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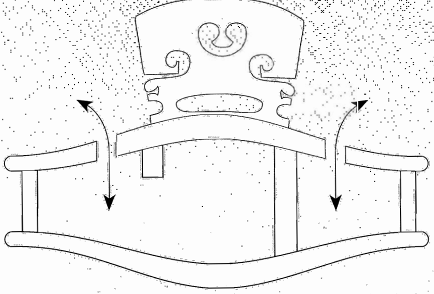

SPECIAL INTERNATIONAL ISSUE

- ***Atmospheric Ultrasound***
- ***Wind Instrument Performance***
- ***Science and the Stradivarius***

Australian Acoustical Society **Vol. 28 No. 2 August 2000**

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CONSULTING NOTE

COVER ILLUSTRATION: *Schematic cross-section of a violin. See article by Gough.*

From the President

In my last column on the need for 'good acoustics' I referred to the distress being experienced by purchase of apartments with poor sound isolation. My practice receives a call almost daily from someone who is experiencing this difficulty as I suspect are being received by acoustic consultancies throughout Australia.

One of the main contributing factors in regard to recently built apartments, town-houses and the like I consider, has been the minimum degree of sound isolation being aimed for. The Building Code of Australia (BCA) sets a minimum design level of Sound Transmission Class STC-45 for inter-tenancy walls with no requirement for impact sound isolation.

As Victoria Division was about to embark on the task of doing something about this issue from initially a parochial stand-point, I was delighted and encouraged to discover that the issue has been one of considerable concern to the Australian Association of Acoustical Consultants (AAAC). This association is a Sustaining Member of AAS with many members who are luminaries within the AAS.

By way of interest to our wider membership, the AAAC has prepared a submission which highlights the short-comings of the present building code system and makes recommendations for appropriate changes. It appears that this submission is generating pressure on the Australian Building Code Board (ABCB) who administers the Building Code, to raise the minimum level and maybe introduce an impact sound isolation rating as well.

Publications such as the Building Australia Magazine are now aware of the work being undertaken by the members of AAAC and are assisting in highlighting the issue to those who face the direct angst of the new apartment owners. These are the builders who build what is designed (hopefully), as well as architects and designers who carry out the design incorporating the requirements of the relevant Building Code as an absolute minimum (again hopefully) and not simply use it as a target.

So our members are lobbying Authorities for change, other members are serving of Standards committees, serving of State committees or Federal Council or organising national and international conferences and preparation of Acoustics Australia. The positions are unpaid and voluntary; members giving of their private and precious time as well as paid employment to enhance this acoustic field of endeavor. The result... bringing about meaningful changes to the acoustic environment and lifting the community out of an apathy as gradually they hear their living conditions deteriorate.

There is indeed much that needs to be done in this regard. For those of us who are yet to become involved at this level, there is a challenge for you. Inter-tenancy noise is only one issue in a plethora of noise annoyances. AAAC has focussed on a very important issue and the AAS takes this opportunity to acknowledge the work of our members and others in preparation of the AAAC submission.

Geoff Barnes

Editorial

THE FUTURE OF PUBLISHING

Readers will notice two things about the present issue of Acoustics Australia: that it is a little thinner than usual, and that we are reprinting three papers from other publications. We are fortunate in being able to reprint a most interesting paper on atmospheric infrasonics from *Physics Today*, a field of research that does not appear to be represented in Australia, and also a delightful paper on the acoustics of violins from *Physics World*. We have also reprinted a note on physiological acoustics (translated from English to French and then back again to English!) from *Médecine des Arts*. We are most grateful to the Editors of these publications for their generous republication permission. The absence of original papers from Australia (we usually have four or five per issue) is, we hope, merely a statistical glitch - we have two "special topic" issues in hand for December and April respectively - but we do urge you all to think about Acoustics Australia when you have something interesting to tell us. As noted in our instructions to contributors, we do not aim to be a primary research journal, but we do maintain high standards through peer reviewing, our papers are listed in key abstracting journals, and we count as a "refereed journal" in the University statistics collected by DETYA.

This circumstance, however, leads me to write a little about the future of publication, and of print publication in particular. How good is the current availability of print materials, what is happening with electronic publication, and what is the scene likely to be in ten years time? The Australian National Library has a Task Force looking into this subject, on which I represent the Academy of Science, and it is perhaps interesting to provide a progress report on what is being done.

As you know, print materials are conveniently classified into monographs (which are mostly books) and serials (which are mostly journals). In the Humanities and Social Sciences, there is nothing really equivalent to the international scientific societies. Of course there are scholarly societies, but understandably they tend to be national because of interests that are defined by language, history, or social culture. Research and scholarly publication is therefore primarily through books. The first part of the work of the Task Force examined the availability of books for research and scholarship in the humanities and social sciences, taking English and Psychology as test cases. Among other things, surveys showed that most of the references cited in a sample of PhD theses were in fact available through Australian libraries, but this might be regarded as an inevitable conclusion, since students tend to make do with what is readily available. At the same time, there is growing concern at the rising cost of books and the decreasing ability of Australian university libraries to purchase new books as they are published.

Of course, it cannot be expected that Australian libraries will have resources to meet all needs of a widely diverse academic community. Why should we have a research collection in 17th-century Croatian poetry or in the political history of Texas? If that is your interest, you should be prepared to travel!

In Science and Engineering the situation is different. Books are not the primary medium of research publication; rather they represent knowledge that has been crystallised in such a form that it is readily available for reference and instruction. The primary medium of research publication is the journal, and these can be divided into two classes: those published by scientific societies, and those produced by commercial publishers. In the fields that I know best, the split between these two sources is about 50:50, with the American Institute of Physics, for example, producing some 25% of the total physics research literature. There are significant cost differences, with a single page (normalised for word-count) being 5 to 10 times more costly from commercial than from society publishers. (Interestingly, the cost per page of journals in the humanities and social sciences is very similar to that in the sciences.)

The Task Force is currently carrying out a further survey of the availability of scientific research journals in Australian libraries, using Physics and Biochemistry as sample disciplines. The survey of physics resources is nearing completion, and indicates that there are still research-level collections of journal resources in most areas in five or more Australian university libraries. Of course, none of these collections includes all journals, and for some significant journals there are fewer than three subscriptions, Australia-wide. We will, perhaps, compile a Register of Endangered Journals in an endeavour to preserve these species. Equally worrying is the rate at which reduced library budgets, rising journal subscription costs, and an impoverished Australian dollar are leading to continuing cancellation of subscriptions. It is to be hoped that coordination of collection resources and improved inter-library loan arrangements will go some way to maintaining a comprehensive National Collection to which all can have access. Unfortunately, Government policies that dictate that universities should be competitive rather than collaborative act directly against this objective.

This brings me to electronic access, for is not the WorldWideWeb going to solve all our problems, with E-journals replacing print versions? Certainly the move to electronic access is gaining pace, and many journals now offer electronic versions which have advantages of rapid delivery, quick access, and easy storage. What many people do not realise is that publishers must meet major editorial and production costs, whatever the final format of the journal. Certainly there is a saving in printing and postage costs, but these are marginal savings if a print version must be produced for those subscribers who wish to maintain a hard copy of the publication for archival purposes. For most journals at present, the electronic version is little cheaper than the print version, though some publishers are currently offering access to electronic versions of a large range of their journals, provided the subscribing library agrees to maintain its present level of subscription payment. Consortium arrangements between groups of libraries might enhance such deals, though the publisher needs to maintain its total revenue base.

While flexibility of access is certainly to be welcomed, any transition to exclusively electronic access is fraught with problems. Will the publisher up-date archival materials to keep pace with changing technology? What about access to back issues if a subscription is cancelled? What is the situation with outside access and inter-library loans? These problems are certainly being examined, but there are as yet no general solutions.

Another possibility is the development of quite new arrangements for journal publishing. An example is the New Journal of Physics published jointly by the British Institute of Physics and the German Physical Society, which has only an electronic version and no printed counterpart. This journal has high editorial and production standards but completely free electronic access, all the costs being met by the equivalent of a "page charge" levied upon papers published in the journal. There are also, even now, preprint archives and other resources to which access is essentially free and that have established quality status. The problem is one of editorial quality control, and here one can, for the present, rely only upon the reputation of the publisher, society, or informal group publicising the material.

Does Acoustics Australia have any plans to "go electronic"? The answer at present is "No", and for good reasons. The objective of our existence is to provide informative and interesting information about acoustics to our readers, most of whom are members of the Australian Acoustical Society. This information comes in several forms—authoritative articles on various acoustic subjects by researchers in those areas, descriptive notes by acoustic consultants on projects of interest, book reviews, news on Society activities and on community developments of concern to our membership, and advertising information to keep readers informed on available products and services. Certainly all of this could be digitised and placed on a web-site—the Society already has its own site—but that is not convenient. We see this journal as being read on the train going home, or after dinner in an easy chair, rather than in front of a computer in the hustle of a busy day, and we design each issue with that in mind. Perhaps, when a light-weight, page-sized, high-resolution, autonomous book-reader is available at small cost, an electronic format will be a better alternative, but that is not yet.

Neville Fletcher

ATMOSPHERIC INFRASOUND*

Alfred J. Bedard Jr[1] and Thomas M. Georges[2]

[1] **National Oceanic and Atmospheric Administration's Environmental Technology Laboratory, in Boulder, Colorado.**

[2] **NOAA/Colorado State University Cooperative Institute for Research in the Atmosphere, also in Boulder.**

The search for ways to monitor compliance with the Comprehensive Test Ban Treaty has sparked renewed interest in sounds with frequencies too low for humans to hear.

Imagine a world in which you could hear not just nearby conversations and the noise of traffic a few blocks away, but also the sound of blasting in a quarry in the next state, the rumblings of an avalanche or volcano a thousand miles away, and the roar of a typhoon halfway around the world. Fortunately, nature has spared our senses from direct exposure to this incessant din. But our relentless quest to extend our senses has yielded instruments that can do just that—and more. Waves of infrasound, sounds at frequencies too low for us to hear, permeate the atmosphere and offer us insights into natural and human-made events on a global scale.

The term infrasound was coined by following the convention adopted nearly two centuries ago for light waves. The invisible, longer waves below the red end of the visible spectrum were called infrared, and shorter waves beyond the violet end were called ultraviolet. ("Infra" and "ultra" are from the Latin, meaning "below" and "beyond," respectively.) The nominal range of human hearing extends from about 20 Hz to 20 000 Hz, so the inaudible sound waves with frequencies below 20 Hz were dubbed infrasound, while those above the upper limit of 20 000 Hz were named ultrasound. (Many animals can hear beyond the human limits, as described in the box on page 50.) Following the optical convention even further, frequencies just below 20 Hz are known as near-infrasound, and frequencies below about 1 Hz are often called far-infrasound. Near-infrasound, if sufficiently intense, is often felt rather than heard—as you might have experienced when you pass cars equipped with "mega-bass" audio systems. (See figure 1 for two examples of low-frequency sound sources.)

Interest in atmospheric infrasound peaked during the Cold War as one of several ways to detect, locate, and classify nuclear explosions at global distances. Now, the Comprehensive Test Ban Treaty calls for a more sophisticated global sensor network to monitor compliance.[1] There is a need to ensure that tests of clandestine, low-yield nuclear devices can be detected under conditions of noise, cloud cover, or other masking situations underground, underwater, or in the atmosphere. An integrated global sensor array now being deployed would address this problem by coordinating observations from multiple ground-based sensor types, including seismic, hydroacoustic, and infrasonic arrays, working in concert. (See Jeremiah Sullivan's article on the Comprehensive Test Ban Treaty, *Physics Today*, March 1998, page 24.)

In anticipation of a CTBT monitoring system, infrasound research has returned full circle to its origins. In this article, we review the science and technology of atmospheric infrasound, beginning with a brief history of its Cold War origins. Our focus, however, is on the richness of Earth's infrasonic environment, unheard and unknown until instruments were built to detect and record it. Practical applications of this new science are just now being contemplated.

A LITTLE HISTORY

Pressure waves from very powerful explosions may be detected after traveling several times around the Earth. Two famous pre-nuclear instances were the explosion of the Krakatoa volcano in 1883 and the Great Siberian Meteorite of 1909. Following each of these events, sensitive barometers around the world recorded impulsive pressure fluctuations as traces on paper charts. Later, meteorologists collected these charts from stations around the world and, by comparing arrival times, were able to reconstruct the progress of pressure waves radiating outward from the source at the speed of sound, sometimes passing an observing station two or three times.

But these disturbances pale when compared with the political shock waves from the explosion of the first Soviet atomic bomb in 1949. Cold War fears stimulated a flurry of "remote-sensing" research—much of it classified—to detect and locate nuclear explosions halfway around the world. Among the technologies explored during those early years of the Cold War were seismic arrays, electromagnetic (radio to gamma-ray) sensors, and arrays of microphones to listen to very-low-frequency sound waves in the atmosphere.

In the early 1950s, a number of institutions contributed to the successful deployment of a global infrasonic monitoring network. Lewis Strauss, in his book, Men and Decisions, describes recording low-frequency air waves at the National Bureau of Standards in Washington, DC, following a 1954 nuclear test in the Pacific. He took the recording to President Eisenhower and played a sped-up version that made the recording audible. Strauss emphasizes the strategic importance, during those early Cold War years, of nuclear intelligence provided by a worldwide monitoring system that included both remote sensing and a radionuclide sampling program.[2]

Early defense-driven infrasound research had multiple foci,[3] including mathematical models for the intensity and spectrum of sound waves generated by various kinds of explosions, how

* Reprinted, with permission, from *Physics Today* **53**, 32-37(2000).

