Stuart sound. Coupled to this perception is the 85% preference for jazz to be played on the Stuart piano. The psychophysical influences involved in this perception could be many, though some obvious influences were apparent. As he played, the researcher Kevin Hunt was focused on the differences of the new sound and how it responded for the sake of the research, so his pianistic style and technique could have been influenced by the inquiry process. Simon Tedeschi, a concert pianist was more used to playing the Steinway throughout his 30 years of performing in large concert halls, mostly on Steinway pianos. An added question that perhaps needs tighter scrutiny, asked whether each pianist’s individual ‘sound’ on either piano could be deciphered. A strong response to this questio revealed that the pianists’ contrasting styles were apparent to the listening audience.

‘Percussive’ piano sound.

The rhythmic and percussive aspect of jazz style may be coupled with the 58% majority perception that the Stuart sound is more percussive than Steinway. A listen to the sounds of both pianos at pianissimo, supports how a majority of 58% would perceive the Stuart sound to be more ‘percussive’.
The physical source of the sound and multi-modal aspects of timbre identification include the psychophysical associations with which the physical sound is being activated and received. The effect of the acoustics of the space, the kinesthetic application/reactions of the pianist to the mechanism and the acoustics, and the inherited biases of the pianist’s experience, all integrate in the psychophysical. The subjective evaluations of timbre in the Piano Contrasts surveys will therefore contain all the bias, expectation and surprise of personal musical experience and opinion. The audience responses of timbre evaluations are therefore understood to illustrate a human perception of the sound as a subjective abstract concept. It was anticipated that audiences would respond with both aesthetic and non-aesthetic descriptions of the sound quality associated with predicted bias and the surprise of something new. The Steinway sound provided a useful measure of the ‘familiar’ in this regard, as it did for the evaluations in chapter four.

The aesthetics of the subjective evaluations made by the performers during the performances are also influential on how the audiences interpret the sounds. A study about the cross modal interferences of sight, hearing, and touch, of pianists’ by A. Galembo found that pianists will kinesthetically adjust to the sound quality and the mechanical mechanism of the instrument as the sound reverberates within the acoustic space, in the effort to produce the desired quality of sonic expression. This sensorial ability was proven to be more reliable in identifying timbre than the purely sonic evaluations. The debate on whether it is the pianist or the piano design that affects the greater influence on tonal quality is of interest here. Is the pianist able to affect the piano sound to produce an intended piano sound, or is the pianist adjusting to enhance the sound of the instrument? This research’s objective is to demonstrate the influence of a different sounding instrument, so it falls on the side of the instrument design as being the more effectual cause of difference in the sounds of the Stuart and Steinway pianos.

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267 A. Galembo.
Establishing the Survey Questions.

The objective of the audience surveys was simply to involve interested audiences in the research project by examining how people described the sounds of the Stuart and Steinway pianos. The survey questions needed to be simple, as it was often the first time people had participated in a survey on piano tone as well as being their first ‘live’ experience of the Stuart & Sons piano sound. The survey questions were therefore presented as multiple-choice, using terms that had previously been used in literature which describes piano timbre. The descriptive terms and descriptor attributes were sourced from journals, web sites and published literature. The simplified process involved describing the instrumental tone of the pianos as a complete entity, as for example sounding ‘bright’ or ‘mellow’. Neither piano had a ‘dull’ sound, so the word wasn’t used, though occasionally ‘dull’ was used in the comments, or ‘other’ options in the multiple-choice. The sources of the actual survey adjectives used in the surveys and the results of how audiences responded is documented in detail later in this chapter, after a brief discussion on the complexities of timbre description.

The performances on both Stuart and Steinway in the series of comparison performances enabled a heuristic development of the researcher’s perceptions of the sound of each piano sound, each as a single comprehensive entity. In interpreting the sound as one entity the relational variants of tone are viewed from the perspective that they interact to produce the overall sound quality of the instrument. An example of this is illustrated as a characteristic of directivity in the introduction of chapter four, where variations in timbre of one sound were observed as a result of their directivity with the 180° microphone array. In this case, the acoustics of the space combined with the projective characteristics of the instrument to produce varying timbres of the same sound as they were projected simultaneously in various directions. The three findings of chapter 4, (see the table 5.5 below, column 1), which distinguish the Stuart sound from the Steinway sound, can be described as a single comprehensive entity in their difference to Steinway. Over twenty Stuart tones across a 3 octave range were identified as having combinations of the three Stuart characteristics of tone, and forty eight sounds were found to have at least one of the distinctive Stuart tonal characteristics.

The interpretation of each piano sound as a single entity enables a descriptive correspondence to occur between the purely sonic, quantifiable findings of chapter four, and the heuristic information accumulated in the pianistic techniques of the researcher, achieving a integration of both perceptual dimensions. The table below illustrates how both the purely sonic and the psychophysical perceptual qualities interrelate within the pianist’s perception. Each of the three quantifiable findings of the Stuart sound characteristics column 1, are interpreted by the pianist-researcher’s subjective description of the sound quality in column 2, and the pianistic application or response of the sonic and subjective characteristics are described in column 3.

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268 See ‘Directivity & Timbre, chapter 4.
G. Sandell proposes the description of the multidimensional composite of tonal elements of one instrument can be described as its macrotimbre -

The features that listeners absorb from such varied input that enables them to identify what they are hearing can be referred to as an instrument’s “macrotimbre.”

The Piano Contrasts concerts provided an opportunity to evaluate how two pianists of varied musical backgrounds, two accompanying musicians, and three hundred audience participants of varied professions and backgrounds, described the qualities they heard in the sounds of the Stuart and Steinway pianos. It was of special interest to assess if the majority of listeners could identify differences in the sound quality of the two instruments, and if these descriptions correlated to the quantified descriptions of the pianos’ sound in chapter four.

My heuristic process in developing a sense of the tonal qualities of both pianos whilst in performance is associated with the perspectives of the individual’s psychophysical experiences. Later in this chapter, I provide my own commentary on a selection of the piano performances from the six concert-surveys, as a companion to the results of the participants’ perceptual results. W. Brent describes the difficulty of deciphering timbre is due to the fact that timbre is described both by the quantifiable sonic multi-dimensions of pitch, frequency, loudness, spectral and duration, described as ‘classification’ as well as being:

‘tied to the physical source of a sound, implying complex multi-modal associations.’

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270 W. Brent.
Timbre Identification: uses of perceptual verbal attributes.

The following pages present a review of verbal attributes used as descriptors of tone in various studies of tonal perception, music reviews, interviews with pianists and piano builders, journal articles and piano brand websites. The perceptual attributes used in the Piano Contrasts audience survey questions derived from these sources are compiled into glossaries (1-17). Attributes used by participants in their descriptive comments found in these sources are also entered into the glossaries.

Perceptual verbal attributes such as ‘bright’, ‘dark’, ‘clear’, ‘dull’ have provided the relational measure in studies of the timbre identification since the studies of Litche in 1941. In these studies, participants’ ability to recognize instrumental sounds were measured with respect to various alterations of the stimuli. A series of studies on piano tone conducted in the 1960s, at Bingham university by Harvey Fletcher and E. Blackham, altered the stimuli of the harmonic partials of synthetically assembled piano sounds, to demonstrate the degree of inharmonicity in piano tone, by adjusting the inharmonic frequencies of piano tone to be perfectly harmonic.

Synthetic tones that were built up of perfectly harmonic partials were described by musicians and non musicians alike as lacking ‘warmth’.

Descriptions of hammer felt density and the iron frame in the Blackham & Fletcher studies illustrate the use of other perceptual attributes:

If the felt is too hard and produces a harsh tone, it can be pricked with a needle to loosen its fibres and will produce a mellower tone. If the tone is too mellow and lacks brilliance the felt can be filed and made harder.

The development of the full cast iron frame gave the sound of the piano much greater brilliance and power.

More recent studies have scaled verbal attributes to achieve finer degrees of interpretation. Many studies of timbre discernment test the attributes potential for categorizing sounds into groups of similarity. The Piano Contrast survey questions illustrated later in the chapter compare the differences of timbre within the one class of instrument, so the most successful attributes would generate responses of the widest differential within a narrow choice, due to the instruments belonging to a similar class. A wide differential response that creates a majority +50%, and a minority -50% is a good result in that it clearly demonstrates a perception of a majority of the participants. The attributes used in the Piano

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272 3 Brent, 7
273 2 Fletcher, H. & Blackham, & Stratton, 27.
274 1 Fletcher, H. & Blackham, & Stratton, 32.
275 4 Fletcher, H. & Blackham, & Stratton, 29.
276 5 Fletcher, H. & Blackham, & Stratton, 28.
Contrasts concert-surveys were derived from literature that specifically describes musical sounds and piano tone. It is the use of attributes in the survey questions that provides the relational measure\(^{277}\) to guide the listener’s discernment of the sounds of the Stuart and Steinway.

Verbal attribute-based relational studies record judgments about a set of sounds relative to a collection of words deemed appropriate for describing timbre.\(^{278}\)

<table>
<thead>
<tr>
<th>dark</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>bright.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directions to the participants: You are to mark category 1, for example, as indicated, if the sound appears ‘very dark’ to you. Category 2 stands for ‘dark’, category 3 for ‘some what dark’, category 4 for ‘neither dark nor bright’, category 5 for ‘somewhat bright’, category 6 for ‘bright’ and category 7 for ‘very bright’.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

W. Brent states, a criticism of this method of surveying is that the information provided anticipates particular aspects of timbre, chosen in advance, makes assumptions about the nature of timbre, threatening to push the research results in particular directions, and may limit the information collected from the participants, as well precluding unanticipated relevant features of timbre.\(^{279}\)

The studies by V. Bismark and A. Houstma presented participants with verbal attributes in scales of timbre quality where pairs of opposite attributes such as ‘dark’ to ‘bright’, provide the relational measure of sound quality.

| soft- loud | relaxed-tense | full – empty |
| weak – strong | calm- restless | solid-hollow |
| gentle –violent | rounded-angular | colourful - colourless |
| fine- coarse | damped-ringing | pure-mixed |
| reserved – obtrusive | smooth-rough | simple-complex |
| low- high | heavy-light | compact-scattered |
| dark – bright | broad-narrow | interesting-boring |
| dull –sharp | wide-tight | lively-dead |
| soft –hard | thick –thin | pleasant-unpleasant |
| dim-brilliant | clean-dirty | open-closed |

Timbres of sounds can be uniquely described if the sounds are rated on a few scales which are characterized by verbal attributes.\(^{280}\)

In one such study, Bismark assembled a wide range of verbal attributes from which after hearing the sounds to be tested, the participants were asked to select a smaller number of attributes which they understood according to their musical experience most suited the sounds, to avoid pre-selection bias of the convener.


\(^{278}\) Brent, 8.

\(^{279}\) ibid

Three of the above scales of semantic differential were found to be the most successful in describing timbre:

<table>
<thead>
<tr>
<th>'sharp - dull', 'soft - hard', and 'round- angular'.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 5.6</td>
</tr>
</tbody>
</table>

Wake and Asahi’s study *Sound Retrieval with Intuitive Verbal Expressions*\(^{281}\), suggests the semantic differential scale of opposite attributes for the end points of the scales (table 5.3), confuses the understanding of the timbre picture, finding that the use of direct opposites, provided a greater differentiation between individual timbres, a practice described as Verbal Attribute Magnitude Estimation (VAME), i.e a single adjective scale.

<table>
<thead>
<tr>
<th>Not Bright :</th>
<th>Bright</th>
</tr>
</thead>
<tbody>
<tr>
<td>: (\frac{1}{2}, \frac{3}{4}, \frac{5}{6}, \frac{7}{8} :)</td>
<td>: (\frac{1}{2}, \frac{3}{4}, \frac{5}{6}, \frac{7}{8} :)</td>
</tr>
</tbody>
</table>

The Piano Contrasts survey questions used verbal-attributes which consist of similarity and opposite dimensions, such as ‘clear-bright’, ‘clear-mellow’ and opposite semantic differential, ‘short note’, ‘singing note’.

