Acoustic Noise as a Non-Lethal Weapon

Roman Vinokur, Wieland Associates, California

In this article, fundamental issues related to acoustical warfare are analyzed. Such arms (powerful loudspeakers, stun grenades, acoustic cannons, etc.) belong to a class of non-lethal weapons utilized to control riots. Guidelines for the implementation and effectiveness of such weapons are reviewed.

Non-lethal weapons are an emerging class of arms employed to incapacitate rioters without inflicting permanent physical damage. The development of non-lethal weapons meets the civilized reverence for life and commitment to the use of minimum force. Many riots are carefully organized by faction leaders, and riot-control forces are commonly outnumbered by rioters who can be broken down into three basic groups: (1) a relatively small group of 'fighters' with small arms and anti-tank/antiaircraft weapons; (2) more numerous semi-armed rioters with clubs, sticks, knives and spears; (3) most numerous non-armed supporters (women, children, older men) who are not active in fighting and primarily serve as human shields for the 'fighters.'[1] For instance, the factions in Somalia utilized large groups of their women and children to screen the movements of gunmen and grenade throwers.

A non-lethal weapon is applied to make the non-armed and possibly semi-armed supporters pull away from the 'fighters' without being injured. Long ago, anti-riot police had already employed water cannons, chemical sprays and rubber bullets. In the 1990s, two new non-lethal weapons were introduced: (1) sticky foam to adhere one person to another person or to an object; (2) acoustic noise sources. The sticky foam allows violent persons to be subdued without injury but it has multiple drawbacks: (1) a relatively short range; (2) a large and bulky dispenser; (3) the front-rank rioters and police/soldiers can glue themselves together. Acoustic weapons (mainly loudspeakers and stun grenades) seem to provide more considerable opportunities for police and army units. However at this time, reliable information on the science and technology of such weapons is not fully described. Moreover, much of what is published on acoustic weapons in the media (in particular, about "acoustic bullets" and 'deadly' infrasound rays) is often based on hearsay and misunderstandings, leading to criticism by professional scientists (in particular, by Dr. Jürgen Altmann from Dortmund University, Germany[2,3]).

Case Histories on Acoustic Weapons

Stukas' Screaming Sirens. Ukraine, August 1941. Withdrawing Red Army troops, accompanied by multitudes of exhausted civilian refugees, were heading to the East. Suddenly German J-87 dive bombers (Stukas) appeared in the sky and began bombing and strafing the road, with their sirens loudly screaming for a greater psychological effect. The attacked people fell to the ground or ran amuck in panic. With the first salvo of bombs, the ground shook, many people were killed and wounded and the sparse anti-aircraft machine guns were annihilated. Several officers organized concentrated rifle volleys, including my father (then a Red Army lieutenant*) with seven or eight soldiers around him – all that remained of his automobile platoon after two months of war. At his command, the soldiers, lying on their backs, simultaneously discharged their rifles on the Stukas at the lowest point of their dives. Another ugly screaming Stuka, another rifle volley from the ground, another round of bombs. As a mechanical engineer and reservist officer (he volunteered for the regular army on the first day of the war – June 22, 1941), my father knew that such a counterattack could not be effective but it was the only available way to resist. The Stukas proved to be the most precise dive-bombers of WWII, but being relatively slow and not well armored, they became easy prey for high-speed fighters. Less than two years later, when Soviet fighters began to appear with increasing numbers, the Stukas that survived were restricted mainly to nocturnal operations.

Polovtsy's War Cries. "Slovo o Polku Igoreve" (1185) is a heroic poem about the daring counter campaign of the Russian Prince Igor against the Polovtsy (also known as Kumans or Kipchaks), Turkic steppe people, whose impetuous cavalry periodically devastated Russian lands.[4] Later this poem provided the subject for Russian composer Borodin's opera "Prince Igor."

> *The earth rumbles, the rivers flow with turbid stream, dust covers the plain, the banners announce: the Polovtsy are coming from the Don river and from the sea; on all sides they have surrounded the Russian hosts. The devil's children have barred the plain with their war-cry, and the valiant Russians have barred it with their scarlet shields . . . From dawn till evening, from evening till dawn, tempered arrows fly, sabers thunder against helmets, lances of Frankish steel crash in the unknown steppe amid the Polovtsian land . . . On the third day, towards noon, Igor's standards fell . . . For now, brothers, a sorrowful time has come, now the wild-growing steppe has swallowed up the Russian force . . .*

It should be noted that the Polovtsy won because of their numeric superiority rather than due to their shrill war cries, mentioned also in Greek and Arab historical documents. Prince Igor was wounded and captured by the Polovtsy but eventually escaped and organized a new army. The Polovtsy were later defeated and pushed to the west by the Tatars, mixed up with Slavs and other European peoples, and disintegrated as a nation.