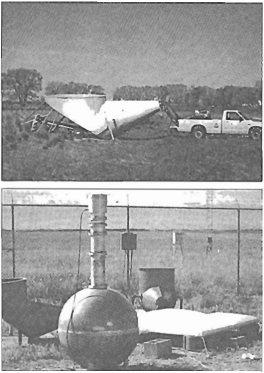

Figure 1. Experimental low-frequency sound generators are used for remote probing and propagation studies. The 10-foot-diameter horn (above) produced audible sound at 100 Hz, which was tracked with a Doppler radar to altitudes of 20 kilometers to obtain temperature profiles of the atmosphere. The 100-gallon sphere with a 1 m neck (below) is a Helmholtz resonator tunable from 10 to 50 Hz. Compressed air is released by rupturing a diaphragm, producing sound waves used for calibrating and testing infrasonic arrays.

these waves propagate long distances through the atmosphere, what kinds of sensors would be best suited for detecting their signatures, and how those signatures could be extracted from a bewildering variety of natural and human-made infrasonic noise. The Limited Test Ban Treaty of 1963, which prohibits testing of nuclear weapons in the atmosphere, oceans, and space, resulted in greater emphasis on seismic methods and less on atmospheric acoustic methods. An advanced infrasonic monitoring network was designed but never deployed. With the evolution of a sophisticated satellite-based nuclear detection system, defense funding for "geoacoustics," as it was then called, all but dried up. The end of that era was marked by a 1967 review with the bizarre title, "Exploring the atmosphere with nuclear explosions."[4] By that time, however, the study of Earth's infrasonic environment had expanded beyond its defense boundaries and had grown into a science in its own right.[5]

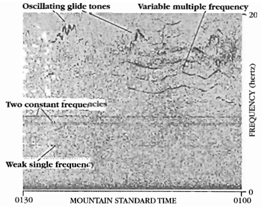

Figure 2. Sonogram of atmospheric infrasound between 1 and 20 Hz, recorded over a 30 minute interval at Boulder, Colorado. A six-month survey revealed more infrasonic activity and a greater variety of signal types above 10 Hz than below. Although the sources of these signals are unknown, the constant spectral lines probably have artificial origins.

NOISE BECOMES SIGNAL

Uncovering the mysteries of natural phenomena that were formerly someone else's "noise" is a recurring theme in science. Since the 1970s, the science of atmospheric infrasonics has focused on understanding the structure of natural infrasound, where it comes from, and how it travels through the atmosphere. If we listen to these ultra-low frequencies with suitable instruments, we find a virtual symphony of natural and human-made sounds whose intensities are comparable with those of audible sounds and whose signatures often reveal distant geophysical events. What we have learned about this "geophysical noise" may now become an important part of the strategy behind the CTBT monitoring network.

As an example of the richness of the near-infrasound environment, figure 2 is a half-hour spectrogram, or "voice-print" of infrasonic signals between 1 and 20 Hz, recorded during midday near Boulder, Colorado. It shows a variety of inaudible signatures, some with complex frequency variations over time, others with unchanging frequency. This picture is but a small sample of a wealth of infrasonic signals of unknown origin. At other times, signals begin and end abruptly, or recur at certain times of day, suggesting sources in civilization.6 Even using direction-finding microphones, the sources have proven more difficult to locate than one would expect. Other more complex signatures may have natural origins.

Figure 3 shows the frequency and amplitude ranges of sounds familiar to us. Below the (frequency-dependent) threshold of human hearing lies infrasound. The pressure fluctuations on our eardrums exerted by ordinary conversation are less than one-millionth of normal atmospheric pressure. Roughly the same range of pressure levels characterize natural and artificial infrasound.

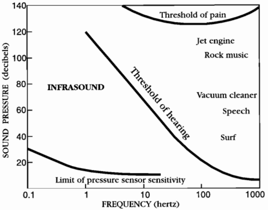

Figure 3. Threshold of human hearing at low frequencies. The low-frequency domain of infrasound lies to the left of the nominal threshold of human hearing and feeling on this pressure-versus-frequency diagram. The regions occupied by familiar sounds are at the right. Frequencies below about 1 Hz can travel relatively undiminished for hundreds or thousands of kilometers through the atmosphere. The curve at the lower left roughly indicates the present limit of detectability imposed by atmospheric winds and turbulence.

One of the most interesting and useful properties of infrasound is that it travels with relatively undiminished strength over global distances. Even our senses tell us that low frequencies can be heard farther away than high frequencies. When you hear thunder from a nearby storm, its sharp crack is full of high-frequency components. But thunder from distant storms is always characterized as a "deep rumble," devoid of high-frequency components.

So audible sound is rarely heard more than a few tens of kilometers from its source. This is because higher frequencies are more strongly absorbed by atmospheric viscosity and thermal conduction. The air may not seem very viscous, but to an air parcel trying to move back and forth at audible frequencies, it is as sluggish as molasses. Absorption increases as the square of the frequency. Ninety-percent of the energy of a 1000 Hz tone is absorbed (in addition to losses due to spreading) after traveling 7 km at sea level. At 1 Hz, that distance is 3000 km, and at 0.01 Hz, it exceeds the Earth's circumference.

The temperature and wind structure of the atmosphere bends infrasonic waves in the same way that lenses refract light waves. The temperature of the atmosphere decreases and increases with altitude in a complicated way, causing reflection and channeling of infrasound waves over great distances (see figure 4). Waves from an explosion, for example, can arrive at a sensor by way of many different paths that bounce between atmospheric layers and the ground.

Seasonal and geographic variations in global winds and temperatures further complicate the interpretation of infrasound from distant events. The direction of middle atmospheric winds strongly affects the observability of infrasound at ground level, as well as one's ability to locate the source. Waves that propagate "downstream" are more readily detected because they are strongly focused at ground level. Understanding upper-atmosphere climatology and its effects on infrasound propagation would thus be a critical requirement in the design of an infrasonic CTBT monitoring network.

UNHEARD SYMPHONY

Just as we recognize the special qualities of each instrument in an orchestra, we tell one infrasound source from another by the frequency-versus-time signature of the sound, the direction it comes from, and how long it lasts. One difference, however, is that the orchestra we are listening to here contains some unknown instruments. The table below lists some of the geophysical infrasound sources that have been identified, along with potential uses that have been contemplated and areas for further research.

One example is the infrasound from an avalanche, which is identified by its distinct train of nearly monochromatic waves. Experiments have shown that deeper, faster-moving avalanches radiate lower frequencies that can be detected hundreds of miles away. Their frequency content is predicted by a model of roll-wave instabilities that modulate changes of state between ice and liquid. This work has resulted in efforts to create

Natural Infrasound—Potential Applications and Future Research

Sources	Applications	Areas for research
Avalanches	Determine location, depth, duration, occurrence statistics	Relate signature to avalanche size and type
Meteors	Determine altitude, direction, type of entry (explosive or bow shock); determine size and impact location	Estimate size and type distribution; determine ablation rates, volumetric meteor survey limits
Oceanwaves	Locate wave interaction areas; determine wave magnitudes and spectra	Monitor evolution of storms at sea; study wave-wave interactions
Severe-weather systems	Estimate storm location and energy	Study storm microphysical processes; model acoustic radiation
Tornadoes	Detection, location, and warning; estimate core radius; image funnel shape at short ranges	Study tornado formation processes; look for infrasonic precursors
Turbulence	Aircraft avoidance; estimate altitude, strength, and spatial extent	Distinguish among several generative processes; develop practical detection systems
Earthquakes	Measure Rayleigh waves; measure sound from intermediate radiation points; measure sound from the epicenter	Look for infrasonic precursors; understand seismic-acoustic coupling
Volcanoes	Estimate location and energy released	Determine relationships between infrasonic and seismic disturbances

infrasonic monitoring networks for short-term warning, as well as for collecting regional avalanche statistics.

An almost continuous but relatively weak background of atmospheric infrasound lies in the 5-to-7-second range of wave periods. These waves, called "microbaroms" are believed to be generated by nonlinear ocean–wave interactions in ocean storms around the world. While nearly monochromatic in frequency, these infrasonic waves, which have been called "the voice of the sea," are relatively incoherent in space, suggesting a spatially extended source. One model for the sound generation process involves trains of interfering ocean waves producing local regions of vertical motion.

Some infrasounds that last for as long as several days have been triangulated to distant mountain ranges and tend to occur when the winds blowing over them exceed a certain speed. This effect may be the low-frequency version of the aeolian tones produced by the cyclic eddy shedding that occurs when wind flows around obstacles. The reported increase in the incidence of suicides during episodes of warm downslope mountain winds (called Chinooks in the western US and the Föhn in the Alps) may be due to some as yet unknown biological response to these ultra-low-frequency pressure fluctuations with 20-to-70-second periods.

Meteors produce infrasound in the form of impulsive pressure waves resembling sonic booms, as well as continuous, isotropic radiation of unknown origin from the length of the path. Sometimes infrasound records can help locate meteorites.

Auroral activity and magnetic disturbances in the polar upper atmosphere also generate infrasound detected on the ground. Robert Service showed a poet's sensitivity to the natural world in his Ballad of the Northern Lights:[7]

They rolled around with a soundless sound
like softly bruised silk;
They poured into the bowl of the sky
with the gentle flow of milk.

Service penned these words more than 50 years before sensitive instruments were developed to record auroral infrasonic waves[8] and the traveling pressure fluctuations associated with geomagnetic activity.[9]

SEVERE-STORM INFRASOUND

In the 1970s, the National Oceanic and Atmospheric Administration began a study of atmospheric infrasound to find out whether it could be used to improve warnings of severe weather events, such as tornadoes.[10] We found that many of the strongest thunderstorms, particularly those powerful enough to reach 15 km altitudes, radiated infrasound with wave periods in the tens of seconds, which could be detected by multiple observatories more than a thousand kilometers away. We found that severe-storm infrasound was not simply a low-frequency kind of thunder. Triangulation shows that it exhibits different spatial and temporal statistics than lightning, and tends to come mainly from the subset of storms that spawn tornadoes. By one estimate, the infrasonic power radiated by the strongest storms is equivalent to the electric power consumed by a city of 100 000.

ANIMAL INFRASOUND

It is well known that bats use ultrasound for echolocation and that dogs and cats hear sounds pitched much too high for humans to hear. But do any animals use infrasound?

The songs of some whales extend into the infrasonic range, apparently for long-distance communication, raising concerns about interference from human activities that have increased the level of background noise in the sea. Human activities have certainly made such communication more difficult. Katy Payne, in her book Silent Thunder, describes the discovery that elephants use infrasound to communicate over long distances.[16] Mel Kreithen and others at Cornell University have found that the hearing range of pigeons extends into the infrasonic range. He speculates that this capability might be part of their navigation "tool box" and that perhaps natural sources of infrasound serve as reference beacons. Recent studies of some dinosaur skulls reveal huge nasal cavities whose sole function appears to be to generate and amplify low-frequency sound.

For what purpose? Generally, animals create and detect sounds for mating, locating prey, navigating, keeping track of their young, or warning others of danger. By generating infrasound, large animals would greatly extend the range of these signals. Some predators may even have evolved infrasound-sensing systems to detect the breathing or heartbeats of prey, but more research is needed to find out whether this is possible against the background of natural infrasonic noise.

In addition, there are many anecdotal reports of unusual animal responses preceding earthquakes. The warning potential of these responses has been the subject of intense research in China. Infrasound is one of many candidate mechanisms, all of which require more rigorous study.[17]

Further work at NOAA in the 1980s and 1990s monitored severe storms at near-infrasonic frequencies around 1 Hz and found a stronger connection with tornadoes themselves. Coincident Doppler radar measurements of tornadoes have revealed a relationship between funnel diameter and infrasound frequency that suggested an infrasound generation model. Radial modes of vibration in vortices can radiate sound waves whose frequency is inversely proportional to the diameter of the vortex core. For example, radial vibrations of a 400 m diameter core would theoretically radiate at about 1 Hz. Measurements of the sound generated by laboratory vortices and aircraft-wake vortices are consistent with this model. One tornado that passed within 3 km of our Boulder, Colorado, observatory left a signature that permitted us to use this model to "image" the increase in the tornado's diameter with altitude, using the observed decrease in the dominant infrasound frequency at higher elevation angles of arrival. This work shows promise for infrasonic tornado detection systems that could complement the existing Doppler radar network.[11]

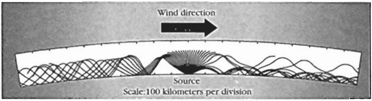

Figure 4. Computer ray trace models how infrasound at a frequency of 1 Hz is refracted and channeled over long distances by the temperature and wind structure of the atmosphere. A 60 m/s jet of wind blowing to the right at 60 km altitude is simulated to show the difference between upstream and downstream propagation. Rays that end abruptly are absorbed by atmospheric viscosity and thermal conduction.

MEASURING INFRASOUND

Sound (and infrasound) waves are longitudinal air waves of compression and expansion. Modern low-frequency pressure sensors, called microbarographs or low-frequency microphones, can record pressure changes of less than 10^{-3} pascals, or 10^{-8} atmospheres. This is still 45 times less sensitive than the human ear is at audio frequencies! (The SI unit of pressure is the newton per square meter, or pascal. One standard atmosphere is about 100 000 Pa. The threshold of human hearing, which acousticians call 0 decibels, is about 20 micropascals.) One type of far-infrasound sensor uses a sensitive diaphragm open to the air on one side and backed by a large, thermally insulated reference volume on the other. A calibrated flow resistor, or leak, across the diaphragm filters out very-low-frequency barometric pressure changes.

The ability of pressure sensors to detect infrasonic waves is usually limited not by their sensitivity, but by local pressure fluctuations in the atmosphere that have nothing to do with sound waves. These may be caused by winds and turbulence near the sensor, or by weather-related changes in barometric pressure. (The pressure amplitude of a typical infrasound signal from a distant source is 0.1 Pa, which is equivalent to the barometric pressure change due to a one-centimeter change in altitude.)

A single pressure sensor often cannot tell the difference between the pressure fluctuations caused by a passing wave of infrasound and the non-acoustic pressure changes. One way to weed out unwanted pressure fluctuations is to apply filters that take advantage of the known spatial and temporal characteristics of the infrasound, as well as those of the unwanted "noise." One property of sound waves is that they travel at about 344 m/s, or roughly 758 miles per hour. Another is that they possess a certain amount of coherence in space and time; that is, they maintain a similar wave-form when sampled by sensors spaced a few wavelengths apart. A known property of the nonacoustic pressure fluctuations is that they are less coherent in space and increase in intensity at lower frequencies. So it makes sense to design sensors that average incoherent pressure fluctuations over space and have a high-pass frequency response.[12]

Attached to the pressure sensor shown in figure 5 are 12 radial arms with ports at one-foot intervals, covering an area 50 feet in diameter. Waves of near-infrasound (with wavelengths much larger than the array) produce a coherent response over all the ports, while smaller-scale pressure fluctuations are partially averaged out. Noise reducers with dimensions greater than 1000 feet have also been used.