Graham Darke defines three types of verbal descriptors in his study, *Assessment of Timbre using Verbal Attributes*\(^{282}\)

i) **Sound Itself**; words of the actual sound as onomatopoeia, and comparison of the timbre of real instruments, ‘flute- like’, ‘bell- like’ for example.

………musicians invoke a comparison with actual instrumental sounds, flutey, stringy, reedy, brassy, organ-like etc. This is similar to the psychophysical sensations of smell- consider the descriptions of the ‘nose’ of a good wine!\(^{283}\)

An Oboe might be described as producing a ‘reedy sound’, whereas a flute produces a ‘mellow tone’.\(^{284}\)

It is the prominence and the decay of partials that determines tone\(^ {285}\)

<table>
<thead>
<tr>
<th>Thin: Flute 2(^{nd}) harmonic prominent (few harmonics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bright : Oboe 2(^{nd})+4(^{th}) harmonic prominent</td>
</tr>
<tr>
<td>Rich: Violin many prominent harmonics</td>
</tr>
</tbody>
</table>

The sound has a double-reed edge to it: it comes out to greet you like an oboe rather than wrapping itself warmly around you like a clarinet. Those expecting Steinway mellowness may be disappointed. What one has instead is a sense of being able to take every detail of far-flung Fred Williams landscape with clarity, precision and, where necessary, with moments of subtly highlighted colour.\(^ {286}\)


\(^{282}\) G Darke.

\(^{283}\) Roederer,156


\(^{285}\) Johnston,108.

\(^{286}\) Peter McCallum, Stuart’s New Piano Rises To The Occasion, Sydney Morning Herald newspaper. 15\(^{th}\) March 1999.
Perceptions of the Stuart & Sons Piano – Kevin Hunt

ii) **Sound Situation** – describing the sound source, place and use of

iii) **Sound Impression** – the adjective, describing one’s subjectivity, ‘bright’, ‘mellow’ for example.

<table>
<thead>
<tr>
<th>Glossary 3. Darke, Wake &amp; Asahi &amp; McCallum</th>
</tr>
</thead>
<tbody>
<tr>
<td>colourful, full, empty, mellow, bright, warm</td>
</tr>
</tbody>
</table>

**Subjective dimensions linked to physical dimensions of timbre:**

A. Houstma’s study of timbre identification uses a scale of semantic differentials of opposite attributes in order to scale the subjective dimensions which in the explanation below are linked with associated physical properties of sound.

In music related studies timbre has always been treated as a multidimensional continuum in which any point is potentially meaningful. It has been established by rating and multidimensional scaling techniques that the space can be adequately described in four subjective dimensions, dull to sharp, compact to scattered, colourful to colourless and full to empty, which are linked to physical dimensions such as spectral energy distribution, amount of high frequency energy in attack, amount of synchrony in high harmonic transients.287

<table>
<thead>
<tr>
<th>Houstma’s Subjective Dimensions of timbre</th>
<th>Houstma’s Physical Dimensions of timbre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dull – Sharp</td>
<td>High frequency energy in attack</td>
</tr>
<tr>
<td>Compact – Scattered</td>
<td>Spectral energy distribution</td>
</tr>
<tr>
<td>Colourful – Colourless</td>
<td>Synchrony in high harmonic transients</td>
</tr>
<tr>
<td>Full – Empty</td>
<td></td>
</tr>
</tbody>
</table>

**Physical Dimensions of Piano Sound - High Frequency Energy in Attack:**

The dimensions and qualities at the beginning of the sound, the attack, is known to be a crucial point of identification of piano tone.288

The onset of a tone is a most important attribute for timbre and tone identification (Ivenson and Krumhansl, 1993). During this transient period, the processing mechanism in our brain seems to be able to lock in certain characteristic features of each instrument’s vibration patterns and to keep track of these features, even if they are garbled and blurred by the signal from the other instrument.289

**Loudness of Attack**

We know that increases in loudness, as produced by a faster velocity strike of the key with a shorter contact period on the string produces a brighter tone.

---

287 2 Houstma, 104-115.
288 2 Anders Askenfelt & Jansson E.
The effective stiffness of a given hammer depends on the impact velocity with which the hammer hits the string, with a greater effective stiffness for higher impact velocities and visa versa. As a consequence, hitting a piano key harder will not only increase the amplitude of the string oscillation (louder tone) but shorten the contact time and thus automatically increase the proportion of upper harmonics (brighter timbre).

**Spectral Distribution**

We know that the inharmonic sounds at the onset of the note are important in the identification of instrumental timbre, particularly of the piano. We also know that more upper partials in sound, produces a ‘brighter’ ‘sharper’ tone, and that increased loudness also produces a ‘brighter’ timbre.

A tonal impression is brighter, and possibly sharper, as richness in overtones increases (in view of the frequency range and the intensity of the upper frequency components) (von Bismarck, 1974). For low tones, rich in overtones, the dense partial sequence in the upper frequency region leads to a rough character. In contrast, overtone-poor sounds have a tendency for dark or soft timbre.

Broad denominations ranging from dull or stuffy (few upper harmonics), to nasal (mainly odd harmonics) to bright or sharp (many enhanced upper harmonics).

Kendal and Carterette’s study found that the use of opposite differentials, i.e. ‘bright – dark’, produced inclusive evaluations, because there is more than one opposite for ‘bright’: ‘dull’ for example. The sound stimuli used in the study were the most dissimilar sounds found in the orchestral wind family, with a descriptor range of 69 adjectives. After hearing the sounds through twice, the professional musician subjects chose 21 adjectives which most suited the stimuli.

<table>
<thead>
<tr>
<th>brilliant</th>
<th>brittle</th>
<th>crisp</th>
<th>edgy</th>
<th>full</th>
<th>fused</th>
<th>light</th>
</tr>
</thead>
<tbody>
<tr>
<td>mellow</td>
<td>nasal</td>
<td>reedy</td>
<td>resonant</td>
<td>rich</td>
<td>ringing</td>
<td>round</td>
</tr>
<tr>
<td>smooth</td>
<td>soft</td>
<td>strong</td>
<td>tremulous</td>
<td>tense</td>
<td>warm</td>
<td>weak</td>
</tr>
</tbody>
</table>

Kendal & Carterette’s verbal attributes. Table 5.8

Single adjective scales were used in the method described as Verbal Attribute Magnitude Estimation (VAME). The results were summarised into four groups of dimensions, into which the above attribute were grouped.

<table>
<thead>
<tr>
<th>Power</th>
<th>smooth, soft, light, weak, mellow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strident</td>
<td>strong, tense, tremulous</td>
</tr>
<tr>
<td>Plangent</td>
<td>ringing, resonant, crisp, brilliant</td>
</tr>
<tr>
<td>Reed</td>
<td>reedy, fused, warm</td>
</tr>
</tbody>
</table>

Table 5.9

**Glossary 4. Kendal and Carterette**

smooth, light, mellow, weak, resonant, warm, power

---

200 Roederer, 124.
201 Fletcher & Rossing, 394.
202 Campbell & Greated, 160.
203 Blackham & Fletcher, 27.
204 Meyer, 30-35.
205 Meyer, 30-35.
206 Blackham, 156.
207 Roederer, 156.
Perceptions of the Stuart & Sons Piano – Kevin Hunt

Historic descriptions of Piano Timbre.

Johann Von Schonfeld’s description of the sound of Anton Walter’s forte piano in 1796, compared Walter’s piano sound to the sound of the Stein piano. Walter’s piano implemented a thinner soundboard and bridge than Stein, which Edwin Good describes as being more responsive, with a ‘clearer’ tone, though softer volume.296

Walter’s fortepianos have a full bell like tone, a clear attack, and a strong, full bass. At first the tone is somewhat dull, but if one has played for some time it becomes very clear, especially in the treble. If they are played very much, the tone soon becomes sharp and iron-like, which can be corrected by re-leathering the hammers.297

Good writes that the thicker strings and the triple–strung treble made it possible to play on Anton Walter’s Viennese forte piano more loudly without forcing the tone, and that the Stein soundboards and bridges were thinner than those of the other Viennese piano makers of the time, a feature that made his instruments more responsive, perhaps ‘clearer’ in tone, but also softer in volume than for example a Walter.298

Commentaries on the significant differences in the Austrian-German (Viennese) and Anglo-German (London) piano designs of the late 18th Century, illustrate the use of tonal attributes which are still is use today, and in some ways the comparison is similar to the piano comparison of the Stuart and Steinway piano sounds. The late 18th Century was a period where national characteristics of piano design influenced national styles of piano performance and composition. The sound of the Austrian-German pianos made by Walter, Stein, Schmit and Graf for example, were made with lighter thinner, more flexible soundboards and the strings were mainly set as bichords, doubled, without wound strings in the bass, whereas the Anglo-German pianos of Stodart, Backers, and Broadwood, implemented a derivative of the Cristofori action, and strings set as trichords, triple stringing, with thicker soundboards. Pianists Johann Hummel and Francis Kalkbrenner described the sound of both types of piano in published critiques of the day. The music of Dussek, Cramer and Field was representative of the Anglo-German piano sound, described as having a ‘fullness of tone’, ‘harmonic sweetness’ and as ‘singing’. The music of Haydn and Mozart was representative of the Austrian-German piano sound, described as ‘small but clear’, ‘bassoon-like’ in the bass, ‘round’, ‘flute-like’, as having an ‘elegant silvery tone’, and ‘feather light’.301

Perhaps the earliest comparison of piano sounds in front of an audience occurred in 1823, at Vienna’s Kartnerthor Theatre, when pianist Ignaz Moscheles performed a piano-comparison concert on

296 Good, 85.
298 17 Good, 85.
299 18 Schonberg, 23-24. original source: Johann Hummel (1827) A complete Theoretical and Practical Course of Instruction in the Art of Playing the Piano Forte, (London: T. Boosey 1828);
300 2 Boehm “ STEIN FAMILY”, 372.
Beethoven’s Anglo Broadwood piano and a Viennese Graf piano. A central difference in these pianos was the contrasting actions, the Broadwood exhibiting the Anglo-German action, and the Graf the Viennese action. The report of the audience reaction favoured the local Viennese instrument, though in the review it was added that Beethoven’s Broadwood piano was in a very worn down condition, these being the years of Beethoven’s developing deafness, and subsequently he was wearing out his pianos with increasingly powerful playing in his efforts to hear them. Moscheles was a pianist of the Viennese school, implementing a pianism of lighter musical aesthetic in the tradition of Mozart, which suited the Viennese design. The Anglo Broadwood piano presented a greater potential for legato and sustain, with a more comprehensive dynamic range, characteristics apparent in the piano music of Beethoven.

In the 19th Century, at the onset of iron frames replaced the wooden frames, the resulting tone was described both as being ‘hard’ and ‘metallic’, and as sounding wonderful both in ‘power and mellowness’.

Another historic piano comparison concert occurred in 1856, when pianist Sigismond Thalberg performed on both the new American Chickering piano and the legendary French Erard, whilst touring America which he travelled with. America’s first influential classical music critic John Sullivan Dwight reviewed this comparison, revealing aspects of American advancements in tuning stability, as well as descriptions of tone.

To our ears there is still a purely musical quality in the Erard tone, which has not quite been reached by others. Forced to loudest effects, they sound a little antique and metallic, particularly in the middle and treble octaves; yet the quality is still musical, the altissimo tones exquisitely so, the bass magnificently rich. The Chickering tones are rounder, mellower throughout the whole compass, but they come to the ear less distinct, as if the tone were not refined to its purely musical element.... It is said the Chickering instruments stand in tune the best.

Arthur Loesser writes that Sigismond Thalberg also performed a comparison concert of Pleyel and Erard pianos.

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302 Seth A. Carlin, “BEETHOVEN, LUDWIG (1770-1827)” in Palmieri, 46.
304 Good, 150.
305 Good, 150.
306 Good, 224. ; source: Dwight’s Journal Of Music (Boston:1851-1881) Sydney Conservatorium of Music library P 780.5 RIP 8.6 (Indexes)
307 Loesser, 407.
The sounds of the famous French pianos of Pleyel and Erard were described by the legendary pianist-composers Franz Liszt and Frederick Chopin, in a practical sense, for specific circumstantial reasons.