Medieval Robbers' Whistle. Another use of acoustic noise as a weapon was described in the poem 'Bylina' relating the fictitious encounter between Il'ya of Murom, the Russian epic hero, and Nightingale the Robber (a fantastic creature, half bird of the forest, half man of the steppe).[4]

> *Il'ya of Murom rode off through the forests of Bryn. Nightingale heard the thud of the hero's horse and whistled loudly. The horse stumbled under Muromets . . . Ilya said to his good horse: "Have you never ridden through dark forests, have you never heard birds whistle?" Il'ya brought out his tempered arrows: he shot once – the arrow fell short; he shot a second time – he overshot his mark; he shot a third time – he pierced Nightingale's right eye and shot him down . . .*

This fable goes back to the twelfth century. However, actual robbers, found frequently in the Russian forests up to the eighteenth century, commonly utilized a stunning whistle to intimidate traveling merchants and their servants. The psychological effect was so significant that even the armed travelers preferred to give up with no resistance. However, the encounters with soldiers or hard-boiled policemen usually proved

* The author is a naturalized American citizen born in the former Soviet Union.

disastrous to the robbers (probably one of such events was colorfully depicted in 'Bylina').

Scots' War Trumpets. The Scots used a bronze-age instrument called the Carnyx, consisting of a long bronze tube terminated in a small horn fashioned in the shape of an animal's head with jeweled eyes and sometimes an articulated tongue. Carnyx players marched at the front of Scottish military formations. According to written accounts of the time, some Roman soldiers ran in terror from the horrible sound.[5]

The Biblical Trumpets of Jericho. Near Jericho, Moses had finally fulfilled his work to bring his people to the Promised Land. Before he died, he had nominated as his successor Joshua, a brave and gifted strategist. According to the Bible, it took Joshua just seven days to subdue Jericho. ". . . the people shouted with a great shout, and the wall fell down flat . . ."[6] However, the Bible does not clearly specify that the walls were destroyed just by the high-intensity acoustic waves. Most likely, there was more down-to-earth action in play. For seven days the attention of Jericho's defenders was occupied by the noisy procession of Joshua's army around the city, so they might not have heard Joshua's sappers secretly undermining the city's walls . . .

LRAD (Long Range Acoustic Device). This weapon is briefly described as a giant loudspeaker that can deliver a shrill 145 dB tone or booms over a distance of more than 300 m, causing headaches and panic. The sound is significantly more powerful than the scream of a standard smoke detector, and cannot be notably reduced by earplugs. The device is likely to be used for crowd control and 'clearing' buildings.[7]

Stun Grenades. Many hostage situations end when a SWAT team tosses stun grenades into a room to disorient the captors with a blinding flash and a very loud explosion. Existing stun grenades contain a concentrated mixture of aluminum and potassium perchlorate that combines violently with a salt containing oxygen when ignited by a fuse. While generally harmless, stun grenades can be harmful to hostages' eyes or ears.

Researcher Mark Grubelich and colleagues at Sandia National Laboratories in Albuquerque, NM, have come up with a kinder, gentler version of the stun grenade.[8] The new Sandia device contains only 20 grams of fine aluminum powder and no oxidizer. The particles ignite when they come into contact with oxygen in the air, spreading out like a cloud of pixie dust. This approach lowers the pressure in the immediate area of the explosion, making injuries less likely.

Letter from a Concerned Science-Fiction Fan. This Internet story does not seem credible but it illustrates the popular rumors on acoustic weapons.

> *". . . several years ago, my nephew was chosen to work on a research project at an area university . . . The project was for the government, and consisted of research into finding sound waves that could be used as weapons during combat. The project was successful. My nephew said that waves were found that could turn someone's brain to jelly in a matter of seconds. This has bothered me considerably, as I am a science-fiction fan, and some of the off-the-wall weapons in the futuristic space books I have read are becoming too real . . ."*

Biological Effects of High-Intensity Noise

In the short run, high-intensity noise is dangerous to the auditory and respiratory systems and provokes negative psychological effects (fear and panic).[2,3,9-11] The long-term effects (that last hours and more) are not discussed in this article.