A similar kind of spatial filter consists of a larger spatial array of such sensors to sample the wave-associated pressure fluctuations at spaced locations. Modern digital array-processing algorithms[13] then search in "wavenumber space" for combinations of time delays over the array that match infrasound waves with different speeds and that come from different directions. The design of the spatial filtering arrays is always a compromise between angular resolution and spatial decorrelation.

Infrasound wavelengths are so long that most sensors are deployed at ground level in two-dimensional arrays. (The wavelength at a frequency of 1 Hz is 340 m; at 0.1 Hz, it is 3.4 km.) When only two-dimensional array processing is practical, the elevation angle of arrival of a wave must be inferred from the speed that it travels across the array. For example, a wave traversing the array at 340 m/s is arriving essentially along the ground; a wave traversing the array at 480 m/s is interpreted as arriving from about 45° above horizontal.

GENERATING INFRASOUND

Historically, low-frequency sound propagation has been studied using explosive sources,[4] but this is practical only in remote areas. To study infrasound and its propagation through the atmosphere in a controlled and unobtrusive way, or to measure the directional response of receiving sensors, it would be useful to be able to generate coherent, narrowband infrasound at will. Practical uses for such sources would include inaudible probing of propagation paths where noise pollution is a concern and assessing atmospheric conditions (like temperature inversions) where audible sound could be harmfully trapped or ducted. But infrasound is difficult to generate artificially, because sources of manageable size are small compared to a wavelength and are thus very inefficient.

In 1988, we designed a 100 Hz audible sound source for use with a radio acoustic sounding system in which atmospheric temperature profiles are measured by tracking vertically traveling sound waves with radar. This audio source required a 10-foot-diameter horn driven by four 18-inch speakers using several thousand watts of electrical power. Figure 1 shows the acoustic horn and speakers mounted on a pickup truck. Sound waves from this system reached a 20 km altitude, but infrasonic versions could approach ionospheric heights.

To generate still lower frequencies, we experimented with a spherical Helmholtz resonator that was tunable from 10 to 50 Hz and sealed with a rupture disk. When pressurized to 1 atmosphere and ruptured, it emitted a consistent pulse waveform that could be recognized more than a kilometer away and detected at 30 kilometers. Figure 1 shows this resonator. The design of a practical coherent source of infrasound remains elusive, but devices such as very large organ pipes, strings, and drums have been suggested. Such an "orchestra" would have dimensions of hundreds of feet and require a huge amount of huffing and puffing to produce a useful infrasound level, which nevertheless would go unheard.

ACOUSTIC-GRAVITY WAVES

Far-infrasound behaves physically just like ordinary sound until its wave period exceeds about 1 minute (0.017 Hz frequency). In a density-stratified atmosphere, the buoyancy forces on a parcel of air become comparable to pressure-gradient forces, and the wave-associated air motion is no longer exactly longitudinal. As frequency decreases, propagation of these "acoustic-gravity waves" becomes more dispersive (frequency dependent) and anisotropic (direction dependent).[14] At wave periods longer than about 4 minutes, the waves are transformed into the almost pure internal atmospheric-gravity waves whose oceanic counterpart is well known. (Lucid treatments of the theory of acoustic-gravity waves are given in reference 15.) These long-period waves are an important component of the signature of distant explosions, even underground ones. Another kind of long-period infrasound radiated by distant explosions is guided along the Earth's surface and is called a Lamb wave.[3] The CTBT monitoring network will have to be "smart" enough to distinguish the long-period signatures of nuclear tests from many natural sources of acoustic-gravity waves. Among those that have been studied are earthquakes, weather fronts, jet streams, and clear-air turbulence in the upper atmosphere.

WHAT NEXT?

Our present understanding of Earth's natural infrasonic environment is largely phenomenological and lacks quantitative, testable physical models for how the various observed infrasound sources actually radiate. The wave theorists have their work cut out for them and should be able to find support in the context of CTBT false-alarm requirements.

The CTBT observing network will be far larger, more sensitive, and more integrated than any previous infrasound/hydroacoustic/seismic network. (See figure 1 in Sullivan's article, *Physics Today*, March 1998, page 24.) Even if the network becomes bored by the absence of any nuclear tests to monitor, it will offer an abundance of high-quality data for global geophysical research. As these data are made available to the scientific community, the monitoring system would become a focal point of international scientific cooperation on topics such as those listed in the table on page 49.

Sonic and infrasonic monitoring systems have a role to play in the exploration of other planetary atmospheres. Indeed, the ill-fated Mars Polar Lander carried a tiny microphone to sample that planet's acoustic environment. No one knows what the Mars microphone would have discovered, although the Planetary Society sponsored a K–12 essay contest to predict what might be heard. Some day we will find out what Mars and other worlds have to say.

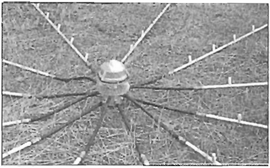

Figure 5. Noise-reducing microphone. The large device uses spatial averaging to smooth out small-scale pressure changes caused by winds and turbulence, thus enhancing its response to longer waves of infrasound. The small white cylinders are porous filters protecting calibrated flow resistors inserted at 1-foot intervals along twelve 20-ft lengths of pipe that radiate from the central sensor.

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THE PHYSIOLOGICAL DEMANDS OF WIND INSTRUMENT PERFORMANCE*

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Summary: Requirements on blowing pressure and lip tension in the playing of woodwind and brass instruments are examined and related to the sound-producing mechanism in each case. Loud playing of high notes on brass instruments is found to be the most physiologically demanding situation, but all instruments have particular requirements for precise physiological control.

1. INTRODUCTION

The playing of musical wind instruments goes back to the dawn of human history, but it is only recently that we have begun to understand in detail the physical principles governing sound production and the physiological variables that must be controlled by the player during performance. Along with this goes a better understanding of the design and construction of the instruments themselves, but that, as they say, is another story.

Setting aside the pipe organ, we can divide musical wind instruments into three classes: reed-driven instruments such as the clarinet, oboe, bassoon and saxophone; lip-driven brass instruments such as the trumpet, trombone and tuba; and air-jet driven instruments of the flute family. In all of these, the player must learn to control the pitch of the note being played by manipulating finger keys, valves or slides, and then must carefully control the actual sound-producing mechanism to produce a satisfactory result. This requires deliberate control of physiological variables such as lip position and tension, blowing pressure, and perhaps vocal-tract configuration. It is the purpose of the present paper to describe what is known of the requirements on each of these variables. Details of the acoustics of the instruments themselves can be found in Fletcher and Rossing (1998).

2. REED-DRIVEN INSTRUMENTS

The clarinet is perhaps the simplest and most studied of the woodwind instruments, because it has an essentially cylindrical tube and a single flat reed with simple geometry. The player's lips enclose the reed and the mouthpiece against which it is clamped with a gap of about 1mm at the tip, and the player applies air pressure that tends to close the reed against the mouthpiece. Analysis of the physics of this situation shows that the reed will begin to vibrate, and thus cause oscillations in the air flow through the aperture between it and the mouthpiece into the instrument tube, once the blowing pressure exceeds one-third of the value required to completely close the reed against the mouthpiece face. To ensure stable playing, the player ordinarily uses a pressure that is one-half to two-thirds of this closing pressure.

To first order, this is all that is required, and the instrument will sound whatever note is dictated by the fingering. In practice there are a few subtleties. In the first place, the production of high notes is aided if the player adjusts the lips so that the vibrating part of the reed is shortened, and there is also an associated reduction of the mouth volume by raising the tongue. This generally increases the closing pressure a little, so that normal blowing pressure is also a little raised. To reduce the loudness of the sound, the player tenses the lips so that the reed aperture is reduced and less air flows through into the instrument. This also causes a small decrease in closing pressure, and so in optimal blowing pressure.

As shown in Figure 1, for normal clarinet playing, the blowing pressure is typically 2 to 3 kilopascals (kPa) for soft playing, and 4 to 4.5kPa for loud playing over the whole pitch range of the instrument (Fuks and Sundberg, 1997), though jazz players may sometimes use a higher blowing pressure to produce an incisive or even rough tone quality. These pressures should be compared with normal sub-glottal pressures of about 300Pa for speech and perhaps 1kPa in singing, and are not so high as to cause much physiological stress. (For those not familiar with these pressure units, 1kPa is equivalent to about 10cm water or 7.5mm mercury. A scale translation is given in each figure.)

Playing technique for the saxophone is in many ways similar to that for the clarinet, and jazz players often switch between the two instruments. The saxophone also has a single flat reed but differs from the clarinet in having a wide-mouthed conical bore. Blowing pressure for the alto saxophone is typically about 2kPa for soft playing, but may rise as high as 8kPa in the middle register for very loud playing where a harsh tone quality is desired, as shown in Figure 1.

Double-reed instruments, such as the oboe and bassoon, have a very narrow conical bore and a narrow reed with two vibrating tongues bound together. The reed aperture is much smaller than in the single-reed instruments and, because the reed is curved across its width and there is significant flow resistance in the narrow reed channel, a higher blowing pressure is required to make it vibrate. The blowing pressure used by skilled players increases by about a factor two between soft and loud playing, and rises by about a factor two across the compass of the instrument, as shown in Figure 1. Pressures of around 10kPa, as required for high loud notes on the oboe

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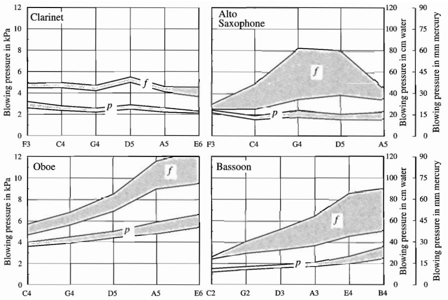

Figure 1. Typical blowing pressure ranges across the musical compass for clarinet, alto saxophone, oboe, and bassoon, for *piano* and *forte* playing. [Data from Fuks and Sundberg (1996).]

or bassoon, impose a significant physiological strain on the player if the condition must be maintained for a long section of music, but this usually results only in facial reddening. For less-skilled players, there may be significant difficulty in maintaining the lips in position on the reed, because mouth pressure tends to blow the lips open. There is no remedy for this except regular practice, preferably begun at an early age, to strengthen the lip muscles.

The reed woodwinds, and particularly the double reeds, do not require a large air flow to produce a moderately loud sound, and players can therefore play quite long passages, up to perhaps 50 seconds in duration, without requiring to take a breath. This, too, imposes a physiological strain on the player because of the build-up of carbon dioxide concentration in the lungs. Normally such a build-up triggers a breathing reflex, but experience players are able to suppress this to a considerable extent. It has recently become common practice for woodwind players to become adept at the techniques of 'circular breathing,' in which the throat and mouth are filled with air from the lungs under pressure to maintain the instrument sound, and then sealed off from the trachea and nasal passages at the soft palate so that a quick breath may be taken through the nose. This technique, which has been used by Australian Aboriginal didjeridu players for thousands of years, allows the player to continue playing without interruption for an indefinite time.

It has already been mentioned that the volume of the mouth is typically reduced for playing high notes and increased for very low notes, as is clear from the lowered chin of bassoon players. There is another aspect of respiratory tract physiology that also appears to enter performance technique, and this concerns the larynx. Mukai (1989) made observations of the larynx of many wind instrument players during performance in the laboratory, using a nasendoscope, and found that, while novice players typically had wide open larynxes, experienced players of all varieties of wind instruments mostly adducted their vocal folds to constrict greatly the laryngeal opening. In the case of players using vibrato, the vocal folds tended to vibrate in synchrony with the vibrato. There do not appear to have been further investigations of this finding in the case of reed instrument players.

3. LIP-DRIVEN BRASS INSTRUMENTS

While the player's lips take the place of the reed in brass instruments, their operation is very different. The reason is that, while pressure in the player's mouth tends to close a reed valve, it tends to open a lip valve. The exact motion of a player's lips is complex and to some extent under conscious control, although the player does not generally realise what changes are being made. The lips may either blow outwards towards the instrument, like an outward-swinging door, or move laterally like a sliding door. More realistically they may combine both these movements or may even have a wave-like motion (Yoshikawa, 1995; Adachi and Sato, 1996).

The important thing acoustically is that the lips are able to act as a sound-generating valve only very close to their natural resonance frequency. This means that lip muscle tension must be adjusted very carefully by the player to match the pitch of each note, and must be increased greatly for high notes. The accuracy of tension adjustment required increases in the upper range of the instrument where the frequencies of

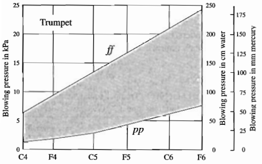

Figure 2. Typical blowing pressure range across the musical compass for the trumpet in *pianissimo* and *fortissimo* playing [Data from Fletcher and Tarnopolsky (1999).]

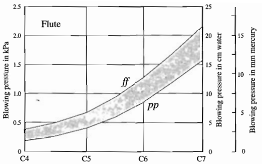

Figure 3. Typical blowing pressure range across the musical compass for the flute, in *pianissimo* and *fortissimo* playing. [Data from Fletcher (1975).]

the natural modes of the horn are close together. For a French horn or a 'natural' trumpet without valves, some of these notes differ by only a semitone, or 7% in frequency, and this requires an accuracy greater than this in the control of lip tension. Small wonder that amateur horn players sometimes 'fluff' notes on their entries!

This high lip tension brings physiological difficulties of muscle tiredness, but the lips are supported by the rim of the mouthpiece cup so that they do not blow out uncontrollably. More importantly, a high lip tension requires a high mouth pressure to force the lips open at all and, if a very loud sound is required, the necessary blowing pressure becomes extreme.