Chopin was fond of Pleyel pianos because of their silvery and somewhat veiled sonority and their easy truth. Chopin himself once said, that when he was in a bad mood he played Erard instruments because of their ready-made sound. But when I am in good spirits and strong enough to find the sounds I want I use Pleyel pianos.\footnote{Ates Orga, \textit{Chopin his life and times}, (Midas Books, 1976), 113.}

A number of contemporary accounts testify to the link between the Pleyel sound and Chopin’s compositions and style of playing. Chopin loved Pleyel grand pianos and played on them in 1841, 1842 and 1848 concerts. Chopin expressed his reasons for preferring Pleyel pianos, explaining that he had more control over the sound than the Erard, whose beautiful tone required less effort, making things too easy.\footnote{Gerard Carter, \textit{The Authentic Chopin and Liszt piano tradition}, (N.S.W.:Wensleydale Press,2008), 30.} Erard [pianos] preferred by Franz Liszt, were less delicate and were deemed better for large halls. Arthur Rubenstein observed in 1904 that the tone of Erards could be tinny compared to the warmer Pleyels and Bechsteins.\footnote{Charles Timbrell, “PLEYEL, ICANCE-JOSEPH,”  in \textit{9 Palmieri}, 296.}

Whilst discussing the contrasts and likenesses of Ravel and Debussy, Arbie Orenstein comments on the sound of Erard and Bechstein pianos:

Ravel appreciated the rather thin, dry tone of the Erard piano, whereas Debussy preferred the Bechstein, with its thicker, deep sonority.\footnote{Arbie Ornstein, \textit{Ravel Man and Musician}, (New York:Columbia University Press, 1975), 126.}

Moving to more recent descriptions of piano tone, jazz pianist composer Chick Corea describes the sound of the Mark Allen piano:

The piano, from the lowest note on the keyboard to the highest, is very clear and sonorous, as opposed to the muddy bass and mechanical, clinky top of most pianos- even the good brands. The low register, if played caressingly, sounds like an organ. The upper sounds like the bells of St Mary’s.\footnote{Len Lyons, \textit{The Great Jazz Pianists}, (New York:Da Capo Paperback , 1989), 267.}
Tonal Descriptions by Current Piano Makers, Dealers and Pianists.

Piano makers and piano retailers descriptions of the timbre of piano sound provides another resource of descriptive terminology.

Steinway describe their tone as:

The sound of the Steinway is one of power, warmth, richness and color. 313

‘The distinctive, thunderous sound Steinways are known for.’ 314

Attributes used in the Steinway publication to describe problems in tone colour are ‘metallic’; ‘brittle’; ‘brassy’. 315

Stuart & Sons describe their tone as:

A multi dimensional soundscape, expanded tonal range improving clarity, dynamic range and sustaining qualities due to greater control over the decay transients. 316

the two pinned system [standard modern piano] produces muddiness,

[the vertical coupling and the vertical soundscape], leaves the sound spectrum totally clean, right through 317

Wayne Stuart describes the Stuart piano sound:

People comment - Our pianos are too clear in their sound, not suited to the 19thC repertoire. 1850-60s Brahms pianos were low tensioned and thin, in sound, with low resonance, low tension, and quite thin and low power. The sound that they know… a quasi ‘Steinway type’ sound, which everyone has copied for over 100 years. 318

In definitions of clarity, attributes are found:

the clarity of the image: sharpness, clearness, crispness, definition.

(Opposite meaning) Antonyms: blurriness. 319

Pianists describe the tone of the Stuart piano:

Bill Risby- [The Stuart] resonates more with itself, the sum is greater than its parts. Ordinary sustain hold down the note and the chords are heard [needs fixing]? completely clearly, …… there are a whole lot of extra sounds I can call upon in order to make music, 320 new ideas which haven’t been tried before, ……

The harmonics are clearer. 321

Glossary 10. Steinway articles written by the Steinway brand: descriptions of Steinway tone.

| metallic | power | warmth | richness | colour |


| Multi dimensional soundscape, muddiness [of traditional coupling], clean, improved clarity, clear, low power [of Brahms 19th C pianos]. |


317 Ibid

318 Stuart & Sons Handcrafted Pianos (accessed 26th May, 2015).

319 “Innovations In The Piano”.

320 Ibid

321 New Oxford American Dictionary

322 “Innovations In The Piano”.
Perceptions of the Stuart & Sons Piano – Kevin Hunt

Michael Szumowski – clarity in the sustain, ‘lifting the blanket off’,
definition, focused sound, harmonics in the after-sound\textsuperscript{322}

Mark Gasser – more versatile, more colours, a new sound world,expanded in every sense.\textsuperscript{323}

Peter Gardner – ‘Remarkably Clear’ \textsuperscript{324}

Reviewer Peter McCallum – “Stuart’s new piano rises to the occasion”:

The sound has a double-reed edge to it: it comes out to greet you like an oboe rather than wrapping itself warmly around you like a clarinet. Those expecting Steinway mellowness may be disappointed. What one has instead is a sense of being able to take every detail of far-flung Fred Williams landscape with clarity, precision and, where necessary, with moments of subtly highlighted colour. \textsuperscript{325}

<table>
<thead>
<tr>
<th>Glossary 12. Pianists/Reviewer about the Stuart piano</th>
</tr>
</thead>
<tbody>
<tr>
<td>clear, extraordinary sustain, focused, clarity in the sustain, versatile, expanded, colourful., Oboe-like,</td>
</tr>
</tbody>
</table>

Comparisons of tonal colour ranges of Yamaha and Kawai pianos.

mellow, mellow to bright \textsuperscript{326}

Kawai vrs Yamaha survey:

‘mellow’, ‘blurry’, ‘distinguished’ \textsuperscript{327}

Piano technician Arian Harris describes the sound of the Fazioli pianos:

The Fazioli tone is clear, pure, and profound, the midsection is rich, and every treble note up to the last is full, balanced, and sonorous. But compared to makes such as Steinway and Mason & Hamlin, the Fazioli sound is relatively lacking in tonal color. \textsuperscript{328}

Piano technician Ed Whiting describes the sound of the Fazioli pianos:

If you combine all of the positive attributes of the New York and Hamburg Steinways in the design of a new piano, then add an owner, head designer, and small production staff dedicated to building exactly to that design, you have the essence of a Fazioli. \textsuperscript{329}

\textsuperscript{322} ibid
\textsuperscript{323} ibid
\textsuperscript{324} 9 “Innovations In The Piano”.
\textsuperscript{325} Peter McCallum, “Stuart’s new piano rises to the occasion,” Sydney Morning Herald newspaper. 15th March, 1999 https://www.newspapers.com/newspage/126103995/
\textsuperscript{326} Mark Goodwin, “What are the tonal differences between amongst Yamaha U3 and U1 pianos,” (blog), 26th May, 2015 http://www.markgoodwinpianos.co.uk/info/yamaha-u3-u1-bright-mellow
\textsuperscript{327} “Kawai uprights (K5)- action and tone vs Yamaha U1” (blog), 26th May, 2015 http://www.pianostreet.com/smf/index.php?topic=46927.0
\textsuperscript{328} Arlan Harris, Fazioli Acoustic and Digital Piano Buyer, (Spring 2010 Ed.) 84. http://www.showcasepianos.com/pg84.html accessed 26th May 2015
Piano technician Steve Pearson describes the sound of Feurich, Shigeru Kawai, Mason & Hamlin Pianos:

Feurich

…. rather like the piano version of a Porsche: fast, positive, and responsive. The tone is very large and rather "open" compared to the more "covered" sound of a Steinway or Blüthner. The dynamic range is huge, the tonal palette rich and varied, and the sustain long and strong in the melody section.330

Shigeru Kawai

Compared to our Hamburg Steinway, our Shigeru has a darker tone, and its sound doesn't carry as well all the way to the back of the hall. That said, both pianos are chosen about equally, with more soloists choosing the Steinway, while the Shigeru is chosen more for chamber music and accompaniment. 331

Mason & Hamlin

The tone is uniquely American—very warm, full, and rich—with a strong bass, and good sustain and singing quality in the treble.332

Bosendorfer 333

‘beautiful singing, and thunderous piano sound ‘Paul Badura - Skoda J Zawinul a ‘fat’ sound, ‘like an orchestra’ Dianne Reeves,

Andre Oorebeek’s use of verbal attributes describe the qualities of tone produced by varied densities of the hammer felt cushion–

…. the right cushion does not sound too percussive or shrill.334

A hard hammer will make the sound too hard and shrill, with the emphasis on the higher partials sequence–the result is a thin, hard tone. A piano tone has a certain duration and also causes a short duration of tone.335

A [good] piano sound tone sounds clear, but is not too loud and not too weak, a sound like a bell, distinct and resonant without a shrill or metallic effect. 336

Glossary 13. Piano ‘brands’ Kawai, Fazioli, Yamaha, Mason & Hamlin, Feurich, Bosendorfer - descriptors comparisons

| mellow, bright, blurry, distinguished, pure, profound, rich, full, balanced, sonorous, dark, warm, full, rich, singing quality, good sustain, strong bass, beautiful singing [tone]. like an orchestra, fat. |

Glossary 14. Oorebeek

| percussive, shrill, hard, thin, clear, bell-like, distinct, resonant, metallic, weak, short |

331 ibid
332 ibid
334 Andre Oorebeek, The Voice of the Piano a piano technician’s definitive guide to voicing (Canada: Crescendo Publications, 2009), 71.
335 2 Oorebeek, 12.
336 3 Oorebeek, 11.
Larry Fine describes a ‘bright’ piano tone as having many loud upper partial frequencies, and a ‘mellow’ piano tone as having few loud upper partial frequencies. ‘Singing’ when a slow and lingering decay is relatively loud and long lasting, ‘dead’ or ‘short’ when the sound dies out quickly.

Other descriptions from E. Good:
If the material [the hammer felt] is too soft the tone will be thick and fuzzy from an absence of upper partials, without the clear definition that piano tone is expected to have. If the material is too hard, upper partials will be too prominent, and the tone will be harsh and hard.

Up to a certain point of tension, the string’s elasticity is improved and it produces a tone rich in partials. Beyond that point, however, the increasing tension brings out stiffness, which damps out partials, and the tone goes dead.

If the hammer should strike the string exactly in the middle, all of the even numbered partials will be damped out, because all of them have a node in the middle of the string. Such a tone would be dull and hollow.

The sound of the Erard piano is ‘Powerful’ and ‘Clear’

Verbal Attributes used in the ‘Piano Contrasts’ Survey questions.

The glossary of verbal attributes listed below in table 5.10 are derived from the piano literature reviewed above, pp. 163-174. These terms were utilised as the descriptor attributes for the questions in the Piano Contrasts audience surveys.

Wayne Stuart’s claim of an improved tonal clarity influenced the selection of attributes for the survey questions.

....the strings vibrate in a more controlled manner improving the dynamic range, increasing sustain and significantly improving tonal clarity sympathetic to the entire piano repertoire.

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338 20 Good, 21.
339 19 Good, 9.
340 20 Good, 9.
341 18 Frederick, “ERARD SEBASTIEN” in 10 Palmieri, 126.
‘Piano Contrasts’ Survey Questions.

Three questions in the Piano Contrasts audience surveys produced perceptual results that indicated how the audiences generally perceived the tonal timbres of the Stuart and Steinway. Each of these questions used the verbal attributes from the above literature combined with the knowledge of the tests conducted in chapter 4.