Noise starts inflicting discomfort to the ears at 120 dB and pain at 140 dB in the audio region (from 20 to 20,000 Hz). Eardrum rupture occurs approximately at 160 dB. But with a nonperiodic blast wave, eardrum rupture begins at 185 dB – about 25 dB higher than in the case of periodic sound waves.

The short-term respiratory effects are strongest at low frequencies (50-100 Hz) and start from approximately 150 dB. With a nonperiodic blast wave, lung rupture begins at about 200 dB. So, in the case of periodic sound waves, it may be expected to start at about 175 dB.

The psychological effects largely depend on coexisting environmental factors (for example, a fire alarm in a building or a tiger's roar in the jungle). Moreover, the reaction of human bodies to the same noise can also be very different and even anomalous (for example, an experimental study done in Russia revealed that about 7% of cadets from one military engineering school that were tested performed better under high-intensity noise than in normal conditions[11]).

The following conclusions can be drawn for minimum and maximum sound pressure levels acceptable for a non-lethal acoustic weapon. The maximum sound pressure level should be under 160 dB to prevent eardrum ruptures among people whose ears are not protected. On the other hand, the minimum sound pressure level should be about 120 dB (taking into account that use of earplugs and earmuffs can reduce the level impinging upon the eardrums by 25 dB on average, and a short-term noise becomes severe over 90-95 dB).

Physiological Effects of Infrasound

For many years, infrasound was suggested to be an effective acoustic weapon because of its enormous effect on internal human organs and its ability to pass through the walls of buildings. The latter was proven both theoretically and experimentally. The former was based mainly on the experiments of the French scientist Vladimir Gavreau who attempted to build a low-frequency acoustic weapon after accidental exposure to infrasound.[12] While working in a concrete building that housed his laboratory, Gavreau and his co-workers periodically suffered from nausea. Eventually, he traced the problem to an improperly installed motor-driven ventilator activating an infrasonic resonance in the building. So, the ventilator actuated the infrasound, and the building interior worked as an infrasonic amplifier. The resonant frequency of that giant amplifier could have been controlled through opening or blocking the windows. In a similar phenomenon, a room with an opened window operates as a classical Helmholtz resonator where the window plays the role of the opening (see Figure 4).[13]

Gavreau believed he had discovered a new weapon – infrasound. He designed and tested infrasonic pipes, horns and whistles (the first one was about 2 m in diameter). The painful symptoms came immediately to Gavreau's laboratory team – hearts, lungs and stomachs were filled with continual painful spasms. Other results included musculature convulsions, spasms and tears. The invention held much favor in numerous popular books and papers. In one of the scientific fictions published for students in physics[14], the author (RV) also drew the readers' attention to the effects declared by Gavreau.

> *". . . sound with a frequency of less than 16 Hz is inaudible. It's called infrasound, and its effect on human beings is not completely understood. We do know, however, that high-intensity infrasound causes headache, fatigue, and anxiety . . . Our internal organs (heart, liver, stomach, kidneys) are attached to the bones by elastic connective tissue, and at low frequencies may be considered simple oscillators. The natural frequencies of most of them are below 12 Hz (which is in the infrasonic range). Thus, the organs may resonate. Of course, the amplitude of any resonance vibrations depends significantly on damping, which transforms mechanical energy into thermal energy . . . this amplitude decreases as the damping increases. Also, the amplitude is proportional to the amplitude of the harmonic force causing the vibrations . . ."*

However, the ensuing experiments exposed less drastic effects.[2,9,15-17] The results of two experimental studies are briefly described below:

1. Twenty healthy males (20 to 30 years old) were exposed to frequencies of 6, 12 and 16 Hz at sound pressure levels of 95, 110 and 125 dB for 20 minutes. Infrasound was observed to increase diastolic blood pressure – the most significant ef-