Fletcher and Tarnopolsky (1999) have investigated these problems for the case of trumpet players, and the results are summarised in Figure 2. For soft playing, the necessary blowing pressure is moderate, though it doubles for each octave rise in pitch and is as high as 6kPa for notes at the top of the range. Increased loudness, however, requires increased blowing pressure, and expert players may exceed 20kPa for high notes played fortissimo. Indeed one player studied reached 25kPa. To set this in context, it implies a pressure in the lungs, throat and mouth of 150 to 190mm mercury, which is greater than systolic blood pressure! It is not surprising that professional orchestral trumpet players are usually sturdy in physique and that, even so, some of them report problems of dizziness and even muscle rupture.

With lower pitched instruments, the pressure problems are less. For the tuba, indeed, problems are rather those of excessive air flow demands in the loud playing of notes at the bottom of the range, leading to hyperventilation.

4. FLUTE-LIKE INSTRUMENTS

The third class of wind instruments is that in which sound is generated by the flow of an air jet across an aperture. The orchestral flute is the principal representative, but recorders, ocarinas, shakuhachi, and pan-pipes all have similar characteristics. The jet actually excites the air column of the instrument by blowing alternately into and out of the aperture, and this jet deflection is caused by sinuous waves propagating along its length from the small aperture between the player's lips. To sound a note, it is necessary that there be very nearly half a wavelength of this wave disturbance on the jet at the frequency of the note being played, and this requires precise control of lip position and of blowing pressure. Only in recorders, ocarinas and whistles is the geometry of the jet defined by a built-in airway.

Measurements on flute players (Fletcher, 1975) confirm the correctness of this theory of sound generation in these instruments. Players reduce the length of the air jet by pushing the lips forward, and increase the blowing pressure and thus the jet velocity, when playing high notes. In fact the jet lengths and blowing pressures used by flute players differ very little from one individual to another, as shown for the case of pressure in Figure 3. The blowing pressure is very closely doubled for each octave rise in pitch, so that it is proportional to the frequency of the note being played — the same result as for trumpet players, but for an entirely different reason! The blowing pressures used in flute playing are the lowest of any wind instrument, ranging from about 0.2kPa for low notes to about 2.5kPa at the top of the range, nearly independently of the loudness of the note being played, as shown in Figure 3. Blowing pressure therefore causes no physiological difficulty at all for flute players.

Since blowing pressure cannot be used to control loudness, the player changes the air flow into the instrument by varying the area of the opening between the lips — a larger opening means a greater air flow and thus a louder sound. The useful width of the air jet is limited, however, by the width of the embouchure hole in the instrument to about 12mm, and it is necessary that the jet be not too thick — the limit is about 1mm — if the sound quality is to be acceptable. An even loudness across the instrument compass also requires a smaller aperture for high notes to compensate for the increased blowing pressure. All these adjustments demand experience and practice, but do not present any physiological problems.

Whereas in most other wind instruments (except perhaps the oboe) the desired tone is nearly steady, flute players favour performance with pronounced vibrato. Measurements (Fletcher, 1975) show that this vibrato is accomplished by imposing a small oscillation on the air pressure in the mouth, with an amplitude about 10% of the steady pressure and a frequency of 5 to 6Hz. The result is not so much a regular oscillation in sound level or in frequency, both of which remain almost unaffected, but rather an oscillation in tone quality caused by variation in the amplitude of the upper harmonics of the sound.

It is not immediately clear how this vibrato is accomplished, and indeed it may vary from one school of playing to another. It could be by rhythmic oscillation of the abdominal muscles, by similar changes in lip tension and thus in lip aperture, or by oscillation of the vocal folds if they are significantly adducted. Mukai (1989) found a narrowing of the airway by the vocal folds for experienced flute players as for other instrumentalists, and an oscillation in airway area in synchrony with the vibrato, but recent studies have suggested that there may be more variation in technique from one individual to another than found in his work.

5. CONCLUSIONS

As set out in this brief review, the production of a well controlled sound from a musical wind instrument involves precise control of a number of physiological variables, particularly blowing pressure and lip configuration. The requirements on these variables are very different between the three classes of wind instruments, and some musical demands may impose quite extreme physiological stresses. It is to be hoped that, by understanding what is required and the reasons for it, players may improve both their technique and their playing comfort.

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SCIENCE AND THE STRADIVARIUS[*]

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Stradivarius violins are among the most sought-after musical instruments in the world. But is there a secret that makes a Stradivarius sound so good, and can modern violins match the wonderful tonal quality of this great Italian instrument?

Is there really a lost secret that sets Stradivarius violins apart from the best instruments made today? After more than a hundred years of vigorous debate, this question remains highly contentious, provoking strongly held but divergent views among players, violin makers and scientists alike. All of the greatest violinists of modern times certainly believe it to be true, and invariably perform on violins by Stradivari or Guarneri in preference to modern instruments.

Violins by the great Italian makers are, of course, beautiful works of art in their own right, and are coveted by collectors as well as players. Particularly outstanding violins have reputedly changed hands for over a million pounds. In contrast, fine modern instruments typically cost about £10,000, while factory-made violins for beginners can be bought for under £100. Do such prices really reflect such large differences in quality?

The violin is the most highly developed and most sophisticated of all stringed instruments. It emerged in Northern Italy in about 1550, in a form that has remained essentially unchanged ever since. The famous Cremonese violin-making families of Amati, Stradivari and Guarneri formed a continuous line of succession that flourished from about 1600 to 1750, with skills being handed down from father to son and from master to apprentice. The popular belief is that their unsurpassed skills, together with the magical Stradivarius secret, were lost by the start of the 19th century.

Every violin, whether a Stradivarius or the cheapest factory-made copy, has a distinctive "voice" of its own. Just as any musician can immediately recognize the difference between Domingo and Pavarotti singing the same operatic aria, so a skilled violinist can distinguish between different qualities in the sound produced by individual Stradivari or Guarneri violins. The challenge for scientists is to characterize such differences by physical measurements. Indeed, over the last century and a half, many famous physicists have been intrigued by the workings of the violin, with Helmholtz, Savart and Raman all making vital contributions.

It is important to recognize that the sound of the great Italian instruments we hear today is very different from the sound they would have made in Stradivari's time. Almost all Cremonese instruments underwent extensive restoration and "improvement" in the 19th century. You need only listen to "authentic" baroque groups, in which most top performers play on fine Italian instruments restored to their former state, to recognize the vast difference in tone quality between these restored originals and "modern" versions of the Cremonese violins.

Prominent among the 19th-century violin restorers was the French maker Vuillaume, whose copy of a Guarnerius violin is shown in figure 1a. Vuillaume worked closely with Felix Savart, best known to physicists for the Biot–Savart law in electromagnetism, to enhance the tone of early instruments. Vuillaume, Savart and others wanted to produce more powerful and brilliant sounding instruments that could stand out in the larger orchestras and concert halls of the day. Improvements in instrument design were also introduced to support the technical demands of great violin virtuosi like Paganini.

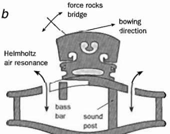

Figure 1

(a) A copy of a Guarnerius violin made by the 19th-century French violin maker Vuillaume, shown from the player's perspective.

(b) A schematic cross-section of the violin at the bridge, with the acoustically important components labelled – including the "f-hole" Helmholtz air resonance.

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BACK TO BASICS: THE COMPONENTS OF A VIOLIN

To understand the factors that determine the quality of sound produced by particular instruments, we must first recall how the violin works (figure 1b). Sound is produced by drawing a bow across one or more of the four stretched strings. The string tensions are adjusted by tuning pegs at one end of the string, so that their fundamental frequencies are about 200, 300, 440 and 660 Hz – which correspond to the notes G, D, A and E. However, the strings themselves produce almost no sound.

To produce sound, energy from the vibrating string is transferred to the main body of the instrument – the so-called sound box. The main plates of the violin act rather like a loudspeaker cone, and it is the vibrations of these plates that produce most of the sound.

The strings are supported by the "bridge", which defines the effective vibrating length of the string, and also acts as a mechanical transformer. The bridge converts the transverse forces of the strings into the vibrational modes of the sound box. And because the bridge has its own resonant modes, it plays a key role in the overall tone of the instrument.

The front plate of the violin is carved from a solid block of fine-grained pine. Maple is usually used for the back plate and for the sides. Two expertly carved and elegantly shaped "f-holes" are also cut into the front plate. The carving of the f-holes often helps to identify the maker of a valuable instrument: never rely on the label inside the violin to spot a fake instrument as the label will probably have been forged as well.

The f-holes play a number of important acoustic roles. By breaking up the area of the front plate, they affect its vibrational modes at the highest frequencies. More importantly, they boost the sound output at low frequencies. This occurs through the "Helmholtz air resonance", in which air bounces backwards and forwards through the f-holes. The resonant frequency is determined by the area of the f-holes and the volume of the instrument. It is the only acoustic resonance of the instrument over which violin makers have almost complete control.

Early in the 16th century it was discovered that the output of stringed instruments could be increased by wedging a solid rod – the "sound post" – between the back and front plates, close to the feet of the bridge. The force exerted by the bowed strings causes the bridge to rock about this position, causing

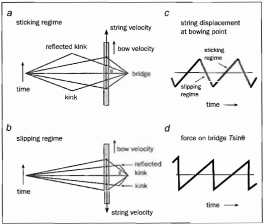

Figure 2 An exaggerated view of the transverse displacements of a bowed violin string, illustrating the "slip-stick" mechanism that generates a Helmholtz wave with a single kink travelling along the string. (a) The shape of a string at five equally spaced time intervals, when the kink is on the far side of the bow from the bridge. This is known as the "sticking regime". At the position where the string is being bowed, the string moves with the same speed, and in the same direction, as the bow. (b) The shape of the string at five equally spaced time intervals for the "slipping regime", when the kink is travelling between the bow and the bridge, and back. The string now moves in the opposite direction to the bow. (c) The displacement of the string at the bowing point. (d) The force $T\sin\theta$ exerted by the strings on the bridge as function of time, where T is the tension of the string.

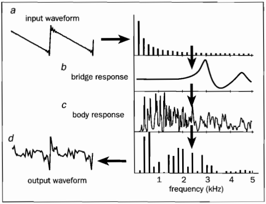

Figure 3 (a) Drawing a bow over the strings of a violin generates a nearly ideal sawtooth force on the top of the bridge. The force can consist of as many as 40 Fourier components, with the amplitude of the nth component decreasing smoothly in proportion to $\sim 1/n$ (main figure). (b) The bridge, which transforms energy from the vibrating strings to the vibrational modes of sound box, has a response that varies with frequency. The resonances at about 3 kHz and 4.5 kHz boost the output sound, while the dip between them reduces the "nasal" qualities in the tone. (c) A mathematically modelled acoustic output of the violin. The output increases dramatically whenever the exciting frequency coincides with one of the many vibrational modes of the instrument. (d) The Fourier components of the multi-resonance acoustic output, produced by bowing the lowest note on the instrument at 200 Hz. The main figure shows the calculated output waveform produced by the idealized input sawtooth waveform. Unlike the Fourier components of the input, the Fourier components of the output will vary dramatically in amplitude from one note to the next.

the other side of the plate to vibrate with a larger amplitude. This increases the radiating volume of the violin and produces a much stronger sound.

The violin also has a "bass bar" glued underneath the top plate, which stops energy being dissipated into acoustically inefficient higher-order modes. The bass bar and sound post were both made bigger in the 19th century to strengthen the instrument and to increase the sound output.

GETTING KINKY: HOW STRINGS VIBRATE

In the 19th century the German physicist Hermann von Helmholtz showed that when a violin string is bowed, it vibrates in a way that is completely different from the sinusoidal standing waves that are familiar to all physicists. Although the string vibrates back and forth parallel to the bowing direction, Helmholtz showed that other transverse vibrations of the string could also be excited, made up of straight-line sections. These are separated by "kinks" that travel back and forth along the string and are reflected at the ends. The kinks move with the normal transverse-wave velocity, $c = (T/m)^{1/2}$, where T is the tension and m the mass per unit length of the string. The bowing action excites a Helmholtz mode with a single kink separating two straight sections (figure 2).

When the kink is between the bow and the fingered end of the string, the string moves at the same speed and in the same direction as the bow. Only a small force is needed to lock the two motions together. This is known as the "sticking regime" (figure 2a). But as soon as the kink moves past the bow – on its way to the bridge and back – the string slips past the bow and starts moving in the opposite direction to it. This is known as the "slipping regime" (figure 2b).

Although the sliding friction is relatively small in the slipping regime, energy is continuously transferred from the strings to the vibrational modes of the instrument at the bridge. Each time the kink reflects back from the bridge and passes underneath the bow, the bow has to replace the lost energy. It therefore exerts a short impulse on the string so that it moves again at the same velocity as the bow.

This process is known as the "slip–stick" mechanism of string excitation and relies on the fact that sliding friction is much smaller than sticking friction (figure 2c). The Helmholtz wave generates a transverse force $T\sin\theta$ on the bridge, where θ is the angle of the string at the bridge. This force increases linearly with time, but its amplitude reverses suddenly each time the kink is reflected at the bridge, producing a sawtooth waveform (figure 2d). The detailed physics of the way a bow excites a string has been extensively studied by Michael McIntyre and Jim Woodhouse at Cambridge University, who have made a number of important theoretical and experimental contributions to violin acoustics in recent years.

It is important to recognize that the Helmholtz wave is a free mode of vibration of the string. The player has to apply just the right amount of pressure to excite and maintain the waveform without destroying it. The lack of such skill is one of the main reasons why the sound produced by a beginner is so excruciating. Conversely, the intensity, quality and subtlety of sound produced by great violinists is mainly due to the fact that they can control the Helmholtz waveform with the bow. The quality of sound produced by any violin therefore depends as much on the bowing skill of the violinist as on the physical properties. One of the reasons that the great Cremonese violins sound so wonderful is because we hear them played by the world's greatest players!

SOUNDS GOOD: HOW A VIOLIN MAKES A NOISE

The sawtooth force that is generated on the top of the bridge by a bowed string is the input signal that forces the violin to vibrate and radiate sound – rather like the electrical input to a loudspeaker, albeit with a much more complicated frequency response. The input sawtooth waveform has a rich harmonic content, consisting of numerous Fourier components.