<table>
<thead>
<tr>
<th>Qu. 4 &amp; 5</th>
<th>How do you describe the sound of the Stuart/Steinway piano?</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Bright and Clear</td>
</tr>
<tr>
<td>B</td>
<td>Mellow and Clear</td>
</tr>
<tr>
<td>C</td>
<td>Singing quality</td>
</tr>
<tr>
<td>D</td>
<td>Short tone, ‘not singing’</td>
</tr>
<tr>
<td>E</td>
<td>Bright and Shril</td>
</tr>
<tr>
<td>F</td>
<td>Soft and Weak</td>
</tr>
<tr>
<td>G</td>
<td>Just as I’d expect a piano to sound</td>
</tr>
<tr>
<td>F</td>
<td>Other: Comments</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Qu. 6 &amp; 7</th>
<th>Is the sound of the Stuart/Steinway Piano?</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Distinctive</td>
</tr>
<tr>
<td>B</td>
<td>Not as good as the Stuart / Steinway</td>
</tr>
<tr>
<td>C</td>
<td>Clearer, more defined than the Stuart / Steinway</td>
</tr>
<tr>
<td>D</td>
<td>Just as I’d expect a piano to sound</td>
</tr>
<tr>
<td>E</td>
<td>Other:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Qu. 14 &amp; 15</th>
<th>Which musical characteristics suit the Stuart/Steinway piano?</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Colourful</td>
</tr>
<tr>
<td>B</td>
<td>Light</td>
</tr>
<tr>
<td>C</td>
<td>Percussive</td>
</tr>
<tr>
<td>D</td>
<td>Powerful</td>
</tr>
</tbody>
</table>

Survey questions 4&5: 6&7; 14&15. Table 5.11

It was expected that most people would hear more ‘brightness’ in the tone in the Stuart sound, especially in the higher notes, because of the wider spectrum and increased loudness at the onset sounding of the note, found as a characteristic in many of the Stuart sounds in chapter 4. An example of the ‘brightness’ in the Stuart sound is heard on the note C5v81STU MW mic2, when compared to the C5v81STE MW mic2, see ‘C5 Directivity’, chapter 4. It was found that the higher level of loudness and the larger amplitudes of upper partial frequencies were the elements that contributed to the ‘brightness’ in the Stuart sound. It was also anticipated that the lower pitches of the Stuart sounds though could be interpreted as sounding ‘fuller’ than Steinway, for example the comparison between C2v20 STU MW mic6 and C2v20 STE MW mic6, shows the Stuart sound has more prominent bass frequencies than Steinway, producing what is described as a ‘fuller’ tonal colour. Both these findings of Stuart piano tone quality, as with many in chapter 4 section 4.24, were found to be particular to the directivity that the sound travelled in from the pianos into the audience area, indicating that particular seated positions of the audience would also influence evaluations of tonal colour. The mixed sounds of the notes’ radiations across all the directions of 180° illustrated in section 4.1, reveals though, that generally the Stuart sounds did sound brighter in the higher registers, and fuller in the lower registers, than the Steinway’s mixed sounds.

\[\text{See sound No.3. in ‘Wider Harmonic Spectrum, chapter 4.}\]
Piano Contrasts- Audience Surveys

Over 300 people participated in six ‘Piano Contrast’ audience survey concerts presented at the Sydney Conservatorium of Music.

<table>
<thead>
<tr>
<th>Audience Survey Concerts</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>No 1 VH 19th July 2010: Piano Duo</td>
<td>131</td>
</tr>
<tr>
<td>No 2 MW 30th Aug 2010: Jazz Trio</td>
<td>17</td>
</tr>
<tr>
<td>No 3 RHW 8th June 2011: Piano Duo</td>
<td>81</td>
</tr>
<tr>
<td>No 4 MW 7th Sept 2011: Jazz Trio</td>
<td>26</td>
</tr>
<tr>
<td>No 5 RHW 14th March 2012: Jazz Trio</td>
<td>22</td>
</tr>
<tr>
<td>No 6 RHW 11th April 2012: Piano Duo</td>
<td>54</td>
</tr>
<tr>
<td><em>Piano Contrasts</em> Participants Nos: 331, Table 5.12</td>
<td></td>
</tr>
</tbody>
</table>

The audiences’ perceptions of tonal qualities in both piano sounds varied from concert to concert, as many other elements varied, though overall perceptions of tone were deduced from the responses and these perceptions did correspond generally with the distinctive characteristics identified in chapter four. Too many variables are at play, acoustically, stylistically and psycho-acoustically in this type of survey to collectively produce concise evidence of the tonal characteristics to match the findings of chapter four, though the simple objective of involving the general public in the process of evaluating the Stuart and Steinway piano sounds was met with great success.

The Stuart and Steinway pianos used in the audience surveys were the same pianos tested in chapter four. The pianos were positioned in each concert with the piano lids opened towards the audience, so the maximum range of tonal quality was intentionally directed towards the audience. The directivity of the sound radiation from the pianos however was found in the tests of chapter four, to be strongest at the 180° directions and closer to the pianist at 45°, see p.132, ‘Directivity’.
The physical dimensions and positions of each piano provided visual reference points to assist the audiences’ assessments of timbre. The pianos were played simultaneously and separately in the duo piano concerts.

Throughout the jazz trio performances, concerts 2, 4, & 5, Kevin Hunt alternated between playing the Stuart and the Steinway pianos. The bass and drums were positioned in between the pianos. The ‘Behind the Screens’ tests required the pianos to have the lids lowered to ‘half stick’ so the audience could not see the high edges of the lids, over the screens.

In the final two concerts, the ‘behind the screens’ segment was presented after interval, as a type of blindfold test with pianos positioned out of the sights of the audience, challenging the audiences to evaluate the piano sounds without visual or directivity stimuli. The ‘behind the screens’ survey results did not produce conclusive evidence, revealing that the benefit of visual connections with the sonic...
Scues related to the directivity, that is, visual and sonic cues of where the sounds are coming from, are needed to thoroughly identify differences in sounds of instruments belonging to a similar class. Similarly, as previously mentioned, Galembo’s research found that experienced pianists had difficulty in identifying the sounds of pianos they knew very well, whilst the pianos were played by another pianist, out of view, behind screens. The effect of the screen used in the Piano Contrast concerts on the timbre of the pianos sounds will be examined with aural examples later in this chapter.

The pianists in the duo piano concerts, Simon Tedeschi and Kevin Hunt were each of differing stylistic backgrounds, and each was well known to the audiences for their disparate stylistic genres of jazz and classical pianism. They had previously performed in many concerts as a duo, and were known for their mixture of classical and jazz styles in their performance repertoires and recordings, so there was an added intrigue as to how each pianist would play the Stuart piano. As stated earlier in this chapter, the styles and pianistic mannerisms of each pianist probably did influence the audiences to conclusively ‘say’ that the Stuart piano sounded more suited to jazz style than the Steinway, and that Hunt’s style was more suited to the Stuart piano than Tedeschi’s. Audiences favoured the Stuart sound to be more suited to jazz style and the Steinway sound to be more suited to classical style, as well as Kevin Hunt’s playing style to be more suited to the Stuart piano and Simon Tedeschi’s to be more suited to the Steinway.

Evaluating Overall Perceptions - 6 concerts.

The verbal attributes used in the survey questions as multiple-choices provided the relational measure to assist the survey participant’s discernment in describing the sounds of the Stuart and Steinway. The frequency at which the verbal attributes were used in the audience responses both as comments and as answers indicated the audience perception. The same set of attribute multiple-choices in each survey question was repeated for each piano sound so the use of a particular attribute in the responses could be categorized as either identifying the Stuart or Steinway sound. In compiling the survey responses, the number of responses that used an attribute to describe a piano sound was tallied against the number of times that same attribute was used to describe the other piano sound. The wider the differential of attribute use in responses, e.g. 66%STU ‘bright’ vrs 40%STE’bright’, established an

344 Galembo.
345 Hajda.
Perceptions of the Stuart & Sons Piano – Kevin Hunt

overall perception of audience timbre identification. The attributes that produced useful differential responses in answers to survey questions were also tallied for their frequency of use in the written comments. A perception was established when it was found that a verbal attribute was used in over 50% of responses to describe one piano sound, that also was used in under 50% of responses to describe the other piano sound. If a participant described both piano sounds with the same attribute, the double evaluation created a 50% - 50% evaluation, equal with no difference in the percentage. Such a response was not regarded as an audience perception for the compiling purpose of this study, because in that instance, the verbal attribute isn’t attributed to one piano sound more favourably than the other.

The audience perception percentage results listed below were compiled and averaged across the audience responses of all six concerts. The percentages are all of the above 50% differential, each percentage having a corresponding below 50%, for the other piano sound. Attributes with similar associations to a type of timbre, are grouped in this summary to observe a general perceptual result of tone colour.

<table>
<thead>
<tr>
<th>Stuart Sound Characteristics</th>
<th>Perceptual Verbal Attributes</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Style/pianism</td>
<td>Bright, clear, clean, metallic, shrill</td>
<td>66%</td>
</tr>
<tr>
<td></td>
<td>Percussive</td>
<td>58%</td>
</tr>
<tr>
<td></td>
<td>Clearer more defined, clarity, resonant</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>Colourful</td>
<td>61%</td>
</tr>
<tr>
<td></td>
<td>Pure, light, airy</td>
<td>77%</td>
</tr>
<tr>
<td></td>
<td>Short Note -not singing</td>
<td>84%</td>
</tr>
<tr>
<td></td>
<td>Kevin Hunt’s pianistic style</td>
<td>83%</td>
</tr>
<tr>
<td></td>
<td>Jazz style</td>
<td>86%</td>
</tr>
</tbody>
</table>

Stuart - Overall audience perception Table 5.13

<table>
<thead>
<tr>
<th>Steinway Sound Characteristics</th>
<th>Perceptual Verbal Attributes</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Style/pianism</td>
<td>Mellow, smooth, deep</td>
<td>71%</td>
</tr>
<tr>
<td></td>
<td>Powerful and dynamic</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>Rich &amp; full</td>
<td>63%</td>
</tr>
<tr>
<td></td>
<td>Singing quality</td>
<td>68%</td>
</tr>
<tr>
<td></td>
<td>Muddy, muffled</td>
<td>54%</td>
</tr>
<tr>
<td></td>
<td>Just as I’d expect a piano to sound</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Simon Tedeschi’s pianistic style</td>
<td>85%</td>
</tr>
<tr>
<td></td>
<td>Classical style</td>
<td>89%</td>
</tr>
</tbody>
</table>

Steinway - Overall audience perception Table 5.14

The averaged percentages above define the overall perceptions of all 6 concerts. The Steinway sound was generally perceived to be more ‘powerful’, ‘mellow’, ‘rich and full’, with a ‘singing tone’, and ‘just as is expected in a piano sound’, and the Stuart sound was perceived to be ‘lighter’, ‘brighter’, more ‘colourful’, with less of a ‘singing quality’, though with more ‘definition’ than the Steinway sound. These perceptions are discussed in detail in the following section, examining responses to specific questions at particular survey-concerts with audio extracts from the concerts.
Audience Perceptions Results Table.

The verbal attributes that generated the most significant perceptual responses from the audiences are listed in the table below. These results are responses to the attributes that were presented in three multiple-choice questions and were also used by the participants in written comments.

<table>
<thead>
<tr>
<th>Qu. 4&amp;5 How do you describe the sound of the Stuart/Steinway piano</th>
<th>Qu. 6&amp;7 Is the sound of the Stuart/Steinway Piano-</th>
<th>Qu. 14&amp;15 Concerts 3,4,5,6. Which musical characteristics suit the Stuart/Steinway piano.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bright &amp; Clear 66% STU</td>
<td>Clearer more defined than Steinway 60% STU</td>
<td>Colourful 80% STU (4,6) 58% STE (3,5)</td>
</tr>
<tr>
<td>Bright &amp; ShriIl 80% STU</td>
<td></td>
<td>Light 63% STU (6) 68% STE (3,4,5)</td>
</tr>
<tr>
<td>Bright &amp;Metallic 80% STU</td>
<td>Clearer more defined than Stuart 40% STE</td>
<td>Percussive 75% STU (3,5) 59% STE (4,6)</td>
</tr>
<tr>
<td>Mellow &amp; Clear 75% STE</td>
<td>Trio Clarity Qu,9,10,11 64% STU 36% STE</td>
<td>Powerful -5% STU 66% STE (3,4,5,6)</td>
</tr>
<tr>
<td>Smooth &amp; Deep 71% STE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic &amp; Powerful 72% STE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comments

| Bright | 57% STU | Rich & Full 63% STE | Colourful 61% STU |
| Mellow, Smooth, Deep, Round | 56% STE | Clear, Defined Resonant, Clarity 61% STU | Light, Pure, Airy, Delicate 79% STU |
| Powerful, Strong Weighty, Grunt, | 57% STE | Dull, Dark 58% STU | Percussive 58% STU |

- Audience Perception Summary: Qu.4,5; 6,7; 14,15. Table 5.15

Detailed breakdowns of the above perception results are illustrated in Appendix 5.