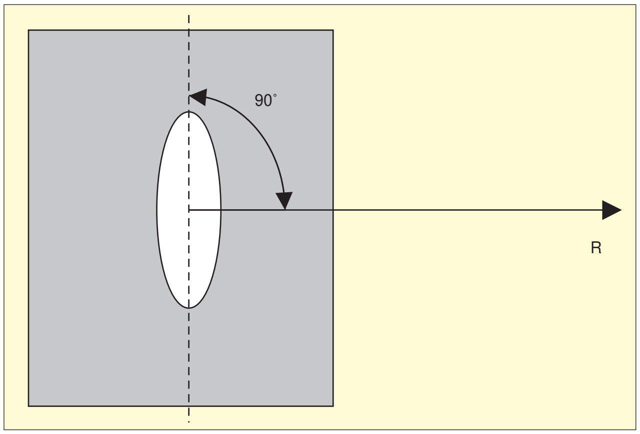

Figure 1. Radiation from a piston set in a plane wall.

fect was seen at 16 Hz, and the maximum mean increase of 8 mm Hg occurred after 30 minutes – and decrease systolic blood pressure and pulse rate.[16]

2. Four male volunteers (college age) were exposed to infrasound frequencies ranging from 1 to 20 Hz at levels of 120 to 144 dB for 8 minutes. All reported painless pressure build-up in the middle ear and experienced body vibration and voice modulation.[17]

Propagation of High Intensity Sound

The sound waves produced by acoustic weapons have to travel over some distance to reach their targets. As sound propagates in air, its energy is gradually attenuated principally due to geometric divergence from the sound source and absorption of acoustic energy in air through such molecular mechanisms as viscosity, thermal conductivity and relaxation processes.

Attenuation of Sound Due to Geometric Divergence. At low frequencies, geometric divergence is the main mechanism of sound attenuation. The ideal model is a piston of radius a in an infinitely hard wall (see Figure 1), vibrating with peak velocity u_0 and frequency f.[18] The infinitely hard wall doubles the amplitude of radiated acoustic pressure. If the wall were not present and the role of the piston is modeled as the open end of a pipe, the radiated sound is less but its physics process is approximately the same. In this case, the radiated sound intensity at a distance r in the axial direction (perpendicular to the piston) is given by equation

$$I(r) = \frac{\pi^2}{2}\rho c u_0^2 \left(\frac{a^2}{r\lambda}\right)^2 \qquad (1)$$

if $\lambda/a << 1$

$\rho \approx$ air density, 1.3 kg/m^3

$c \approx$ speed of sound in air, 340 m/s

λ = wavelength, c/f

As follows from Eq. 1, the acoustic pressure is relatively small at very low frequencies. Low-frequency (long wavelength) sound spreads out uniformly in all directions from the piston. But high-frequency sound is chiefly sent out perpendicular to the piston, with little beam spread. The geometric divergence makes the use of infrasound impractical for long-distance applications.

Attenuation of Sound Due to Absorption. For simplicity, consider just plain waves in order to neglect geometric divergence with distance. The attenuation of low-intensity sound is a linear process, described by an exponential relationship

$$\frac{I(r)}{I(r_0)} = e^{-\alpha(r-r_0)}$$

where $I(r)$ and $I(r_0)$ are the sound intensities at a distance of r and r_0, respectively; α is the attenuation coefficient that depends mainly on frequency ($\alpha \sim f^2$) and relative humidity and less strongly on temperature and ambient pressure.[9,19]

For example, at a temperature of 30° C and relative humid-

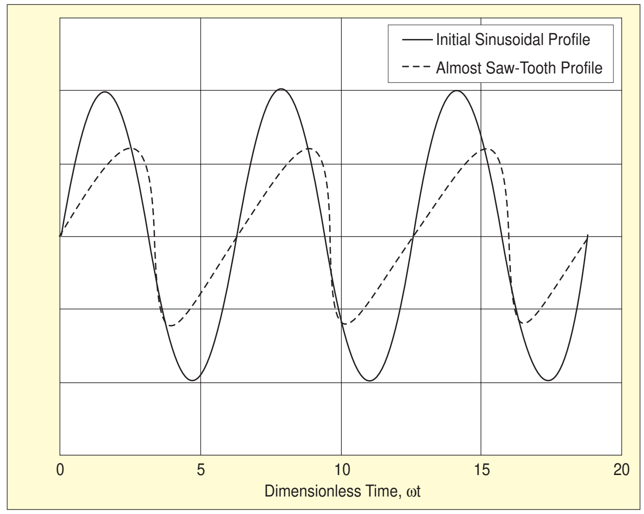

Figure 2. A high-intensity sinusoidal wave gradually changes with distance to a saw-tooth profile.