Since the violin is a linear system, the same Fourier components or "partials" appear in the output of the violin. The amplitude of each partial in the radiated sound is determined by the response of the instrument at that particular frequency. This is largely determined by the mechanical resonances of the bridge and by the body of the instrument. These resonances are illustrated schematically in figure 3, where typical responses have been mathematically modelled to simulate their influence on the sound produced.

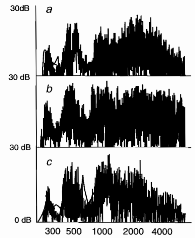

Figure 4. Acoustic response of (a) 10 master Italian violins, (b) 10 fine modern instruments and (c) 10 cheap factory-made violins. The violins were excited by a simple electromechanical driver at the bridge. All the instruments have an air resonance just below 300 Hz and strong structural resonances between 400–600 Hz. There is a gap in structural resonances at around 700–800 Hz, while above 1000 Hz the spacing of the modes becomes closer and the average response approaches a continuum. The factory-made instruments have a rather weak response at high frequencies in contrast to the over-strong response of the modern violins, which may contribute to a certain shrillness in their quality. (H Dünnwald 1991 *J. Catgut Acoustical Soc.* 1 57)

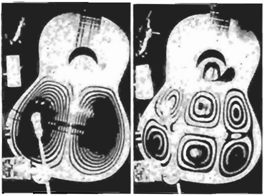

Figure 5. Time-averaged interference holograms showing two-dimensional flexural standing waves on the front plate of a guitar. The interference patterns, which indicate contours of equal-amplitude vibrations, are much more symmetrical than those observed for the violin. The contours in a violin cross the edges of the instrument – in other words, the sides of a violin transfer significant vibrations from the front to the back. Unfortunately, it is not easy to obtain similar high-quality interference patterns for a violin, which has smaller, more curved and less reflective surfaces.

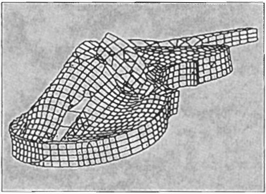

Figure 6. A finite-element reconstruction showing one of the acoustically important structural modes of the body of a violin. The snapshot view shows, on a much exaggerated scale, the highly asymmetric vertical displacements and flexural vibrations of the instrument. The results were obtained when the displacement was at its maximum. Note that vibrations of all parts of the instrument are involved in the resonant mode. In particular, the resonances of the front and back plates cannot be considered in isolation from the rest of the instrument, as has often been assumed in the past. (George Knott 1987 MSc Thesis Naval Postgraduate School, Monterey, California. See Hutchins and Benade in further reading)

At low frequencies the bridge simply acts as a mechanical lever, since the response is independent of frequency. However, between 2.5 and 3 kHz the bowing action excites a strong resonance of the bridge, with the top rocking about its narrowed waist section. This boosts the intensity of any partials in this frequency range, where the ear is most sensitive, and gives greater brightness and carrying power to the sound. Another resonance occurs at about 4.5 kHz in which the bridge bounces up and down on its two feet. Between these two resonances there is a strong dip in the transfer of force to the body. Thankfully this dip decreases the amplitude of the partials at these frequencies, which the ear associates with an unpleasant shrillness in musical quality.

The sinusoidal force exerted by the bridge on the top plate produces an acoustic output that can be modelled mathematically. The output increases dramatically whenever the exciting frequency coincides with one of the many vibrational modes of the instrument. Indeed, the violin is rather like a loudspeaker with a highly non-uniform frequency response that peaks every time a resonance is excited. The modelled response is very similar to many recorded examples made on real instruments.

In practice, quite small changes in the arching, thickness and mass of the individual plates can result in big changes in the resonant frequencies of the violin, which is why no two instruments ever sound exactly alike. The multi-resonant response leads to dramatic variations in the amplitudes of individual partials for any note played on the violin.

Such factors must have unconsciously guided the radical redesign of the bridge in the 19th century. Violinists often place an additional mass (the "mute") on the top of the bridge, effectively lowering the frequency of the bridge resonances. This results in a much quieter and "warmer" sound that players often use as a special effect. It is therefore surprising that so few players – or even violin makers – recognize the major importance of the bridge in determining the overall tone quality of an instrument.

One of the reasons for the excellent tone of the very best violins is the attention that top players give to the violin set-up – rather like the way in which a car engine is tuned to get the best performance. Violinists will, for example, carefully adjust the bridge to suit a particular instrument – or even select a different bridge altogether. The sound quality of many modern violins could undoubtedly be improved by taking just as much care in selecting and adjusting the bridge.

The transfer of energy from the vibrating string to the acoustically radiating structural modes is clearly essential for the instrument to produce any sound. However, this coupling must not be too strong, otherwise the instrument becomes difficult to play and the violinist has to work hard to maintain the Helmholtz wave. Indeed, a complete breakdown can occur when a string resonance coincides with a particularly strongly coupled and lightly damped structural resonance.

When this happens the sound suddenly changes from a smooth tone to a quasi-periodic, uncontrollable, grunting sound – the "wolf-note". Players minimize this problem by wedging a duster against the top plate to dampen the vibrational modes, or by placing a resonating mass, the "wolf-note adjuster", on one of the strings on the far side of the bridge. However, this only moves the wolf-note to a note that is not played as often, rather than eliminating it entirely.

The Helmholtz motion of the string and the wolf-note problem were extensively studied by the Indian physicist Chandrasekhara Raman in the early years of the 20th century. His results were published in a series of elegant theoretical and experimental papers soon after he founded the Indian Academy of Sciences and before the work on optics that earned him the Nobel Prize for Physics in 1930.

GOOD VIBRATIONS: THE ROLE OF RESONANCES

The existence of so many resonances at almost random frequencies means that there is simply is no such thing as a "typical" waveform or spectrum for the sound from a violin. Indeed, there is just as much variation between the individual notes on a single instrument as there is between the same note played on different instruments. This implies that the perceived tone of a violin must be related to overall design of the instrument, rather than to the frequencies of particular resonances on an instrument.

An interesting attempt to look for such global properties was recently made by the violin maker Heinrich Dünnwald in Germany. He measured the acoustic output of 10 Italian violins, 10 fine modern copies and 10 factory-made violins, all of which were excited by an electromagnetic driver on one side of the bridge (figure 4). Between 400 and 600 Hz, the factory-made violins were found – surprisingly – to be closer to the Italian instruments than the modern copies. At frequencies above 1000 Hz, however, the factory-made instruments had a rather weak response – in contrast to the over-strong response of the modern violins, which may contribute to a certain shrillness in their quality.

In practice it is extremely difficult to distinguish between a particularly fine Stradivarius instrument and an indifferent modern copy on the basis of the measured response alone. The ear is a supreme detection device and the brain is a far more sophisticated analyser of complex sounds than any system yet developed to assess musical quality.

Although such measurements give the frequencies of important acoustic resonances, they tell us nothing about the way a violin actually vibrates. A powerful technique for investigating such vibrations is called time-averaged interference holography. Bernard Richardson, a physicist at Cardiff University in the UK, has made a number of such studies on the guitar and violin. Some particularly beautiful examples for the guitar are shown in figure 5. Unfortunately, it is not easy to obtain similar high-quality images for the violin because it is smaller, the vibrations of the surface are smaller, and the surfaces of the violin are more curved and less reflective than those of the guitar.

Another powerful approach is modal analysis: a violin is lightly struck with a calibrated hammer at several positions and the transient response at various points is measured with a very light accelerometer. These responses are then analysed by computer to give the resonant frequencies and structural modes of vibration of the whole instrument. This technique has been used to teach students about violin acoustics at the famous Mittenwald school of violin making in Germany and by Ken Marshall in the US. Marshall has also shown that the way the violin is held has little effect on its resonant response.

Similar information can be obtained by finite-element analysis: the violin is modelled as a set of masses that are connected by springs, which makes it relatively straightforward to evaluate the resonant modes and associated

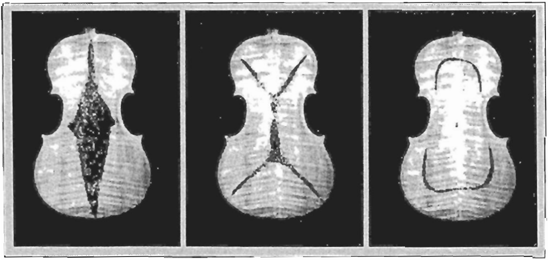

Figure 7. When glitter is poured onto violin plates that are freely suspended above a loudspeaker, the glitter bounces up and down, and moves towards the nodal lines of important low-frequency resonances. In an attempt to compensate for the natural variation in the properties of the wood used to make a violin, many scientifically minded violin makers adjust the arching and thickness of the top and bottom plates to achieve particular resonant frequencies and nodal patterns in an instrument.

vibrations of the whole structure (figure 6). Various physical parameters of the materials used to make the violin can also be incorporated in the calculations. It is then possible to construct a virtual violin and to predict all its vibrational and acoustic properties. This might be the first step towards designing a violin with a specified response and hence tonal quality – once we know how to define "quality" in a measurable way.

BUILD QUALITY: HOW TO MAKE A GOOD VIOLIN

So how do skilled violin makers optimize the tone of an instrument during the construction process? They begin by selecting a wood of the highest possible quality for the front and back plates, which they test by tapping with a hammer and judging how well it "rings".

The next important step is to skilfully carve the plates out of the solid wood, taking great care to get the right degree of arching and variations in thickness. The craftsman has to learn how to adjust the plates to produce a fine-sounding instrument. Traditional makers optimize the thickness by testing the "feel" of the plates when they are flexed, and by the sounds produced when the are tapped at different positions with the knuckles. This is the traditional equivalent of nodal analysis, with the violin maker's brain providing the interpretative computing power.

However, in the last 50 years or so, a group of violin makers has emerged who have tried to take a more overtly scientific approach to violin making. The pioneer in this field was Carleen Hutchins, the doyenne of violin acoustics in the US. Now almost 90 years old, but still active in the field, she founded the Catgut Society of America in 1958, together with William Saunders of "Russell–Saunders coupling" fame and John Schelling, a former director of radio research at Bell Labs. The society brings together violin makers and scientists from across the world, with the common aim of advancing our understanding of violin acoustics and developing scientific methods to help makers improve the quality of their instruments.

One common practice that has been adopted by violin makers has been to replace the traditional flexing and tapping of plates by controlled measurements. During the carving process, the thinned plates are suspended horizontally above a large loudspeaker. The acoustic resonances excited by the loudspeaker can readily be identified by sprinkling glitter onto the surface of the plates. When the loudspeaker has excited a resonance, the glitter bounces up and down, and moves towards the nodal lines of the resonant modes excited (figure 7). The aim is to interactively thin or "tune" the first few free-plate resonances to specified frequencies and nodal patterns.

Unfortunately, there are very few examples of such measurements for really fine Italian instruments because their owners are naturally reluctant to allow their violins to be taken apart for the sake of science. The relatively few tests that have been performed suggest that the early Italian makers may have tuned the resonant modes of the individual plates – which they could identify as they tapped them – to exact musical intervals. This would be consistent with the prevailing Renaissance view of "perfection", which was measured in terms of numbers and exact ratios.

Members of the "scientific" school of violin makers might reasonably claim that this could be the lost Stradivarius secret. However, it must indeed have been secret, since there is no historical evidence to support the case. Although many first-class modern violins have been built based on these principles, there is little evidence to suggest that they are any better than many fine instruments made with more traditional methods.

However, neither traditional craftsmanship nor scientific methods can hope to control the detailed resonant structure of an instrument in the acoustically important range above 1 kHz. Even the tiniest changes in the thickness of the plates will significantly affect the specific resonances in this frequency range, as will the inevitable variations in the properties of the wood. Furthermore, the frequencies and distribution of the resonant modes of the violin depend on the exact position of the sound post, which imposes an additional constraint on the modes that can be excited. Top players regularly return their instruments to violin makers, who move the sound post and adjust the bridge in an effort to optimize the sound. This means that there is no unique set of vibrational characteristics for any particular instrument – not even a Stradivarius!

KNOTTY PROBLEM: THE EFFECTS OF WOOD

Another factor that affects the quality of a violin is the internal damping of the wood. This strongly affects the multi-resonant response of the instrument and the overall background at high frequencies. In particular, the difference between the peaks and troughs of the resonant response is determined by the quality-factor of the resonances. This largely depends on internal losses within the wood when it vibrates: only a small fraction of the energy is lost by acoustic radiation.

The strongly peaked frequency response of the violin has a dramatic influence on the sound produced when "vibrato" is used. In this playing technique, the finger stopping the string is cyclically rocked backwards and forwards, periodically changing the pitch of the note. Because the response has such strong peaks and troughs, any change in pitch also produces cyclic variations in the overall amplitude, waveform and spectral content of the sound (figure 8).

Vibrato is very common nowadays because it captures and holds the attention of the listener, enabling the solo violin to be heard even when accompanied by a large orchestra. It would have been considered far less important when Stradivari was alive because vibrato was used only for special theatrical effects and the violin was expected to blend in with other instruments.

Vibrato adds a certain "lustre" and interest to the quality of sound produced because the ear is particularly sensitive to changes in the waveform. In a recent radio broadcast, for example, the English violinist Tasmin Little demonstrated the marvellous tone of the Stradivarius violin used by Nathan Milstein, one of the finest violinists of recent times. After playing just a few notes on the violin, she described the tone as "wonderfully exciting, almost deafening, very vibrant. It is

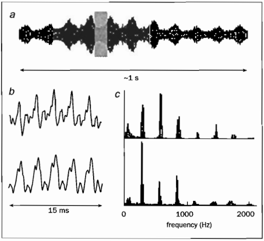

Figure 8. The "vibrato" playing technique, in which the finger stopping the string is cyclically rocked backwards and forwards, periodically changes the pitch of a note. (a) A one second section of a single bowed note played on a Stradivarius violin, showing the periodic changes in amplitude that are also produced with the use of vibrato. (b) Shorter time intervals, illustrating the periodic changes in waveform at the maxima and minima of the amplitude envelope. (c) The associated periodic changes in the amplitudes of the Fourier components. The shaded band in (a) indicates the time interval used to extract the components.

alive. It has an incredible ring under my ear. It is amazing". There can be little doubt that Little's subjective assessment is directly related to the extremely large changes in amplitude, waveform and spectral content associated with the use of vibrato, which gives "life and vibrancy" to the sound.