Interpreting Audience Perceptions

Responses to questions 4 & 5, 6 & 7, and 14 &15 indicated audience perceptions that identified the tonal colours of the Stuart and Steinway piano sounds. The scales of tonal quality designated by the verbal attributes, attracted responses of clear differences indicated by the percentage differences for each piano sound. As previously mentioned, the frequency of use of a specific attribute in the survey responses established a figure of above or below 50% of the total number of participant responses for that particular question. The percentage indicated the majority perception, either a Stuart majority (+50%), or a Steinway majority (+50%). For example, in concerts 4 & 6, for questions 14 & 15, 80% of participants used the attribute ‘colourful’ in their responses to describe the sound of the Stuart piano sound. This is interpreted as a majority perception, because only 20% responded that the Steinway sound was more ‘colourful’ than Stuart. This % difference indicated the overall perception that the majority (80%) of the participants described the Stuart sound as being more ‘colourful’ than Steinway.
Perceptions of the Stuart & Sons Piano – Kevin Hunt


Qu. 4 How do you describe the sound of the Stuart piano
Qu. 5 How do you describe the sound of the Steinway piano

The attributes of ‘bright’, ‘mellow’, ‘smooth’, and ‘deep’, established distinctions in the perceptual responses of participants to survey questions 4 & 5. Two attribute groups, one using ‘bright’ and the other using antithesis qualities of ‘bright’ though not ‘dark’ defined majority audience perceptions of the Stuart and Steinway sounds in the responses to questions 4 & 5. ‘Bright’ was combined with adjectives establishing a choice of ‘bright’ within the multiple-choice question346 because it was anticipated that both pianos could be perceived as sounding ‘bright’ as neither piano possessed a particularly ‘dark’, or ‘dull’ sound. ‘Bright & clear’ for the Stuart sound and ‘mellow & clear’ for the Steinway sound, were the verbal attributes used most distinctively in the responses to describe the Stuart and Steinway sounds in questions 4 & 5. ‘Bright’, yielded a significant response from the audiences in five concert surveys, showing consistently that a higher percentage of the audiences perceived the sound of the Stuart piano to be ‘brighter’ in tone colour than the Steinway. When ‘bright’ was presented as various VAME347 attributes, i.e. ‘bright & clear’ ‘bright & shrill’, participants responded using ‘bright’ as majority above 50% descriptor for the Stuart piano tone, and as a below 50% descriptor for Steinway piano tone, establishing a wide differential of the perception that the Stuart sound is ‘brighter’ than Steinway. ‘Shrill’ is an attribute that is not used as a complementary description of tone, derived from glossary 14, which denotes A. Oorebeeck’s description of a piano sound as being too ‘percussive’ or ‘shrill’.348 ‘Mellow & clear’ and ‘smooth & deep’ yielded majority responses as descriptors of the Steinway sound for questions 4 & 5 in concerts 1,2,3,5 & 6.

Responses to questions 4 & 5 indicated that the larger venues produced wider differentiated perceptions of the Stuart sound as ‘bright’ and the Steinway sound as ‘mellow’ and ‘smooth’. 80% of the participants perceived the sound of the Stuart to be ‘brighter than Steinway and 71% of participants perceived the Steinway sound to be more ‘smooth & deep’ than Stuart in the larger venues of concerts 1 & 2. In the smaller venues, the differential was less, with 69% of participants perceiving the Stuart sound to be ‘brighter’. Overall, 76% perceived the Steinway sound to be more ‘mellow’ than Stuart in the larger venues, concerts 1,2,& 4, and 67% perceived the Steinway sound to be more ‘mellow and clear’ than Stuart in the smaller venues, concerts 3,5, & 6. An opposite perception was received at concert No5, where 100% of the written comments described the Steinway sound as having a ‘brighter’

346 Verbal Attribute Magnitude Estimate, 347 ibid 348 A. Oorebeeck,71.

| Qu. 4&5 | How do you describe the sound of the Stuart/Steinway piano |
|-----------------|-----------------|-----------------|-----------------|
| Bright & Clear  | 66% STU          | 1,3,5,6         | Overall perception % |
| Bright & Shrill | 80% STU          | 1,5,6           | Stuart ‘bright’: 77% |
| Bright & Clean  | 85% STU          | 2               |                 |
| Mellow & Clear  | 75% STE          | 3,5,6           | Steinway ‘mellow’, ‘smooth’, ‘deep’: 73% |
| Smooth & Deep   | 71% STE          | 1,2,3,5,6,      |                 |

Qu. 4 & 5 Survey results table 5.16
and more powerful sound than the Stuart, whereas at the same concert, the multiple choice survey questions responses were tallied to 80% of participants describing the Stuart sound as ‘brighter’ than Steinway. These observations are examined later in this section, using audio extracts from these performances.

**Written Comments:** ‘bright’ ‘mellow’, ‘smooth’, ‘deep’ and ‘round’.

As a singular attribute, ‘bright’ was used in the written comments of 30 participants, with 57% describing the Stuart sound as a ‘brighter’ sound. A small differential for perceptions of ‘bright’ for both piano sounds was apparent in the comments, except for concert 3, where 83% identified the Stuart sound to be brighter than Steinway. In contrast to all the above findings, 100% perceived the Steinway to be ‘brighter’ in the trio concert No 5, as previously mentioned.

<table>
<thead>
<tr>
<th>Concert Comments</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘mellow’, ‘smooth’, ‘deep’, ‘rounded’ in comments.</td>
<td>STE</td>
<td>STU</td>
<td>STU</td>
<td>STU</td>
<td>STU</td>
<td>STU</td>
</tr>
<tr>
<td>Written comments ‘mellow...’</td>
<td>Table 5.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

‘Mellow’, ‘smooth’, ‘deep’ and ‘round’ were used as single attributes in written comments, though not exclusively as descriptors of the Steinway sound. The majority of written responses at concerts 2,3,4 and 6, described the Stuart as sounding more ‘mellow’, ‘smooth’ ‘deep’ or ‘rounded’ than Steinway. The audio excerpts from these concerts confirm this also. At the quieter dynamic levels, the Stuart sound presents more variation and clarity, which in many instances produces a sense of a purer sound than the Steinway. The 75% & 71% majority perceptions which described the Steinway sound as more ‘mellow’, ‘smooth’, ‘deep’ and ‘round’ in the responses to multiple-choice questions 4 & 5, was not replicated in the comments.

<table>
<thead>
<tr>
<th>Concert comments</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘bright’ in comments.</td>
<td>STU</td>
<td>STU</td>
<td>STU</td>
<td>STU</td>
<td>STU</td>
<td>STU</td>
</tr>
<tr>
<td>Comments, ‘bright..’</td>
<td>Table 5.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Stuart tone was found to sound ‘deeper’ than Steinway in the lower notes, C2 65….Hz, in chapter four:

<table>
<thead>
<tr>
<th>Stuart</th>
<th>C2v81 STU MW mic6 USB Audio 5: trk 3 C2v81 STU MW mic 6.wav</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steinway</td>
<td>C2v81 STE MW mic6 USB Audio 5: trk 4 C2v81 STE MW mic 6.wav</td>
</tr>
</tbody>
</table>

Sound table 5.2
Stuart: ‘bright’: a louder, wider, more stable harmonic spectrum.

A brighter tone was found to be a tonal distinction of the Stuart piano tone in chapter four. Several elements are known to cause ‘brightness’ in piano tone, as discussed in detail throughout chapters 3 & 4. In chapter four, it was found that when compared to Steinway, the ‘brightness’ in the Stuart tone was due to: i) the presence of a greater number of partials of higher frequency observed in a wider harmonic spectrum, ii) a sound of greater loudness observed by vibrations of larger amplitudes, and iii) a slower rate of decay of the fundamental frequency, after .5s, establishing a more stable clarified after-sound. There are numerous examples of these three combined elements of the Stuart timbre throughout chapter four, one example, C4v20 MW mic2,349 exhibits the three elements of brightness:

i) a wider harmonic spectrum,
ii) greater loudness,
iii) a slower rate of decay of the fundamental frequency, and 2\textsuperscript{nd} harmonic frequency after .5s.

<table>
<thead>
<tr>
<th>Stuart</th>
<th>USB Audio 5: trk.5 C4v20 M19(STU) MW mic2.wav</th>
<th>Steinway</th>
<th>USB Audio 5: trk.6 C4v20 STE MW mic2.wav</th>
</tr>
</thead>
</table>


Over 80\% of the participants identified the Stuart sound to be ‘brighter’ in tone than the Steinway sound in the larger performance spaces, at concerts 1 & 2, see concerts No 1 & 2 appendix 5, table 5a.6. The findings of chapter four established that the Stuart sound projected a wider spectrum over a longer distance than Steinway. See section 4.25 Projection chapter 4. The stronger projection of the Stuart sound over a longer distance of 6m, the 5\textsuperscript{th} tonal distinction finding of chapter four, was found to be established by the sounding of a more comprehensive harmonic spectrum at an average of 8dB louder than Steinway, to a distance of 6 metres. The Stuart soundboard was found to be moving significantly more with larger amplitudes of vibrations for the notes C2, C3, and C4.

<table>
<thead>
<tr>
<th>Stuart</th>
<th>USB Audio 5: trk 7 C3v81 M19(STU) MW mic8.wav</th>
<th>Steinway</th>
<th>USB Audio 5: trk 8. C3v81 STE MW mic8.wav</th>
</tr>
</thead>
</table>

349 See sound No.2 in ‘Eight Introductory Sounds of Stuart Piano Tonal Distinction,’ chapter 4.
Perceptions of the Stuart & Sons Piano – Kevin Hunt

**Concert No 1 - Video extract.**

In the video extract 5.1 below, the Stuart piano (brown) is being played by Kevin Hunt and the Steinway piano (black) is being played by Simon Tedeschi. The extract from the performance of ‘Gershwin Medley’ is edited into 3 sections, each illustrating differences of both pianos’ tonal characteristics. In the first section [00m:18s], the pianos are being played similarly, albeit harmonized slightly differently, the rhythms, dynamics and articulations are similar, so the pianos are heard as a homogenous sound. The video is then edited forward about 1 minute to the 2nd section, which exhibits Simon Tedeschi playing the Steinway in a leading role [00m:18s - 1:07], and the 3rd section follows with Kevin Hunt playing the leading role on the Stuart piano [1m:08s – 2:0]

| Video extract: trk 9: USB Audio 5 : Trk.9 Gershwin extract. 2 Pianos.mov |
| 2 pianos – Gershwin Concert 1. Sound table 5.5 (Audio/visual). |

**Section 1 – Gershwin video**

The ensemble sound of both pianos heard in the 1st section [00m:18s], could be described as being ‘bright’ and ‘full’. Some imbalances of volume and tonal colour observed in this section, present higher. The ‘brighter’ Steinway tone dominates the blend of the 2 instruments. The sound of the upper register ‘stab’ chords, played in unison by both pianos, is dominated by the more immediate attack sound and ‘brightness’ of the Stuart sound. characteristics of each piano’s tonal characteristics of specific pitch registers. The repetitive left hand phrases played by both pianists in rhythmic unison are harmonized. The lower phrase in the bass register of the Steinway sounds ‘brighter’ in tonal colour than the phrase played on the Stuart, over an octave.

**Section 2 – Gershwin video**

The differences in tone in the right hand registers above middle C, are more noticeable in the section 2 [00m:18s - 1:07], where the Steinway lead exposes a ‘fuller’, wider tone in the treble registers to that of the previous two piano ensemble sound. When the camera vision splits into two, [.36s] it is possible to see that even though Tedeschi is playing the lead with at times, quite a forced fortissimo, an effect which is applied to many right hand phrases played in this swing-be bop jazz style, the tone of the Steinway does not reach the ‘brightness’ previously heard in the homogenous 2 piano sounds played at fortissimo in the same treble registers in section 1.
Section 3 – Gershwin video

In the following 3rd section [1m:08 – 2:03], Hunt plays the Stuart piano leading the music, with a different range of dynamics. An immediate change in the density of the lead piano texture is evident, when the melodic block chords are played at mezzo forte. The melodic chordal passage is ‘light’, very ‘clear’, less ‘percussive’, and with cantabile. A clarity of sound without the ‘fullness’ of the Steinway is heard in the Stuart lead. As the lead continues, a more extensive dynamic range of single note phrases is exhibited, ending in the extremely ‘bright’ notes played with fortissimo in the higher register.