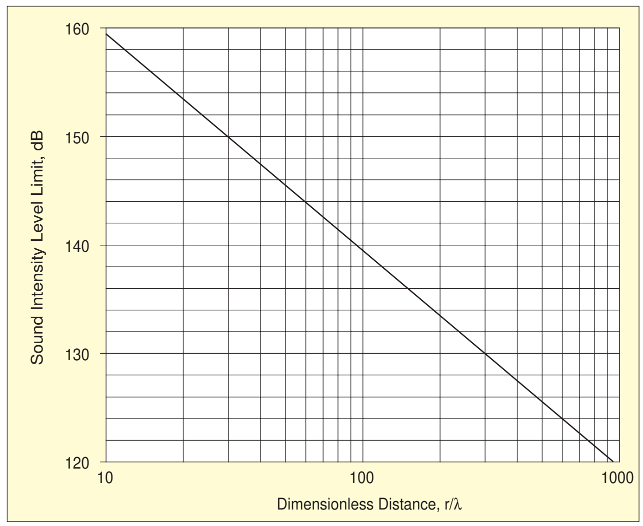

Figure 3. Sound intensity level limits, calculated using Eq. 2 and plotted to illustrate the effect of nonlinear absorption for a plain sound wave.

ity of 50%, the attenuation coefficient is 3.6 dB/km at a frequency of 500 Hz; therefore at a distance of 1000 m, the level decrease is negligible (just 3.6 dB). In general, the low-intensity sound absorption in air is linear and can be neglected at short distances from the source (less than several hundred meters) except for very high frequencies (over 5,000 Hz). The high-intensity sound propagation is nonlinear because the speed of propagation is not the same for the regions of higher and lower pressure. As a result, the waveform, being sinusoidal at the start, distorts to a saw-tooth (shock-wave) profile as shown in Figure 2. The nonlinear energy dissipation is much more extensive than the linear damping mechanisms and is not described by the exponential relationship. The sound intensity of a plain saw-tooth wave at a distance r from a source cannot exceed the limit value

$$I_{\lim}(r) = \frac{\rho c^3}{\left[\pi(\gamma+1)\right]^2}\left(\frac{\lambda}{r}\right)^2 \qquad (2)$$

where γ = 1.4 is the ratio of specific heats for air. For diverging spherical waves, the role of nonlinear absorption is less pronounced; so, Eq. 2 can be employed only as a first approximation. The limit sound intensity level

$$L(r) = 10\log\left[\frac{I_{\lim}(r)}{I_{00}}\right]$$

is plotted vs. dimensionless distance r/λ in Figure 3. The nonlinear absorption notably limits the efficiency of the "differ-

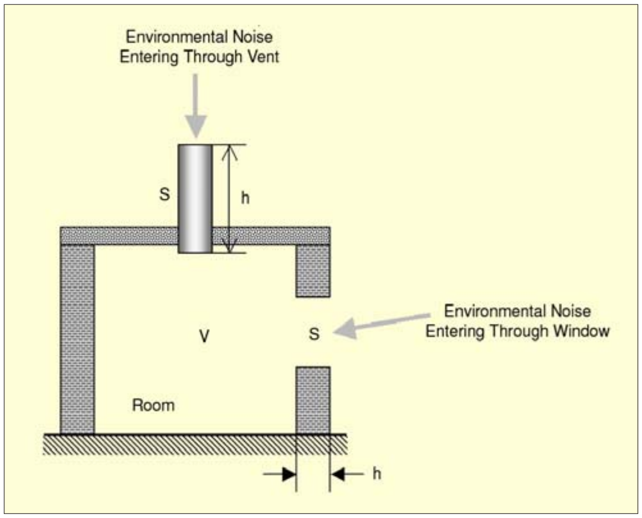

Figure 4. A room with a vent or open window can operate as a Helmholtz resonator at low frequencies.

ence frequency method" based on the nonlinear interaction of two high-frequency waves with frequencies f_1 and $f_2 \approx f_1$.[2,19] In the linear case, superposition of such waves would produce an amplitude-modulated wave. In the nonlinear case, the waves with the combination frequencies are produced and the most powerful component has a frequency of $\Delta f = |f_2 - f_1|$.