To achieve such large changes in the frequency response of the violin, the individual resonances of the instrument have to be strongly peaked, which requires high-quality wood with low internal damping. Unfortunately, wood can absorb water, which increases the damping: this explains why violinists often notice that the responsiveness of an instrument, which includes the ability to control the sound quality using vibrato, changes with temperature and humidity.

The choice of high-quality wood for making instruments has always been recognized by violin makers, and well seasoned wood is generally recommended. However, by measuring the pattern of growth-rings in the wood of a Stradivarius, we know that the Italian violin makers sometimes used planks of wood that had only been seasoned for five years. However, such wood is now 300 years old, and the intrinsic internal damping will almost certainly have decreased with time, as the internal organic structure has dried out.

The same will obviously be true for all old Italian instruments. The age of the wood may therefore automatically contribute to the improved quality of the older instruments. This may also explain why the quality of a modern instrument appears to change in its first few years. Surprisingly, many players still believe that their instruments improve because they are loved and played well, which would be very difficult to explain on any rational scientific basis!

THE SECRET AT LAST?

Many other theories have been put forward to account for the Stradivarius secret. The most popular for well over a century has been that the varnish had some sort of "magic" composition. The main function of the varnish is to protect the instrument from dirt and to stop it absorbing moisture from the player's hands. The varnish also imparts great aesthetic value to the instrument, with its translucent coating highlighting the beautiful grain structure of the wood below.

However, historical research has shown that the varnish is no different to that used by many furniture makers when Stradivari was alive. Claire Barlow and co-workers at Cambridge University, for example, have used electron microscopy to identify many of the important ingredients of the varnish itself, and the materials that are used to smooth the surface before the varnish is applied. It turns out that most could easily have been bought from the pharmacist shop next to Stradivari's workshop. Apart from the possibility that the varnish was contaminated with the wings of passing insects and debris from the workshop floor, there is no convincing evidence to support the idea of a secret formula!

Indeed, ultraviolet photography has revealed that many fine-sounding Italian violins have lost almost all their original varnish, and were recoated during the 19th century or later. The composition of the varnish is therefore unlikely to be the long-lost secret, although too much varnish would certainly increase the damping and therefore sully the tone.

Other researchers, meanwhile, have claimed that Stradivari's secret was to soak the wood in water, to leach out supposedly harmful chemicals, before it was seasoned. Although this would be consistent with the idea that the masts and oars of recently sunken Venetian war galleys might have been used to make violins, the scientific and historical evidence to support this view is unconvincing.

Over the last 150 years, physicists have made considerable progress in understanding the way the violin works. In the 19th century the "modernized" Stradivarius violin emerged with an "enhanced" tone as a result of scientifically guided "improvements" by the leading violin restorers of the day. However, Stradivari would be amazed to find that the modern musical world credits him with such a secret. After all, how could he possibly have had the clairvoyance to foresee that his instruments would be extensively modified in the 19th century to produce the kind of sound we value so highly today? Indeed, those sounds would have been totally alien to the musical tastes of his time!

Science has not provided any convincing evidence for the existence or otherwise of any measurable property that would set the Cremonese instruments apart from the finest violins made by skilled craftsman today. Indeed, some leading soloists do occasionally play on modern instruments. However, the really top soloists – and, not surprisingly, violin dealers, who have a vested interest in maintaining the Cremonese legend of intrinsic superiority – remain utterly unconvinced.

Maybe there is an essential aspect of violin quality that we are still failing to recognize. Many violinists say they can distinguish an instrument with a fine "Italian Cremonese sound" from one with, say, a more "French" tone, such as my Vuillaume violin. But we still do not know how to characterize such properties in meaningful physical terms.

What we need is more research, with high-quality violinists working with psycho-acousticians, scientists and sympathetic violin makers, to make further progress in solving this challenging and fascinating problem.

FURTHER READING

A H Benade 1976 *Fundamentals of Musical Acoustics* (Oxford University Press) – non-mathematical, but full of penetrating insights

L Cremer 1984 *The Physics of the Violin* (MIT Press, Cambridge, Massachusetts) translation J S Allen – detailed mathematical description of the essential physics of violin acoustics

N H Fletcher and T D Rossing 1998 *The Physics of Musical Instruments 2nd edn* (Springer, New York) – authoritative book with all the relevant background science

C M Hutchins 1981 The Acoustics of Violin Plates *Scientific American* October p170

C Hutchins and V Benade (ed) 1997 *Research Papers in Violin Acoustics 1975–93* vols 1 and 2 (The Acoustical Society of America, New York) – excellent overviews of all aspects of violin acoustics

M E McIntyre and J Woodhouse 1981 On the fundamentals of bowed string dynamics *Acustica* **43** 93

SOLVING A BAFFLING PROBLEM AT WARRINGAH AQUATIC CENTRE

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ABSTRACT: Warringah Aquatic Centre has for 20 years been a major sporting and recreation drawcard for tens of thousands of people on the lower north shore and lower northern beaches of Sydney. Noise reverberation has always been a concern at the Centre, even though baffles were installed in the concrete ceiling about 15 years ago. When the baffles began to deteriorate over the past couple of years, the situation became critical. This article describes how the problem was overcome, in spite of considerable challenges.

1. INTRODUCTION

The Warringah Aquatic Centre at Frenchs Forest on Sydney's lower North Shore records about 360,000 visitors a year, from casual swimmers and families to aquarobics and swim class students and, of course, clubs and schools holding sporting carnivals.

The building is of concrete construction approximately 65 metres long, 50 metres wide and 9 metres high from the concourse around the pool to the underside of the effective ceiling which is profiled, with roof lighting and high and low levels. Tiered seating is provided on each side and at one end of the pool.

Noise levels in the pool had been deteriorating over some years and the problem became critical towards the end of 1998. Mr Gary Penfold, General Manager of the Centre described the problem: "Aquarobics and swim classes couldn't hear their instructors, and school carnivals were chaotic. We were getting more and more complaints."

Warringah Shire Council sought an acoustic assessment in early 1999. PKA Acoustic Consulting was asked to investigate:

- Existing reverberation times
- Existing ambient sound levels
- Pre-existing reverberation times
- Recommended reverberation times

The investigation was based upon site visits, acoustic measurements, drawings and photographs provided by Council as well as computer modelling and general acoustic calculations.

2. TESTING EXISTING AMBIENT NOISE

The old noise baffles were removed before a noise data logger (Acoustic Research Laboratories type EL-015) was set up on top of the fire hose reel cupboard next to the Manager's Office at one corner of a mezzanine level around the pool. The logger was set to update every 15 minutes and to operate from 5pm (1700 hours) on Friday, 5 March 1999 until 9.30am (0930 hours) on Friday, 12 March 1999.

Inspection of the graphs and figures indicated that the highest noise levels were recorded on the evening of Friday, 5 March, between the time the logger was set up and 11pm (2300 hours). The L_{Amax} (maximum RMS Sound Pressure Level) was 106.5 dB(A) during this period and the other parameters were:

L_1	102.0 dB(A)
L_{10}	95.4 dB(A)
L_{Aeq}	91.0 dB(A)
L_{90}	84.5 dB(A)

Other periods when L_{Amax} reached over 100 dB(A) were Saturday evening (103), Monday daytime (102), Tuesday daytime (103), Wednesday daytime (103), Thursday daytime (104).

From these measurements, it is obvious that noise levels in the pool centre were extremely high and close to being unacceptable under the requirements of Worksafe Australia, namely 85dB(A) for eight hours.

Using the data logger information, the noise exposure level was calculated as follows for representative eight-hour periods during each day.

	9am - 5pm L_{Aeq} dB(A)	2pm - 10pm L_{Aeq} dB(A)
Saturday, 6 March	76	79
Sunday, 7 March	74	73
Monday, 8 March	83	81
Tuesday, 9 March	82	78
Wednesday, 10 March	83	80
Thursday, 11 March	83	78

On three occasions, employees were exposed to 83 dB(A), just below the statutory 85 dB(A) L_{Aeq} limit.

Reverberation times in the enclosed pool were determined using large 800mm inflated balloons that were pricked with a pin, the resulting burst being recorded through a Sennheiser "Dummy Head" microphone system onto a Sony DAT recorder type TCD-D7.

3. ANALYSING THE ACOUSTIC TESTS

The recordings were analysed by audio input into a computer. The digital recordings were transferred to computer wave files and analysed using SIA Smart-Pro to obtain the octave banded reverberation times for the pool enclosure.

The following results were obtained:

Octave band centre freq (Hz)	125	250	500	1k	2k	4k
Reverberation time (seconds)	6.0	6.0	6.4	6.6	6.5	5.0

Reverberation times in the enclosed pool after baffles were originally installed were estimated as an average of about 2.5 seconds, based upon descriptions provided by pool staff together with photographs of the original acoustic treatment.

If the reverberation time could be reduced from 6 seconds to about 2.3 seconds, the maximum sound level would be reduced by about 4 dB, from 83 to 79 dB(A).

Following this analysis, PKA Acoustic Consulting submitted a report to Warringah Shire Council recommending the installation of 672 baffles below the ceiling in Stage 1 of a noise reduction program. The report predicted that reverberation would be reduced to 2.16 seconds. The report went on to recommend the installation of a further 318 baffles in Stage 2 if noise levels could not be reduced to a satisfactory level in Stage 1.

Computer modelling on a Macintosh, running Bose Modeller Version 4.7, was used to assist in determining the extent and layout of acoustic absorbing material. Bose Modeller is a sound system design program usually used to place loudspeakers in a room or auditorium. PKA Acoustic Consulting has adapted the product to model predicted reverberation times versus actual. The dimensions and existing materials of the pool area were entered into the modeller and the existing reverberation times predicted. These agreed very closely with those measured, so no further adjustments to the model were necessary.

A variety of alternative sound absorbing treatments were then entered into the modeller and a number of permutations of acoustical treatments were tried.

Eventually, traditional baffles were recommended. These were constructed of powder-coated metal perforated on both faces and the edges, with infill of medium-density glasswool. Each baffle, measuring 1200mm long by 1000mm high and 110mm thick, was covered with 50-micron black polythene sheeting to prevent deterioration by moisture. Deterioration of the original baffles had, to some extent, been caused by moisture in the swimming centre. Low frequency noise absorption is slightly enhanced by the polythene sheeting while mid and high frequency absorption is reduced.

The deduced acoustic performance of the baffles per square metre of surface area was:

Octave-band centre freq (Hz)	125	250	500	1k	2k	4k
Absorption coefficient (sabins)	1.03	0.67	0.60	0.57	0.61	0.70

The completed design positioned 650 rectangular baffles to hang vertically, approximately 100mm below the ceiling around the pool. The layout is shown in Figure 1.

4. INSTALLATION

Warringah Shire Council called for tenders to supply baffles and install them as recommended by John Andrew's report. The successful tenderer, Alliance Noise & Energy Management, recommended a number of changes to the original concept outlined by Council. A key recommendation

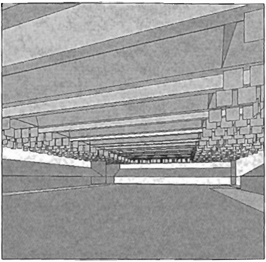

Figure 1 Computer-generated perspective view showing recommended positions for the baffles at Warringah Aquatic Centre. In fact, some baffles were moved from the rear of the building and suspended over the pool.

was to suspend the baffles on brackets hooked over the skylight openings rather than drilling masonry anchors into the reinforced concrete roof which presented a risk of moisture damage in the long term. Alliance also recommended a novel approach to installation. The workers would enter the building from the roof, lifting off skylights and working from suspended gantries rather than from scaffolds and hydraulic lifts within the pool enclosure.

Two working platforms were designed and built, then lowered through the skylight openings travel along tracks below ceiling height. The gantries provided a safer option for installation workers than scaffolds or lifts and allowed work to be undertaken without interfering with normal activity in and around the pool, if desired. The gantry system provided the managers of the centre the option of remaining open throughout the installation process. In the end, however, management decided to close the pool during September and October 1999 to undertake comprehensive refurbishment, including replacing tiles, doors and the skylights in the roof. The gantries allowed all this work to go ahead simultaneously. It also allowed the installer to place some baffles directly over the pool, which had not originally been envisaged in Stage 1 of the PKA report. Some of the baffles originally specified to hang in an area immediately above tiered seating were moved to the area above the pool.

Spacing of the baffles varied, partly because of the roofing design and partly to accommodate other items suspended from the roof, such as lighting and public address fixtures. Three basic spacings were approved: two metres and four metres along the length of the pool and approximately 3.5 metres across.

Suspension of the baffles was achieved by a system of specially fabricated brackets, T-bars and stainless steel wires. Fabrication of the majority of components was done off site to reduce time on site. With corrosion of the original baffles in mind, Alliance heavily anodised the aluminium components and inserted nylon bushes between all aluminium and stainless steel connections to prevent electrolysis.

"The Alliance design solutions were imaginative and appropriate for us, both in terms of installation methods and the final product," said Gary Penfold. "It was important to us —given the other work going on at the same time—that the installation teams were professional, thorough and solution-oriented. They were working with other teams around them at all times, as well as teams of workers refurbishing all the change rooms and replacing virtually every door in the Centre."

"The new system has transformed the Centre," said Mr Penfold. "Before the new baffles were installed, we could not have a normal conversation around the pool," he said. "Everyone had to shout to be heard as the noise reverberated. Now, the Centre is a much more pleasant environment. We can talk in quite normal tones."

John Thornton, Managing Director at Alliance Noise & Energy Management, said: "The Warringah Aquatic Centre had a noise problem that is not unique. Our challenge was to ensure a long-term and aesthetically pleasing solution that we could erect with a minimum of fuss. When people are working 10 metres above a concrete floor or pool, safety is a major issue. Developing the working platforms solved both the safety issue and made the work much more simple than scaffolding or hydraulic lifts."

5. CONCLUSION

PKA Acoustic Consulting returned to the Centre at the end of November to complete a new set of reverberation measurements.