In conclusion, the video extracts show the audience perceptual responses of ‘bright’ for the Stuart sound and ‘mellow’ ‘smooth’ ‘round’ & ‘deep’ for the Steinway sound could be associated with the pitch register. In the video extract from concert No 1, the bass register of the Steinway sounded ‘brighter’, than Stuart, and the treble register of the Stuart sounded ‘brighter’ than Steinway. This general tonal description concurs with the findings of chapter 4, see section 4.1


In concerts 3, 5 & 6, 69% of participants identified the Stuart sound to be ‘brighter’ than Steinway, and 64% of participants described the Steinway sound as more ‘mellow, round, smooth and deep’ than Stuart. Concerts 3 & 5 produced the largest percentage differences that concur with these overall perceptions. At concert No 3, 62% of participants answered qu. 4&5 describing the Stuart sound as ‘bright’ and 83% of the participants described the Stuart sound as sounding ‘brighter’ than Steinway in the written comments of qu. 4&5. At concert No 5, 76% of participants answered qu.4&5 that the Steinway sound was more ‘mellow & clear’ than Stuart.

In contrast to these perceptions, the written comments of concert No 3, saw 54% of participants commenting that the Stuart sound was more ‘mellow’, ‘round’, ‘smooth’ and ‘deep’ than Steinway in comments associated with questions other than qu. 4&5. At concert 5, 100% of the written comments described the Steinway sound as ‘brighter’ than Stuart. Similarly at concert 6, 62% of participants’ comments described the Stuart sound as more ‘mellow’, ‘smooth’, ‘round’ or ‘deep’ than Steinway. In the recording extracts below, albeit not high quality recordings, the contrasts of ‘brightness’ between the pianos sounds is lessened in the smaller venues, with Stuart sound of concerts 2, 3 & 5, sounding not as ‘bright’ as it does in the larger venues at concerts 1, 2, & 4.

The audio sound excerpts examined in the following pages are from concerts 3, 5 & 6. In some of these examples the Stuart sound could be described as sounding more ‘rounded’ in tone than the Steinway, supporting the written comments and evidences of chapter 4. The room noise on these recordings is a necessary part of the experience, because the microphones are placed within the audience area so the
recorded sound is representative of how the pianos sounded to the audiences. Added noises are the sound of survey papers being written on and turned over.

**Visions Fugitives, No 8 Commodo, Concerts 3 & 6.**

Classical Piano.

At concerts No 3 & 6, pianist Simon Tedeschi played three of Sergey Prokofiev’s Vision Fugitives, Op.22 a set of 20 pieces, on both pianos. In the audio extracts presented below of piece No 8, ‘Commodo’, a distinct difference in the piano tones is audible. The majority of audience responses to survey questions 4&5 described the Stuart sound as ‘brighter’ than Steinway, and the Steinway sound as more ‘mellow’, ‘smooth’ and ‘round’ than Stuart. The audio examples below generally agree with these perceptual descriptions, although in listening to theme 1, it is evident that the Stuart sound could be described as being more ‘mellow’ than the Steinway, concurring with the 54% audience perception in the written comments, previously mentioned. Three audio excerpts of ‘Commodo’ are compared from Tedeschi’s performances in Concerts 3 & 6.

**Commodo Theme 1:**

<table>
<thead>
<tr>
<th>Theme 1. Concert 3</th>
<th>Theme 1. Concert 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>USB Audio 5: trk.10 <strong>Steinway</strong> theme 1.wav</td>
<td>USB Audio 5 trk.12 <strong>Steinway</strong> theme 1.wav</td>
</tr>
<tr>
<td>USB Audio 5: trk.11 <strong>Stuart</strong> theme 1.wav</td>
<td>USB Audio 5: trk.11 <strong>Stuart</strong> theme 1.wav</td>
</tr>
</tbody>
</table>

| Sound table 5.6 |

![Commodo Theme 1](Commodo Theme 1. Fig 5.5)

Theme 1: Concert 3  8th June 2011

The Steinway sound balances the treble melody and bass quavers in an overall lighter sound than the Stuart, with less pronouncement of the left hand quavers, producing an effect of lightness in the treble. The Stuart is played slightly faster and louder with the quavers in the bass sounding heavier, with more attack, played with less legato than the Steinway. This is possibly due to the generally faster attack and a louder, wider onset spectrum in the Stuart sound, qualities found in the Stuart sounds of chapter four. The Stuart is more responsive than the Steinway in this tenor register, the octave below middle C, with a louder onset or attack at the beginning of the sound, and a more comprehensive dynamic range, which requires a greater application of pianissimo from the pianist, to achieve the same pianissimo as was played on the Steinway. The Stuart treble melody does have a more ‘mellow’ and ‘round’ tone and a larger presence of sound than the Steinway’s treble theme 1.
Theme 1: Concert 6  11<sup>th</sup> April 2012

Similar to concert No 3, the left hand quavers on the Stuart sound heavier with louder attack, than the Steinway, generally the Steinway blend is lighter than Steinway

Commodo Theme 2:

<table>
<thead>
<tr>
<th>Theme 2, Concert No 3</th>
<th>Theme 2, Concert No 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>USB Audio 5: trk.14</td>
<td>USB Audio 5: trk.16</td>
</tr>
<tr>
<td>Steinway theme 2.wav</td>
<td>Steinway theme 2.wav</td>
</tr>
<tr>
<td>USB Audio 5: trk.15</td>
<td>USB Audio 5: trk.17</td>
</tr>
<tr>
<td>Stuart theme 2.wav</td>
<td>Stuart theme 2.wav</td>
</tr>
</tbody>
</table>

Sound table 5.7

Theme 2: Concert 3

In the second theme, after the slight pause and a diminuendo, the brightness of the Stuart tone is enhanced expressively by the pianist playing the accentuated melodic quavers 'shorter’ on the Stuart than on the Steinway. The Steinway is played with a more cantabile interpretation, with longer accentuated quavers. The audience at this concert responded to the survey question about the ‘singing quality’ of tone, with 75% associating the Steinway sound with ‘singing quality’ and 92% of participants describing the Stuart sound as ‘short tone not singing’. On closer listening, the legato ‘e’ treble quavers on the Stuart are not short at all, it is only the accentuated quavers that are played short. The legato quavers on the Stuart are sustaining their harmonic spectrum for a longer duration than the Steinway. Sustain in this register was found to be greater in the Stuart sound in chapter four, see section 4.2.

Theme 2: Concert 6  11<sup>th</sup> April 2012

The Stuart sound is clearer than Steinway, the notes are more distinct and the crescendo is played more dramatically on the Stuart. There is less pianistic ‘staccato’ applied to the accentuated quavers than in concert 3. Again, the melodic ‘e’ treble notes of the Stuart sound are sustaining their spectrum for a longer period than Steinway. The accentuated ‘e’ is brighter at the onset on the Steinway, and then decays quickly- changing with the effect of a change in timbre to a less bright, ‘mellow’ tone. Similar to concert No 3, 81% of participants at concert No 6 described the Stuart as 'short tone, not singing’ and 63% described the Steinway as having more of a ‘singing quality’, a perception not heard in this example.
Commodo Theme 3:

<table>
<thead>
<tr>
<th>Theme 3: Concert No 3.</th>
<th>Theme 3: Concert No 6.</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

Sound table 5.8

Commodo Theme 3: Fig 5.7

Theme 3: Concert 3  8th June 2011
The differences in piano tone in the third theme are clearly audible. The higher key transposition to C major of the 1st theme played with more pianissimo than theme 1, has brought out ‘brightness’ in the Stuart sound, and a more ‘round’, ‘mellow’ tone of the Steinway.

Theme 3: Concert 6  11th April 2012
In the first melodic phrase of theme 3, the Stuart is played with more legato than the Steinway. The Stuart’s ascending chromatic line is rounder in tone than Steinway. As the line crescendos the tone of the Steinway ‘brightens’ more than the Stuart. At the return to the A major key, the lower register, the left hand quavers of the Stuart are more pronounced than on the Steinway. The balance between the treble and bass is more subtle on the Steinway, as it was in theme 1.

Conclusion ‘Commodo’ concerts 3 & 6

With the same pianist performing identical music on the Stuart and Steinway pianos, a range of timbre was exhibited which supports the range of perceptual audience responses. In ‘Commodo’ both pianos produced a more mellow (less bright) tone when the left hand quavers were played more prominently. The louder attack of the Stuart notes in the tenor register, the left hand quavers of theme 1, was a distinctive difference in the piano sounds. The playing of theme 2 of ‘Commodo’ in concert 3, displayed a difference in how the pianist accentuated melodic quavers, possibly in musical reaction to the difference in piano sound, with more detached shorter notes being played on the Stuart piano, and a more cantabile interpretation played on the Steinway. The playing of theme 2 at both concerts 3&6,
illustrated the greater treble sustain of the Stuart notes, an octave above middle C, a characteristic found in the tests of chapter four.

At concert No 3, 62% of participants answered qu. 4 & 5 and 83% of participants commented describing the Stuart sound as ‘bright’ in comparison to the Steinway sound. As previously mentioned, in contrast to these perceptions, in written comments associated with other questions, 54% of participants also commented that the Stuart sound was more ‘mellow’, ‘round’, ‘smooth’ and ‘deep’ than Steinway.

‘Little Rootie Tootie’ - Jazz Piano, Concert 3.

At concert No 3, jazz pianist Kevin Hunt played ‘Little Rootie Tootie’ by Theloniouls Monk, on both the Stuart and Steinway pianos.

In the 1st section of part 1, the Stuart sounds louder, and as though it is being played more solidly than the Steinway. The pianist plays the same music differently on both pianos. This research suggests that the pianist has anticipated how stylistically to play the contrasting of piano sounds for this piece. The Steinway is played more lightly, with longer tenutos in both the melody notes and the chords in the left hand than on the Stuart. The Stuart is played at a slightly faster tempo, with more rhythmic triplet tension, a with a more ‘percussive’ detached interpretation of the melody notes and chords. The range of dynamic in the playing styles is more varied on the Steinway, whereas the Stuart dynamic is a constant forte. In this section it could be said the Steinway is being played in a more sedate ‘classical’ manner, and the Stuart is being played in a more aggressive ‘jazzy’ way.

In the 2nd section of part 1, at 14s in both performances, the pianists choice of register for the right & left hand phrases is different for each piano. The pianist decides to use higher octaves in the Stuart performance. The timbres of the lightly played high triplets are contrasting, the Stuart being significantly brighter, albeit at the octave higher. The left hand melody in the tenor register melody has a ‘smooth’ tone on the Stuart, and the Steinway lower bass melody is ‘bright’, as found in chapter four, see test on C2 65.406 Hz, chapter four section 4.1.

In the 2nd section of theme 1, the pianos sound a little more similar. In the 1st section of part 2, the pianist plays the pianos each in a different stylistic manner in the left hand. In the Steinway performance, the left hand chords are played again as tenuto on each beat, as a background rhythmic function. Whereas the Stuart left hand chords are used to more sparsely, simply to support the melody, harmonically.
Perceptions of the Stuart & Sons Piano – Kevin Hunt

**Little Rootie Tootie** pt. 3

<table>
<thead>
<tr>
<th>![Steinway pt. 3](Steinway pt. 3.wav)</th>
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<td>USB Audio 5: trk 27</td>
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Prt. 3 returns to the similar contrasts in playing style of prt.1

**Little Rootie Tootie** pt. 4

<table>
<thead>
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<td>USB Audio 5: trk 29</td>
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<td>Sound table 5.12</td>
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</tbody>
</table>

An improvisation on the chords of ‘Little Rootie Tootie’ at a faster tempo is played as part 4. The quaver line show the Steinway sound to be ‘lighter’ than the Stuart’s. The Stuart has a heavier more percussive sound in this performance. A closer listen reveals that the left hand comping\(^{350}\) chords in the Stuart performance are heard to be louder in relation to the right hand quavers. Here we hear the ‘tenor’ register of the Stuart sound producing a more sensitive dynamic sound then the Steinway, possibly requiring a greater pianistic control. A similar dynamic was heard in the A major sections of themes 1 & 3 in the audio extracts of ‘Commodo’.