Sound Amplification Effects in Rooms. A simple Helmholtz resonator is a container of gas (usually air) with a small hole or open neck,[18,19] and a common example is an empty bottle. At low frequencies (if the acoustic wavelength notably exceeds the resonator's dimensions), the air in and near the neck moves like a solid mass compressing or expanding a spring (the air volume). If the air volume is V and the hole or flanged neck has cross-sectional area S, the Helmholtz resonant frequency is given by equation

$$f_H \approx \frac{c}{2\pi}\sqrt{\frac{S}{V\left(h+0.8\sqrt{S}\right)}} \tag{3}$$

where h is the neck length or (in case of a hole) the wall thickness. A room with an open window can operate as a Helmholtz resonator where the window functions as a hole.[13] A ventilation duct passing air from the room to atmosphere can also function as the Helmholtz resonator's neck (Figure 4). In particular, if: $V = 50$ m^3, $h = 0.1$ m and $S = 1$ m^3. Then Eq. 3 calculates that $f_H \approx 8$ Hz. The outside acoustic noise can be drastically amplified at the Helmholtz resonant frequency of a room because the loss factor of air volume is commonly low (0.01 in order of magnitude) at infrasonic frequencies. Such an effect can be employed to drive rioters out of a building by connecting an infrasound generator to the ventilation ducts and running it at the resonant frequency. Although the short-term biological effects of infrasound are less pronounced than indicated by Gavreau's experiments, the long-term effects can exhaust the rioters and weaken their ability to resist.

Optimization of Acoustic Weapons

Estimation of Distance Range. Both Eqs. 1 and 2 present the inverse square law relationship between sound intensity and propagation range. In reality, the attenuation should be even more rapid because Eq. 1 does not take into account sound absorption and Eq. 2 does not account for geometric divergence. However, for simplicity consider: (1) high-intensity sound attenuation follows the inverse-square-law $I \approx r^{-2}$; (2) the sound intensity level should be reduced by 40 dB (from 160 dB, near the source, to 120 dB).

Defining the near-source distance as r_{near} and the maximum distance as r_{far}, obtain

$$\frac{r_{far}}{r_{near}} = 10^{\frac{40}{20}} = 100 \tag{4}$$

The effective size of a typical sound source is about 1 m, so it is reasonable to suggest $r_{near} = 3$ m (the inverse-square-law attenuation starts from the distances exceeding the effective size of the source). From Eq. 4, we obtain $r_{far} = 3 \text{ m} \times 100 = 300$ m. Thus, the maximum distance range for non-lethal acoustic warfare is several hundred meters.

There are two main ways to overcome this limit: (1) to develop 'ugly' sounds that are effective even if their intensity level is below 120 dB; (2) to implement movable robots with loudspeakers. The latter also offers a safer 'work' environment for the acoustical operators.

"Sound Quality" Instead of Loudness. The "sound quality" concept grew from the understanding that noise level only reflects the loudness of a sound, but we must also take into account frequency and amplitude variation over time, spectral balance and tonality.[9,20] In particular, noise with a marked tonal component is more annoying than a smooth-spectrum noise of the same level. The subjective level of a tonal noise is often evaluated as the measured noise level plus 5 dBA. A similar approach is commonly utilized to assess the effect of intermittent noise. One goal is to reproduce a sound that can be annoying even at relatively moderate levels. The benefit is twofold: (1) to reduce the nonlinear sound absorption and therefore to increase the distance range of the acoustical weapon; (2) at lower levels, the auditory and respiratory traumas are less probable. The other goal is directly opposite and consists of creating a relaxed environment. Loud but peaceful music can possibly calm violent spirits.

Portable Robots With Loudspeakers. In June 1982, the Bekaa Valley in Lebanon became the world's first large-scale robotic battlefield. The Israeli Air Force jets tried to pinpoint the militant groups in the territory controlled by Syria.[20]

> *The Syrian Army had hidden nineteen anti-aircraft missile batteries in the valley to block Israel's bomber squadrons. Soviet trainers had taught the Syrian operators to keep the missile's radar systems switched off as much as possible; they knew that the Israelis would watch for any radar emissions and use the information to evade the missiles or attack them. Soon, the first wave of Israeli planes seemed to appear. The Syrian operators switched on their radars and began tracking and firing . . . However, the aircraft proved to be drones, unmanned model aircraft, which were acting as decoys. Each second that the radars were active, Israeli electronic warfare specialists in a second wave of real aircraft could plot the positions of the batteries and shoot radar-seeking missiles at them. All nineteen batteries were destroyed.*