The test demonstrated that noise levels were consistently lower around the pool, with reverberation times averaging between 2.1 and 2.3 seconds throughout the eight locations. Across the octave band, reverberation times ranged from 1.4 seconds at 125Hz in one location to 2.7 seconds at 1,000 Hz at another.

Octave-band centre freq (Hz)	125	250	500	1k	2k	4k
Reverberation time (seconds)	1.6	2.2	2.4	2.5	2.4	2.0

The overall average reverberation time was 2.19 seconds with 650 baffles installed, compared with the prediction of 2.16 seconds with 672 baffles.

The desired result had been achieved in a single stage.

News...

ACOUSTICS 2000

ACOUSTICS 2000, Putting the Science and Technology to Work, will be held at Joondalup Resort, Western Australia, 15-17 November 2000. This AAS Conference marking the turn of the century, will be a time to consider how well the acoustics profession is serving the community in applying the best available science and technology. The emphasis of the Conference will be on practical applications of acoustical science and technology and practical solutions to acoustic problems.

The keynote speaker for the conference will be Professor Bill Kuperman, Director of the Marine Physical Laboratory at Scripps Institution of Oceanography in the USA

Typical subjects will include: architectural acoustics, environmental noise, occupational noise, engineering noise control, speech and hearing with a substantial session on underwater acoustics. There will be workshops on active noise control and on environmental noise monitoring. A technical tour has been arranged to the HMAS Stirling Navy Base at Garden Island.

The Conference will commence on Wednesday evening, 15 November, with registration and an informal social function. Sessions of papers and workshops will run on Thursday and Friday morning, with a site visit to Garden Island on the Friday afternoon. The Conference Dinner will be held on the Thursday evening.

Critical date for Abstracts is 31 July 2000 and for Final Papers is 8 September 2000.

Registration fee is $300+GST before 20 October 2000 rising to $350+GST. For Students the fees are $200+GST and $230+GST respectively.

Further information from
http://www.users.bigpond.com/Acoustics/ or Australian Acoustical Society, WA Division, PO Box 1090, West Perth, WA 6872, Australia, Tien Saw tel (08) 9458-0028, tiens@barclayeng.com.au
See insert this issue.

ACOUSTICS 2001

ACOUSTICS 2001 will be held in Canberra from 21-23 November 2001. This conference will take a theme related to its location in the city which is the centre of Government for Australia. Information about this conference will be available from the AAS http://www.users.bigpond.com.au/Acoustics/

WESTPRAC VII

WESTPRAC VII, the seventh Western Pacific Regional Acoustics Conference, will be held in Kumamoto Japan from 3 to 5 October, 2000. The city of Kumamoto is about two hours from Tokyo by air and about two hours from Fukuoka International Airport By Express Bus or Train.

The presenters for the plenary lectures will be Neville H. Fletcher from Australia and Keniti Kido from Japan. The distinguished lecturers Masakazu Konishi (U.S.A), Hugo Fastl (Germany), Koeng-Mo Sung (Korea) and Seiichi Yamamoto (Japan). The topics for the contributed papers will include a broad range of topics including general acoustics, noise and vibration, ultrasonics, architectural acoustics, underwater acoustics etc. In addition there will be a technical exhibition and a social program.

Further information from
http://cogni.cs.kumamoto-u.ac.jp/westprac7/ or WESTPRAC VII, Department of Computer Science, Kumamoto University, 2-39-1 Kurokami Kumamoto, 860-8555, Japan, fax: +81 96 342 3630, westprac7@cogni.cs.kumamoto-u.ac.jp

NOISE-CON 2000

NOISE-CON 2000, the 2000 National Conference on Noise Control Engineering will be held at the Newport Beach Marriott Hotel in Newport Beach, California on 2000 December 3-5. NOISE-CON 2000 is being organized as a joint meeting by the Institute of Noise Control Engineering of the USA (INCE/USA) and the Acoustical Society of America (ASA). It will be held in conjunction with the 140th meeting of the Acoustical Society of America on December 4-8.

NOISE-CON 2000 will open on Sunday, December 3 with parallel technical sessions, a plenary session, and a reception. Joint technical sessions on December 4 and 5 will be held concurrently with ASA technical sessions.

Further information from
http://users.aol.com/inceusa/ or Acoustical Society of America 2 Huntington Quadrangle, Suite 1N01, Melville, NY 11747-4502 fax: (516) 576 2377, asa@aip.org

Internoise 2001

Internoise 2001, the 30th International Congress on Noise Control Engineering to be sponsored by I-INCE, the International Institute of Noise Control Engineering, will be held in The Hague, The Netherlands (or Holland), on 2001 August 27-30. The theme of Internoise 2001 will be Costs & Benefits of Noise Control. The Hague is within 30 minutes by taxi or by train of the International Amsterdam Airport Schiphol.

Technical papers in all areas of noise control engineering are welcome. A technical exhibition will include acoustic materials, passive and active devices for noise control, software for acoustical instruments and analyses, noise measurement instruments such as sound level meters, sound intensity analysers, sound and vibration spectrum analysers and noise monitoring equipment.

The key dates are: abstract submission by 1 December 2000, notification of acceptance 1 February 2001 and manuscripts by 1 May 2001.

To receive regular email updates on the conference you can register with listserv@dto.tudelft.nl with *subscribe internoise* in the body of the email.

Further information from
http://www.internoise2001.tudelft.nl or Congress Secretariat, P.O. Box 1067, NL-2600 BB Delft, The Netherlands, fax +31 15 2625403, secretary@internoise2001.tudelft.nl

Bid for Internoise 2003

The SA Division of the AAS is putting in a bid to host the Internoise 2003 conference in Adelaide for December 1-3, 2003. Peter Teague will be presenting the bid proposal at this year's Internoise in Nice at the end of August. The proposed theme for the conference is "Environmental Noise and Vibration" and the proposed conference president/chairman is Prof. Colin Hansen. The organising committee will include local SA members of the AAS that are researchers or consultants in acoustics/noise control in addition to representatives from the EPA. The proposed venue is Adelaide University (where the 5th ICSV conference was held in 1997) and we expect to attract over 600 delegates to Internoise 2003. Our bid will be competing with bids from South Korea and Singapore. The winner will be announced at the end of this year's Internoise conference.

ICSV8

The Eighth International Congress on Sound and Vibration sponsored by IIAV, the International Institute of Acoustics and Vibration, will be held in the Hong Kong Special Administrative Region, China, from 2 to 6 July 2001. IIAV is an international non-profit scientific society affiliated to the International Union of Theoretical and Applied Mechanics (IUTAM). IIAV is currently supported by 30 national and international scientific societies and organizations. The Hong Kong Polytechnic University and the Hong Kong Institute of Acoustics are the organizers of the Congress.

The Eighth International Congress is part of a sequence of congresses held in the USA (1990 and 1992), Russia (1993 and 1996), Canada (1994), Australia (1997), Denmark (1999) and Germany (2000), each attended by several hundred participants worldwide.

The key dates are: abstract submission by 1 December 2000, notification of acceptance 15 January 2001 and manuscripts by 15 April 2001.

Further information from http://www.iiav.org or ICSV8, Dept Mechanical Engineering, Hong Kong Polytechnic University, Hunghom, Hong Kong, China, fax: +852 2365 4703, mmicsv8@polyu.edu.hk

17th ICA

The 17th International Congress On Acoustics will be held in Rome, Italy, 2-7 September 2001. The congress will be held at the Engineering Departments in San Pietro in Vincoli, next to the Colosseum, in the centre of Rome. A preliminary application form is available via the www and the pages will be regularly updated.

Further information from http://idac1.idac.rm.cnr.it/ica2001/ or Secretariat, ICA 2001, Dipartimento di Energetica, University of Rome "La Sapienza", Via A. Scarpa, 14 - 00161 Rome, Italy. fax: +39 06 4976 6932, ica2001@uniroma1.it

Euronoise 2001

In continuation of earlier Euro-noise conferences held in 1992 in London, in 1995 in Lyon and in 1998 in Munich, the fourth European Conference on Noise Control, Euronoise 2001, will be held in Patras from January 14 to January 17, 2001. The Conference is being organised by the Laboratory of Fluid Mechanics and Energy (LFME) of the University of Patras, Greece in cooperation with the European Acoustics Association (EAA).

The central theme of the Conference is Acoustic Materials and Systems for Noise Control. Besides the distinguished lectures, oral and poster sessions, several special mini-symposia and workshops, initiated and structured by recognized experts, will be organized. Also, an exhibition will be held along with the Conference. The Conference language will be English.

Further information from http://euronoise2001.upatras.gr/ or LFME: Laboratory of Fluid Mechanics and Energy, University of Patras, P.O.BOX 1400, 26500 Patra, Greece, fax: +30 61 996344 euronoise2001@upatras.gr

STANDARDS AUSTRALIA

International Standards developed by ISO (the International Organization for Standardisation) and IEC (the International Electrotechnical Commission) are important in establishing the technical foundation for the global market. ISO and IEC Standards are widely adopted at the national (or regional) level and used by manufacturers, trade organizations, purchasers, testing laboratories, consumers and others, thereby playing an important role in the removal of technical barriers to trade. As a signatory to the World Trade Organization's Agreement on Technical Barriers to Trade, Australia is required to adopt international Standards as the basis for national Standards where possible, and to participate actively in international standardisation activities.

Many international acoustics Standards are developed under the auspices of ISO Technical Committee (TC) 43 Acoustics and IEC/TC 29 Electroacoustics. Standards Australia committees are invited to comment on draft Standards and subsequently vote on the proposed international Standard, often with a view to subsequent adoption in Australia. In areas where there is particular Australian interest in international standardisation activities, an Australian expert is nominated as a member of the relevant ISO or IEC working group and plays an active role in drafting the international Standard .

ISO and IEC working groups are increasingly using electronic tools to develop and discuss drafts, thereby avoiding the expenditures involved in attending international meetings. IEC is the first major global Standards body to implement "electronic" Standards preparation, and anticipates meeting its target of a 100% electronic environment by January 2001. ISO has recently introduced Livelink, a web-based tool that enables working group members who are geographically dispersed to work on projects as a team. Despite the progress in electronic working, face-to-face meetings are still required at critical stages of most Standards development projects. Both ISO/TC 43 and IEC/TC 29 will be holding meetings in Newport Beach, California, in December 2000, and several Australian delegates are expected to attend.

One area of particular interest to Australia is the development of the proposed IEC 61672 Electroacoustics-Sound level meters. It is expected that the Standard will comprise three parts, Part 1: Specifications, Part 2: Conformance test methods, and Part 3: Periodic tests. Part 1 has been circulated to national committees for vote, and a draft of Part 2 has been circulated for comment. The Australian response to IEC will be developed based on input from Committee AV-002 Acoustics, Instrumentation and Measurement Techniques, following the advice of the Australian expert on the IEC working group on sound level meters. It is anticipated that once IEC 61672 is published, AV-002 will consider adopting this Standard as a replacement for AS 1259 Acoustics-Sound level meters.

Australia has representatives on a number of other ISO and IEC working groups, including ISO/TC 43/SC 1/WG 17 Methods of measurement of sound attenuation of hearing protectors, ISO/TC 43/SC 1/WG 43 Procedure for describing aircraft noise heard on the ground, ISO/TC 43/SC 1/WG 49 Assessment of noise annoyance by means of socio-acoustic surveys, ISO/TC 43/SC 2/WG 18 Sound insulation of buildings, and IEC/TC 29/WG 17 Sound calibrators-Test procedures. All the Australian representatives are also members of Standards Australia, thereby facilitating dissemination of information on international activities to within Australia, as well as providing a focal point for communication of Australian views to international working groups.

Inquiries relating to the above activities should be directed to Jill Wilson, Projects Manager, Environment, Materials and Consumer Standards Australia, GPO Box 5420, Sydney, NSW 2001, phone (02) 8206 6821, fax (02) 8206 6022, e-mail jill.wilson@standards.com.au.

Expressions of Interest for Committees

The Australian Acoustical Society is represented on a number of Standards Australia Committees by members working in fields of acoustics related to the committees work. It is important that the Society continues to be represented on Standards Committees by members and that they provide feed-back on the activities of the Committees.

A vacancy has arisen in the AV/2 Committee - Acoustics - Instrumentation and Measurement Techniques and AV/3 Acoustics - Human Effects.

Any member who would like to nominate for either of these two committees are invited to provide a brief description of their experience in these particular fields and return it by 30 September 2000 to the General Secretary, Australian Acoustical Society, PO Box 4004, East Burwood, Victoria 3151, watkinsd@melbpc.org.au

NSW Noise Control Regulations

Five years ago NSW Noise Control Regulations were substantially improved on previous legislation and covered a range of new issues reflecting the changing sounds that our community produces. The idea of regulating for noise was to provide the community with important thresholds of behaviour consistent with reasonable harmonious living in medium and high density settlement situations where specific situations could be identified and described. These are all obvious, dominate any local councils complaint registers and include animals, parties, noisy power tools, air conditioners, noisy vehicles, alarms, etc.

As most of these are controlled by councils it was important that they had adequate legislative tools to control them. These regulations have worked well and the current review has shown that few changes are needed. The noise source with the most impact continues to be motor vehicles and this problem has been approached in two ways.

Firstly there was a need for better strategic thinking on the whole question of transportation corridors vs residential areas. This was best dealt with using flexible policy guidelines backed up with statutory controls on whatever agreed outcome was arrived at by using the policy procedures.

The second approach was to limit individual vehicle noise and this has been achieved through the regulations. One important change to the current proposal, brought about through finding a loophole in the current controls is to require all motor cycles to have appropriate noise levelling stamped on the muffler. This is to ensure that the exhaust system passed at the annual registration test is the same (or as good) as the one inspected on the road - and allows enforcement officers to do a quick sight check without having to conduct a time consuming noise test.

The other significant change is to introduce a sight test on proper muffler systems for all vehicles being sold as second hand - so the onus will be on the seller to have a quiet vehicle. Again this makes enforcement easier. The overall theme in proposed changes is to make enforcement easier and more effective.

The proposed regulations are due to become law on 1 September 2000.