**Conclusion ‘Little Rootie Tootie’ audio excerpts.**

The Stuart sounds more percussive than the Steinway in these excerpts. The melody notes are played with more tenuto on the Steinway. The Steinway sound in these excerpts could be described as sounding lighter, and brighter than the Stuart. Excerpt part four showed that the balance of sound level between the accompanying left chord and the right hand improvised quavers was differently played on each piano. The Steinway balance was more pianistic, with quieter left hand chords. The right hand chords of the Steinway sounded ‘clearer’ and ‘brighter’, possibly as a consequence of the quieter left hand chords. The Stuart sounded more ‘percussive’, and more ‘powerful’.

The pianist’s improvised interpretations of ‘Little Rootie Tootie’ are very differently played on each piano. The Stuart is played in a heavier, louder manner, with more syncopation, whereas the Steinway is played slightly more gently with more tenuto.

‘Deep River’- Jazz Piano, Concerts 5 and 6.

At concert No 5, 76% of the survey participants described the Steinway piano sound as being more ‘mellow & clear’ than the Stuart sound, and 59% described the Stuart sound as ‘bright & clear’. In the written comment responses, 100% of participants described the Steinway sound as being ‘brighter’ than the Stuart at concert No 5. Kevin Hunt performed improvisations on the spiritual ‘Deep River’ on both pianos in concert No 5 as solo piano pieces.

\(^{350}\) Term for chords that accompany the melody.
Extracts of the concert No 5 versions of Deep River are presented below. They reveal aspects of Stuart and Steinway piano sounds that the pianist is working with and reacting to, throughout the performances.

*Deep River* Melody 1 prt 1.

<table>
<thead>
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<tbody>
<tr>
<td></td>
<td>USB Audio 5: trk 31. Stuart melody 1 prt 1 Deep River .wav</td>
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</tbody>
</table>

The Stuart and the Steinway are played in different registers. The Stuart melody is played in the higher treble register, which is possibly the most unique sounding register of the Stuart piano, the octave above middle ‘c’. As previously noted, the findings of chapter four found this register of the Stuart piano sound to have an enhance quality of sustain. The Steinway is played in a powerful, strong hymn style, exhibiting a ‘brighter’ tone than the Stuart’s upper register. The crescendo played on the Steinway demonstrates a perfectly balanced climax chord, with a ‘bright’ high melody note. On the Stuart, the dynamic is held at the *mp*, and the accented chord is played with the same dynamic and tonal ‘roundness’.

*Deep River* Melody 1 prt 2.

<table>
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<tr>
<th>Deep River melody 1 prt.2</th>
<th>USB Audio 5: trk 32. Steinway melody 1 prt 2 Deep River.wav</th>
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<tbody>
<tr>
<td></td>
<td>USB Audio 5: trk 33. Stuart melody 1 prt2 Deep River.wav</td>
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</table>

The low ‘c to f’ upward glissando of the Steinway is ‘brighter’ the Stuart low ‘c’ is ‘rounder’ in tone. A close listen to the resting note of the ascending glissando ‘f’, reveals the Stuart tone sustained its spectrum more evenly than Steinway. The Steinway low ‘f’ is heard to change in timbre in a more rapid decay after its initial sounding, as it’s being held. The Stuart timbre of this note is more consistent, more sustained, with a slower decay. This characteristic of the Stuart sound at this register was observed in the tests of chapter four, notably in the sound C2v81 MW mic2. The final melody phrase continues to be played in the higher register on the Stuart.

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351 see section 4.2
Deep River Bridge:

The bridge is played in the same register on both pianos. The ‘rounder’ tone of the Stuart is more obvious in comparison to the ‘brighter’ sounding Steinway. Several written comments were critical of the Stuart sound, using attributes, ‘muffled’ and ‘muddy’ to describe the sound. Another more complimentary comment described the Stuart sound as - ‘deep and rich like listening to vinyl’. The two accentuated ‘F’ chords sound to be more successfully balanced and sustained on the Steinway, possibly a pianistic error of chordal balance, whilst playing the Stuart.

The upper notes of the chord are heard more clearly in the chords played on the Steinway at fortissimo. The notes in the bass registers of the Stuart chord respond more to the fortissimo than the treble notes in the chord. Here perhaps the overall brightness of the Steinway tone is enabling a clearer presentation of the chord at fortissimo. Achieving a good resonance of closely voiced chords played at fortissimo in the higher registers on the Stuart piano could possibly require a different weight pressure on the notes within the chord, than is being applied in this extract. Chapter four closely examines the resonances of single notes, whereas a test on the resonance of chords would be a useful follow up study.

A comment in response to pianist’s sound of concert 6:

Steinway is conventional and immediately recognizable. But can hear more detail with the Stuart. But I think the Steinway is more expressive. I think we are socialized to expect a more prominent melody than Stuart can deliver. While the pianist is the most important ingredient, the Stuart is the more expansive of the two.

This comment from concert No 6, offers a participant’s description of the Stuart sound not projecting melody notes as clearly as the Steinway. The top note, i.e. melody note, of the chordal texture of the Stuart sound in the previous extract of ‘Deep River’ was not as clearly heard as when the Steinway was played. Pianistic interpretation, style and the room acoustic cannot be ruled out as influences of this difference in tonal balance. At concert No 4, in the larger venue, the Stuart piano was heard to sound extremely clear balanced melodic and chordal textures.

Deep River Melody prt 3 and final vamp.

Played at pianissimo, the Stuart sound has a more ‘percussive’ onset. A wider dynamic range in volume and harmonic spectra is exhibited here in the Stuart sound. The sound analysis in chapter four found that more harmonics were present in the onset of the Stuart sound, which contributed to the more percussive edge to the front of the sound, and also a faster onset rate of decay. (see section 4.23 chapter

352 Survey response, written comment - qu.11 & 12 concert No 6, participant No 47.
Perceptions of the Stuart & Sons Piano – Kevin Hunt

The sound of the Stuart is bigger, as the instrument is longer and wider than the Steinway. The softs and louds of this section are more expansive in the Stuart sound than the Steinway. On the few occasions that the Stuart is played at a fortissimo, a ‘brightness’ of tone is present.

Conclusion – interpretations of ‘Brighter.’

The audio extracts of ‘Commodo’ ‘Deep River’ and ‘Little Rootie Tootie’ reveal the extent of the influence the pianists’ interpretation of the music and their manipulations of the piano sounds has on the overall tonal colour of the sound that radiates to the audience. The audience interpretations of the attributes ‘bright and mellow, round & smooth’ are also particular to their individual experience.

Generally the audio extracts reveal that in the performances of ‘Deep River’, and ‘Little Rootie Tootie’ the Steinway sound was ‘brighter’ than the Stuart, agreeing with the 100% perception of the written comments of concert No 5, and the minority perceptions of 31% of responses to qu. 4&5. In ‘Deep River’ the pianist played the Stuart at a softer dynamic than the Steinway, emphasizing a more ‘colourful’ interpretation, and more use was made of the treble and bass registers than in the Steinway performance. The Steinway is played in a more conventional, gospel piano style, using a narrower range of dynamics with the ‘fuller’ sound of the middle registers. In ‘Little Rootie Tootie’ the pianist played the Stuart with a slightly louder, heavier style than the Steinway, again producing a sound that was not as ‘bright’ sounding as the Steinway.

The known ‘brightness’ of the Stuart tone may not have been exploited to its capacity by a different pianistic weighting of the fortissimo chords. See p.38 for a contrasting chordal sound of the same Stuart piano, in a different acoustic space.

Conclusion: perception responses, questions 4 & 5.

In answers to the survey questions 4 & 5, ‘bright’ was identified as the perceptual characteristic to describe the Stuart sound when compared to Steinway, and the Steinway sound was clearly perceived as sounding more ‘mellow, smooth and deep’, than the Stuart sound. The comment-responses however presented a less clear overall perception, with the Stuart sound being described as both ‘bright, mellow, smooth, deep and round’, by a majority of participants. The audio extracts from Concert No 5, concur with the 100% written responses that the Steinway sounded ‘brighter’ than the Stuart.

Qu. 6&7 ‘clearer more defined’

Is the sound of the Stuart/Steinway Piano?

The multiple-choice option, ‘clearer more defined than the Stuart/Steinway’ Qu.6 & Qu.7, attracted an overall perceptual response across the 6 concerts of 60% participants saying the Stuart sound was ‘clearer more defined’ than the Steinway sound. The use of the attributes, ‘clarity’, ‘resonant’ and ‘defined’ in comments were compiled as responses about a more defined sound definition. The clarity, resonance and definition of sound is described below by Wayne Stuart as a consequence in the Stuart sound of the vertical coupling implemented by the Stuart bridge agraffe, which couples the strings.
vertically onto the bridge and soundboard, as compared to the two pinned horizontal coupling of the Steinway and most other modern pianos’ strings.

The real issue—when you open the pedal, because of the nature of the coupling, of the string to the soundboard of the two pinned system, produces muddiness, because of complex counter-phasing issues at the point of enunciation of the sound. We don’t pursue that whole ideology, we pursue vertical coupling and the vertical soundscape, they are very different concepts. Now that completely changes the way the wire behaves on excitation, and also on the attack and decay transients—are totally different to the standard piano, it leaves the sound spectrum totally clean, right through the frequency range, so you don’t get masking and all sorts of other what they call inharmonicity effects, from the vibration of the strings, so if you can wipe all those problems away, you can create these extreme frequencies, and not have tuning problems in the extreme ranges.

The Stuart agraffe vertical string coupling was found to affect a more significant vertical vibration of the piano string C2 65.406 Hz than the Steinway horizontal coupling in tests conducted previously in this research, see chapter two.

Piano sounds in the Jazz Trio

In responses to survey questions about the trio sound at concerts 2, 4 & 5, overall 69% of participants described the Stuart piano sound as being ‘clearer’, more ‘distinct’ and with having more ‘projection’ than the Steinway sound. And 57% of participants’ written comments at these concerts used the attributes ‘clarity’, ‘definition’ and ‘resonant’ for affirmative descriptions of the Stuart sound with the jazz ensemble.

Piano sound in the jazz trio ensemble is blended within a complexity of the frequencies and dynamics of the double bass, and drum kit. The accentuated low frequencies of the double bass, the percussive attack and wash of the cymbals, and the explosive drum accents produce a complex and constantly changing spectra of ensemble sound which sets a challenging sonic environment for piano sound to interact with. The most obvious consideration is volume, particularly when the music is played at tempos upwards from M.M=120. At the moderate to bright tempos, the cymbals are struck by the tip of wooden drum sticks producing an immediate ‘bright’ attack and frequency that can’t be matched by piano sound. The walking notes of the bass at these tempos produce a constant deep and percussive harmonic spectra, with a powerful forward motion and density that also cannot be produced by piano sound. Both of these sounds are integral to the jazz ensemble sound. When the bass is ‘walking’ and the cymbals are ‘swinging’ the sound is unmistakably a jazz sound. With its continuous dense, wash of sound, and its relatively constant dynamic range, the rhythm section sound is a stylistic component of the repetitive nature of jazz, a music genre with dance origins. When the genre of jazz was spawning a myriad of styles, between the 1920s-80s, jazz pianists, many of them leaders of their ensembles, developed individual textural pianistic sounds to project their particular style and sound with the
rhythm section\textsuperscript{354}. These pianistic sounds are still clearly identifiable as particular jazz piano styles and are blended into contemporary jazz piano styles in the 21\textsuperscript{st} century. Some examples of these sound/styles are, i) the tremolos of Earl ‘Fatha’ Hines ii) the combined accentuated-tenuto ‘off’ beats of Thelonious Monk’s right hand single notes; iii) the block chords of George Shearing; iv) the staccato Mj6th chords in the high register of Count Basie, v) the accented simultaneous use of both extremities of the piano compass by Duke Ellington; vi) the metric double handed chordal polyrhythms of Erroll Garner and Dave Brubeck; vii) the simultaneous contrast of cantabile melodic tones in the right hand with rhythmic left hand accents by Bill Evans; viii) accented double octave unison phrases of Phineas Newborn Junior and Oscar Peterson; ix) the combined use of the sustain pedal and modal chords of parallel 4ths and 5ths at fortissimo by McCoy Tyner. Throughout this stylistic development, there seems to be no evidence of which piano make was preferred by each of the jazz pianists for their particular styles. As with classical performers, there were many sponsorships of brands, but these business arrangements didn’t necessarily indicate a preference of instrument tone for particular styles of music.