Roger Treagus

Rail Noise Policy

The NSW EPA is to start a major review on rail noise policy late 2000. It will cover all rail systems, public and private, locomotive types, light rail and very fast rail, and also cover the relationships and responsibilities between the various stakeholders. To start the process off, the EPA will be inviting stakeholders to provide their ideas as to what should go into the policy. The complex nature of rail administration suggests the importance of a very strong liaison component to the development so that any outcome will be supported by industry as well as the community. The general philosophy to be followed will be the same as that for previous policies - i.e., the establishment on an environmental goal and with procedures put in place to ensure either the attainment of the goal or an approach to the goal as closely as practicable. The view would always be for the community to be given adequate protection. The review may take up to a year and include a study on practices in other jurisdictions.

Roger Treagus

Wind Tunnel Meeting

The Victorian Division Meeting on May 2 took the form of a site visit to the Royal Melbourne Institute of Technology, Bundoora campus to inspect the wind tunnel. The RMIT Vehicle Aerodynamics Group, which has been investigating the aerodynamic noise generated by wind around motor car bodies, both on-road and in wind tunnels, has made much recent use of this tunnel.

The meeting began with the group leader, Simon Watkins, describing the interior noise generated by wind passing over and around motor vehicle surfaces, especially at body shape discontinuities such as at corners (eg, the corner pillars at each side of the windscreen) and at mirrors and radio aerials. While the on-road tests, and also some made in the Monash University wind tunnel, involved the vehicle bodies in a turbulent environment, those done in the RMIT wind tunnel were done in a smooth airflow, minimum turbulence environment, because under these conditions the interior noise showed maximum response from the body discontinuities and reduced the background noise from general turbulence.

Some examples of the frequency spectra and conditions obtained under wind tunnel (smooth flow) and atmospheric conditions (much turbulence) showed that the interior body noise was broad band from around 200 to 1000 Hz, and not obviously related to interior body resonances. While noise from wind around exterior mirrors still showed as broad band, only noise due to exterior objects of small cross section area, such as aerials, produced tonal components. Interior body resonances were found to be excited by disturbances such as wind for slightly open windows.

Then Juliette Milbank described the small-scale low noise wind tunnel which was constructed for developing the noise-reducing materials and shape of the baffles, screens, etc required for minimizing tunnel fan and wind noise and turbulence. Those present inspected the full-scale and small-scale tunnels to see the actual measures used to achieve this noise and turbulence reduction.

Louis Fouvy

Sound Demonstration

The NSW Division held a technical meeting on the evening of 21 June 2000 at the premises of CSR's Commercial Design Centre in Pyrmont. After a brief introduction from CSR's Technical Support Manager, Michael Ryan, an update on the forthcoming changes to sound insulation criteria in the BCA was given by Consultant Peter Knowland. Following this a rare chance was had by all to experience being on either side of walls with STC's of 35, 45, 50 and 55. The four individually sealed rooms have been set up to enable various sound sources such a home movie sound, rock music, dinner party noise and traffic to be heard, at the same volume, on both sides of the walls. It was generally agreed that an STC of 45 was inadequate for all sound sources and even 50 was not considered adequate particularly for the home movie sound track and rock music. Peter concluded by reminding us all of the four factors involved in setting standards for good sound insulation: the sound transmission of the walls; the sound level in the source room; the background noise level in the receiver room; and the character of the sound source. The combination of Peter's many years of experience and CSR's practical demonstrations provided an enjoyable and educational meeting.

Ken Scannell

Search for Dome Souvenirs

The Australian Academy of Science has launched a search for souvenirs of the Dome, which is the Academy of Science landmark in Canberra. They are seeking souvenirs that may have been collected some time ago on school trips or holidays. They are hoping that people across Australia will donate those marvellously kitsch ashtrays, place mats, fridge magnets, etc that feature an image of the Dome. The souvenirs will first be displayed at the Canberra Museum and Gallery and then on a rotating basis in the Dome. If you have some suitable material then send it to Dome Souvenir Search, Aust Academy of Science, GPO Box 783, Canberra ACT 2601.

Acoustics Award

INC offers an exciting challenge within the acoustics industry with the creation of the DECI-TEX Innovation In Acoustics Award. Entries in this competition must design, develop, or use DECI-TEX Acoustic textiles in an innovative application. Not every idea is totally original. Even if your idea has been mentioned in applications for the product, there is still scope for originality.

INC Corporation Pty Ltd has pioneered the development of Acoustic Textiles. The DECI-TEX range commenced 4 years ago. Since then, INC has continued to develop innovative products for a diverse range of acoustical applications. The technology is not only cost effective, but provides excellent acoustic benefits. These innovative products are user friendly, can replace the traditional bulk insulation materials and can enhance the absorption performance of foams, fibreglass, mineral wool, polyester, felt and fabrics.

To enter the competition, register your interest by requesting a DECI-TEX information pack on CD. Entry is open to individuals and companies that practice in the field of acoustics and the deadline is the end of October. *For more information INC, 22 Cleeland Road, Oakleigh South Vic. 3167 Australia, tel (03) 9543 2800, fax: (03) 9543 8108, decitex@inccorp.com.au*

President of IIAV

At the Annual General Meeting of the International Institute of Acoustics and Vibration (IIAV), held on July 3, 2000, Professor Colin Hansen of the Department of Mechanical Engineering, Adelaide University, became the third President of IIAV, succeeding Dr Hanno Heller of Germany. He was elected by a vote of the general membership which comprises almost five hundred acoustics and vibration specialists from more than fifty four different countries.

The founding President was the late Sir James Lighthill of the UK, who, together with Professor Malcolm Crocker, laid the foundation for the organisation that we see today. Professor Hansen's primary goals during his term of office include fostering better relations with other acoustics and vibrations organisations, working to expand the membership base of the IIAV and making sure that the IIAV continues to sponsor high quality annual conferences that offer interesting and enjoyable social and cultural activities as well as a strong technical program.

Young Professional Engineer of the Year has been awarded to James Moody from Vipac Engineers and Scientists. Twenty three year old James is a satellite designer and has been employed with Vipac since March 1999. He is working as systems engineer in the Vipac team working on the design and integration of the FedSat Satellite, the first Australian satellite to be launched in 30 years.

Acoustic Research Laboratories have launched a new website at www.acousticresearch.com.au. The new site is regularly updated with information on the Rion range of sound and vibration measuring instruments and the Australian manufactured noise and vibration loggers from ARL. Links are provided from the site to various other useful sites. *Further Information: Acoustic Research Laboratories. tel 02 9484 0800 fax 02 9484 0884*

Letter...

I am currently compiling an account of acoustical activities in Victoria. Amongst the numerous source documents required for this work are the AAS Conference Proceedings. I would be glad to hear from any readers who have any of these from 1968 onwards and no longer need them or who know of their location. Please contact me by phone on 03 9817 1881, or at 241 Cotham Rd, Kew, 3101.

Louis Fouvy

Book Review

Recreational Noise Effects on Man and on the Environment

International Institute of Noise Control Engineering, 1999, pp 120, hard cover, Distributor INCE(NZ) Ltd, P O Box 57032, MANA 6230, Wellington, New Zealand, tel +64 4 233 2066, fax +64 4 233 2017, philip_d@iconz.co.nz. Price, including postage, NZ$135 or US $75 or A$115.

This bound volume comprises the papers presented at the International symposium on Recreational Noise held in Queenstown, NZ following the Internoise 98 conference. It has been published in collaboration with Noise Control Engineering Journal so the format of the papers is consistent with that Journal's requirements. This also explains why the pagination of the volume commences from page 79.

The 23 papers, each between four and six pages cover a range of topics from the noise of aircraft overflights through motor racing and other ground based activities on to pop music and theme parks. The first paper by Louis Sutherland sets the scene by focussing on how to measure, evaluate and conserve natural quiet. These three aspects, as related to various types of noise generated by recreational activities, are addressed in the papers. Six of the papers discuss the effects of the noise that is an essential part of the experience of a theme park and disco music.

A special time was set aside in the symposium program for discussion groups for the main streams. A summary of the points raised in these discussion groups is provided in the volume along with the list of attendees.

This volume consists mainly of contributed papers and so cannot be expected to cover all the aspects which are relevant to recreational noise. However it does form a valuable record of the papers and the discussion at the symposium and would provide useful information for those dealing with recreational noise issues.

Marion Burgess

Marion Burgess is a Research Officer at the Australian Defence Force Academy and attended the Symposium.

New Members

NSW		
Member	Mr Thomas Mitchell, Mr Grant Haigh	
QLD		
Member	Mr David Davis	
VIC		
Member	Mr Jim Antonopoulos	
Graduate	Ms Emily Hulce	
SA		
Member	Mr Neil Mackenzie	
Subscriber	Mr Lee Piekarski, Mr Dennis Batge, Mr Rory Hughes, Mr Ian Phillips, Mr Darren Marinoff, Mr John Dunsford, Ms Maryann Woods, Ms Margaret Thompson, Ms Jennifer Corkhill, Mr Marc Simpson, Mr Kar-Khee Lee, Mr Ronald Churchill	
Student	Ms Jacqueline Munn, Mr Nicholas Burgan, Mr Colin Kestell	

Diary...

2000

Sept 17 - 21, VILNIUS
1st Int Conf (10th Anniversary).
Details: Acoustical Soc Lithuania, Kriviu 15-2, 2005 Vilnius, Lithuania; Fax: +370 2 223451; daumantas.ciblys@ff.vu.lt

October 3-5 KUMAMOTO
WESTPRAC VII
Details: Dept Computer Science, Kumamoto Uni. 2-39-1 Kurokami, Kumamoto, 860-0862. Tel: +81 96 3423622 Fax: +81 96 3423630 westprac7@cogni.cs.kumamoto-u.ac.jp
http://cogni.cs.kumamoto-u.ac.jp/ westprac7/

October 16-20 BEIJING
6th Int. Conf. on Spoken Language Processing
Details: ICSLP 2000 Secretariat, Institute of Acoustics, PO Box 2712, 17 Zhong Guan Cun Rd, Beijing 100 080, China, Fax: +86 10 6256 9079, mchu@plum.ioa.ac.cn

*** November 15-17 PERTH**
Acoustics 2000
Putting the Science and Technology to Work
AAS Annual Conference
Details:
http://www.users.bigpond.com/Acoustics/ or AAS-WA, PO Box 1090, West Perth, WA 6872, Tien Saw tel (08) 9458-0028, tiens@barclayeng.com.au or Daniel Lloyd tel (08) 9321-520 dlloyd@ermperth.erm.com.au

December 3-5, NEWPORT BEACH
NOISE-CON 2000
Details: http://users.aol.com/inceusa/ or ASA, 2 Huntington Quadrangle, Suite 1N01, Melville, NY 11747-4502 fax: (516) 576 2377, asa@aip.org

December 4-8, NEWPORT BEACH
Meeting of ASA
Details: ASA, ASA, 2 Huntington Quadrangle, Suite 1N01, Melville, NY 11747-4502 USA. Fax +1 516 576 2377, asa@aip.org

***December 4-7, Canberra**
8th Aust Int Conf Speech Science & Tech, SST-2000
Details: SST-2000, School of Computer Science, ADFA, Canberra ACT 2600, spike@cs.adfa.edu.au
http://www.cs.adfa.edu.au/sst2000

2001

January 14 -17, PATRAS
EURONOISE 2001
Details: http://euronoise2001.upatras.gr/ or LFME: Laboratory of Fluid Mechanics and Energy, University of Patras, P.O.BOX 1400, 26500 Patra, Greece, fax: +30 61 996344, euronoise2001@upatras.gr

June 4-8, CHICAGO
141th Meeting of ASA
Details: ASA, 500 Sunnyside Blvd, Woodbury, NY 11797-2999, USA, Fax: +1 516 576 2377, Web: asa.aip.org

July 2-6, Hong Kong.
8th ICSV
Details: Dr K M Li, Dept Mechanical Engineering, Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, Fax: + 852 2365 4703, http://www.iiav.org/ mmicsv8@polyu.edu.hk

Aug28 - 30, THE HAGUE
INTER-NOISE 2001
Details: http://www.internoise2001.tudelft.nl or Congress Secretariat, P.O. Box 1067, NL-2600 BB Delft, The Netherlands, fax +31 15 2625403, secretary@internoise2001.tudelft.nl

September 2-7, ROME
17th ICA
Details: A. Alippi, 17th ICA Secretariat, Dipartimento di Energetica, Universitá di Roma "La Sapienza", Via A. Scarpa 14, 00161 Roma, Italy, Fax: +39 6 4424 0183, www.uniroma1.it/energ/ica/html

September 10-13 , PERUGIA
ISMA 2001 ,
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Details: c/o "Perugia Classico" - Comune di Perugia, Via Eburnea,9, I-06100 Perugia, Italy, Fax: +39 75 577 2255, perusia@classico.it

October 7 - 10, Atlanta
2001 IEEE Int Ultrasonics Symp joint plus World Cong on Ultrasonics.
Details: Fax: +1 217 244 0105; www.ieee-uffc.org/2001

*** November 21-23, CANBERRA**
Acoustics 2001 *AAS Annual Conference*
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L_{max}	with all time constants (F, S and I) and
L_{min}	with A-, C- and Flat-weighting.
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L_E	Except for L_{peak} these functions may also
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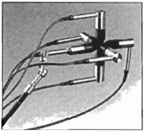

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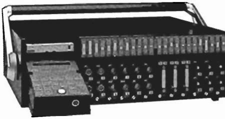

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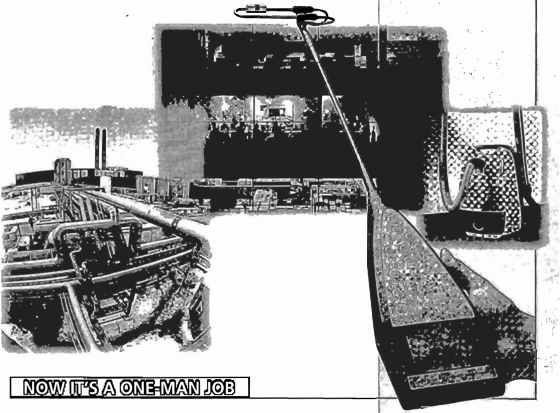

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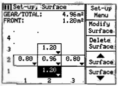

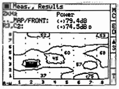

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