The audience surveys do not set out to claim whether the Stuart piano or the Steinway piano is ‘better’ for jazz style, or as it has just been stated, better for \textit{a specific} jazz style. Rather the exercise is simply to listen to both instruments in the jazz context, and observe how their tonal dimensions differ and how audiences evaluate the differences.

Concert-survey No 2, presented specific questions about how each piano sound interacted within the jazz ensemble sound.

Qu.9. Which piano sound produces the better ensemble sound?
Response: 64\% Stuart piano

Qu.10. Which piano sound produces a clearer tone with the bass & drums?
Response: 77\% Stuart piano sound.

Qu.11 Which piano sound is better at projecting its sound over the bass& drums?
Response: 83\% Stuart piano sound.

\textsuperscript{354} This information is general, and can be accessed in many literary and audio collections of jazz piano history. Such as: Gunther Schuller, \textit{The Swing Era} (Oxford University Press 1989); Frank Tirro, \textit{Jazz A History}, (Yale University, 1993); Len Lyons, \textit{The Great Jazz Pianists} (Da Capo, 1989).
Perceptions of the Stuart & Sons Piano – Kevin Hunt

Overall, at concert No 2, in response to Qu.9-11, 75% of participants preferred the sound of the Stuart piano in the jazz trio ensemble sound. Written comments of participants at concerts 4 & 5 described the Stuart piano’s ‘clarity’ ‘projection’ and ‘resonance’ within the ensemble sound. 57% of participants responded that the Stuart was more resonant, and distinct within the trio sound.

… the cymbal swing feel matches the gritty edginess of the Stuart sound.

The evaluation of a clearer definition of piano tone within the jazz ensemble sound must be associated with how the onset or the beginning of the sound is perceived. Tests in the identification of piano tone have shown that without hearing the very beginning of the sound, it is impossible to identify piano tone. In the jazz ensemble sound, the onset attack sound of the cymbal directs the rhythmic pulse of the ensemble performance, and the attack sound of the piano indicates the rhythmic intention of the piano phrase, as does the attack sound of each of the bass notes of the ‘walking’ lines. So in this regard, the attack sound of the piano is an important element of clarity in the overall ensemble sound.

The overall audience perceptions of 69% and 57% that the Stuart sound is more ‘clearly defined’ in the sound of the jazz ensemble concurs with the findings of chapter four, which have shown that the Stuart sound is louder and has a wider harmonic spectrum than the Steinway sound, at the onset of the sound.

Audio examples below present the sounds evaluated by the audience of the Stuart and Steinway pianos in the jazz trio setting at concert No 5. Both pianos were played in the one trio performance of ‘No Moon At All’. In contrast to the above mentioned perceptions, at this concert, 59% of participants responded to qu. 6&7, saying that the Steinway sound was ‘clearer, more defined’ than the Stuart sound, and 62% responded to qu. 9&10 that the Steinway sound was more ‘distinct and resonant’.

Audio examples below present the sounds evaluated by the audience of the Stuart and Steinway pianos in the jazz trio setting at concert No 5. Both pianos were played in the one trio performance of ‘No Moon At All’. In contrast to the above mentioned perceptions, at this concert, 59% of participants responded to qu. 6&7, saying that the Steinway sound was ‘clearer, more defined’ than the Stuart sound, and 62% responded to qu. 9&10 that the Steinway sound was more ‘distinct and resonant’.

Tri - concert No 5.

| No Moon At All prt1, improvised trio chorus |
| USB Audio 5: trk 38, Steinway Prt 1 No Moon At All.wav |
| USB Audio 5: trk 39, Stuart Prt1 No Moon At All trio.wav |

Sound table 5.17

In the ‘No Moon At All’ audio extract, the ‘brighter’ Steinway tone previously heard in the solo extracts in the audio extracts is not identifiable in the trio setting. The Steinway has a ‘rounder’ tone.

At times the pianist sounds to be playing the Stuart with more fortissimo than the Steinway, which may account for some of the extra brightness. Either the harmonic spectra of the Stuart sounds are not as affected by the sounds of the accompanying instruments, or the harmonic spectra of the Steinway sound is affecting a rounder sound on the overall ensemble sound.

355 Written comment- Concert No 4 Qu.16
When the short chords are played in part 2 of ‘No Moon At All’ the Stuart chords sound clearer more consistently at each dynamic. The Steinway sound is less defined at the softer playing of the chords.

The jazz ballad ‘My One and Only Love’ was played on both pianos in the ‘behind the screens’ test at concert 5. The pianos were positioned out of the sight of the audience, behind screens. The audience evaluations of the piano sounds did not produce an overall perception, with percentage differences tallied at 50%. The sound of the trio behind the screens is captured in the audio extracts below.

**My One & Only Love**

The melodies 1st section of this extract are played in both the low and high registers. The extreme high register of the Stuart is obviously brighter, though the Steinway is played more with exuberance, achieving generally a brighter mood and tone. The Stuart is played more reflectively. The overall tone of the Stuart sound could be described as being not as ‘bright’ as the Steinway.

In part 2, the melodies are played in the same registers though the Steinway is played with more energy, generating a larger ensemble sound. The Stuart is being played lightly in a generally a quieter ensemble sound. The sound of the Steinway could be described as being ‘clearer’, and ‘brighter’ than Stuart in this extract.

**Qu. No 14 & 15 : ‘colourful’**.

Survey question No 14 & 15 asked the audience which piano sound was best described as being ‘colourful’. The overall audience perception across the 6 concerts was that 61% of participants said the Stuart piano sound was more ‘colourful’. At concert No 4, in the larger venue, a significant 82% of participants described the Stuart sound as being more ‘colourful’ than Steinway.

**Chordal Resonance**

Possibly an influence on this perception was the performance of an improvised introduction to the jazz standard ‘On A Clear Day’ which experimented with the Stuart piano’s chordal sonorities. The sostenuto pedal which implements a selective sustain, standard in all modern pianos, was used in part 1.
of the improvisation, lifting the dampers of the low C octave, below the range of the Steinway. This musical endeavour was not repeated on the Steinway, so a direct comparison was not made of this particular sound.

The key of the piece was F, and the lifted dampers of the low Cs and Fs, opened up a myriad of harmonic spectra and sympathetic vibrations throughout the whole range of the strings and soundboard, as each of the chords relating to the key of F were struck. Even though the recording quality is not of a high standard, the chordal qualities of the Stuart are clearly audible.

<table>
<thead>
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Playing in this manner, engaged the pianist to listen closely to the resonances of each chord and how the new chordal resonance can sound over the previous chordal resonance, without closing off the dampers, keeping the whole piano resonance open.357

In prt 2, the high registers are resonated before the dampers are closed, followed by a chordal melodic passage, and finally florid arpeggios.

<table>
<thead>
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<th>On A Clear Day – improvised introduction Stuart Piano prt. 2</th>
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<td>Sound table: 5.22</td>
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</table>

The melody of ‘On A Clear Day’ is played in a florid rubato style displaying the wide spectra of colourful tonal qualities of the Stuart piano, across its expanded frequency compass.

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<tr>
<th>On A Clear Day – improvised introduction Stuart Piano prt. 3</th>
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357 Sydney pianist Bill Risby pioneered the sostenuto pedal explorations of the Stuart piano tonal spectrum in recording sessions at the Stuart & Sons ‘White Room’ studio, in Newcastle in 2011.
In conclusion, Design or Pianist?

In the discussion of section 1 of the Gershwin video extract above, the attribute ‘bright’ was used to describe the sounds of the treble register of the Stuart sound and the bass register of the Steinway sound. It is well known that the register or frequency of pitch is a factor in influencing the character of timbre, and in this example we hear the effects of each piano makers’ manipulations of the tonal characteristics of each register as well as their individual design implementations of the string-bridge coupling, string length, string width, string material, sound board mass and thickness.

The audio extracts revealed also that the volume, or weight applied by each pianist in the playing of a phrase, was indicative of the type of tonal colour each instrument projected to the audience. The pianistic interpretations of the music, and their relative pianistic styles therefore influenced the tonal quality of each instrument.

Earlier in this chapter we saw how the varied pianistic styles of both pianists playing in concerts No 1, 3, & 6, has influenced the perceptions of the audience regarding the associations of piano sound with genres of music and pianistic style. The Stuart piano sound was perceived by a majority of participants to suit the playing of Kevin Hunt and to suit Jazz music more than the Steinway. And the Steinway was perceived to suit both Classical music and Simon Tedeschi’s pianism, more so than Stuart. (See section 5.2). The difference in the qualities of timbre of each piano sound played by pianists of contrasting stylistic backgrounds and techniques illustrated in the audio-visual Gershwin excerpts, warrants the question, does the pianist or the piano have a greater influence on the tonal colour of the instrument?

The evaluations made of the sounds of the Stuart and Steinway at performances, at the hands of the pianists, brings into question how much the pianist is affecting the tone colour. So the audience perception is not only about the instrumental sounds, but how the pianists play the instruments.

The extent to which the pianist is able to influence the tonal colour of piano sound by particular touch has long been a point of conjecture between pianists and physicists. The argument is based on whether it is types of touch, or only the speed of key contact, velocity, which influences piano tone quality. Pianists naturally believe that the timbre of piano sound is affected by many types of contact the fingers have with the keys, and the physicists say because there is no connection with the pianist’s key-touch whilst the hammer is in flight, the only measure of influence of the pianist is velocity, or the speed of the hammer flight. We know that as the velocity of the hammer contact with the string is increased, not only the loudness increases, but the ‘brightness’ of tone increases, because the contact time of the hammer on the string is reduced by a compression of the hammer felt density on contact, which in turn excites more high partials in the string to oscillate, a process Roederer describes as loudness-timbre coupling. Roederer lists other ways the pianist can affect tone psychoacoustically:

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358 Meyer, 30.
360 Roederer, 124.
Perceptions of the Stuart & Sons Piano – Kevin Hunt

Subtle tone duration control; small variations of loudness from tone to tone; lifting the melody above the accompaniment; loudness and timing differences of the notes of a chord; the percussive component given by the ‘thump’ sound of the keys as they hit the stop rail.361

Supporting the pianists’ argument, A. Askenfelt’s tests have found a connection between types of pianistic touch and hammer movement362 and A. Galembo’s studies have found that pianists more accurately identify a make of piano kinesthetically, through the touch and the tactile senses of pianos’ key and action mechanism, than by listening to the sound of the piano out of sight, in a performance space, from the audience area.363

Affirmative responses to the survey questions No 9 & 10, which asked about the individual pianists’ ‘sound’, may suggest that the audiences perceived that each pianist sounded as themselves, regardless of which piano they were playing!

Q 9.3 Do you think Simon Tedeschi produces his own similar sound on both instruments?
Q 10. Do you think Kevin Hunt produces his own similar sound on both instruments?

At concerts 1, 3 and 6, 88%, 78% & 63% of participants, respectively, responded that Simon Tedeschi produced his ‘sound’ on both instruments, and 90%, 70% & 70% participants respectively, responded that Kevin Hunt produced his ‘sound’ on both pianos.

The same pianist played the same pieces of music on both the Stuart and Steinway pianos in concerts No 3, 5 & 6. This process was initially presented to aid the audiences’ assessments of the instrumental sounds by narrowing the variables, listening to the same musical subject, and the same pianist, on each piano. Though this process also revealed how the pianists reacted or manipulated particular characteristics of each piano sound, for instance the ‘fullness’ of the Steinway sound, and the onset ‘brightness’ of the Stuart.

362 20 Roederer, 124.
363 4 Galembo.