The potential benefits of robot planes, vehicles, and submarines have been long recognized. The reason is at least twofold: (1) they put no soldier's life at risk; (2) they are much cheaper. For instance, a real fighter-plane costs 8-10 times an unmanned drone aircraft; the difference is mainly due to the cost of providing self-defense measures, an ejection seat and other mechanisms to keep the pilot safe. The use of robot aides – UAV (Unmanned Aerial Vehicles) – by the U.S. army was widespread during the Gulf War in 1991. Now hundreds of projects for unmanned vehicles are developed around the world. The Hermes 450s, which Israel uses to patrol its frontiers, join a number of UAVs being used in the United States to help agents spot illegal immigrants trying to cross the border. The drones weigh almost 1000 lbs, have a 35 ft wingspan and can fly faster than 100 mph. They will patrol at 12,000 to 15,000 ft and can stay aloft for 20 hours at a time. Pilots on the ground will remotely control them unless the flight is preprogrammed, with another agent interpreting the images and using global positioning to send agents to respond to what the drones detect.

Such vehicles (both aerial and ground) can also be adjusted for the transportation and operation of powerful loudspeakers. The benefit is twofold – the operator is neither at risk of being shot by armed rioters, nor at risk of losing health near the working loudspeaker. Moreover, a 'noisy' robot can closely approach the rioters in order to compensate the sound attenuation with distance that is especially significant at low frequencies. The loudspeaker could be steel-shielded for protection against bullets, the noise being radiated through curved metal horns.

Vortex Ring Generators. In some publications, vortex ring generators are mentioned as non-lethal acoustical weapons even though they do not utilize acoustic waves. Vortices occur in nature as tornadoes, waterspouts, cannon smoke rings, etc., assuming a spinning axial or toroidal shape. The field of aerodynamics stimulated vortex studies is related to turbulent flow. In the 1990s, a vortex ring generator was first proposed as a non-lethal weapon to control a large rioting crowd, threatening troops at a stone-throwing distance. The goal was to replace rubber bullets in targeting dangerous individuals to persuade them to vacate the area. A standard grenade launcher can be converted to a vortex generator mode.[21] There are two main design objectives. One is to target an individual with a series of impact pulses at frequencies near the resonant frequencies of the human body. The other design objective is to apply malodorous agents (skunk perfume, etc.) to a riot leader in order to make the supporters pull away from him.

Conclusions

History provides many examples of acoustic weapons used for a psychological effect. Nowadays, powerful loudspeakers, stun grenades and sirens are applied as non-lethal weapons to control riots. Stun grenades are also used by SWAT teams. Vortex ring generators (safer alternatives to rubber bullets) sometimes are defined as a kind of acoustic weapon, although they do not actually use acoustic waves.

There are some rumors and exaggerations in the media about "acoustic bullets" and deadly waves turning "someone's brain to jelly." Indeed, acoustic noise starts inflicting discomfort to the ears at 120 dB and pain at 140 dB in the audio region. Eardrum rupture occurs at approximately 160 dB; lung rupture may happen at 175 dB. So, non-lethal acoustic weapons should create sound levels between 160 dB (to avoid injury) and 120 dB (otherwise, the effect could be neutralized considerably just by using earplugs).

High-intensity noise propagation is rather limited due to: (1) nonlinear sound absorption, increasing with frequency; (2) significant geometric divergence at low frequencies (this factor can also affect troops near the loudspeaker). The distance range of non-lethal acoustic warfare is within a few hundred meters. Some problems can be solved through the implementation of robots (drones or ground vehicles) carrying and automatically controlling powerful loudspeakers. Another concept comes from the understanding that the perceived loudness of a sound is largely determined by its frequency and amplitude variation, spectral balance and tonality. In particular, tonal or intermittent noise is much more annoying than stationary broad-band noise of the same physical level. In general, 'ugly' sound annoys even if its measured level is not too high. Another idea is to create a relaxed audio environment, using loud but peaceful music to calm violent spirits. Yet another application could deal with rioters barricaded inside a building – a powerful infrasound machine connected to the ventilation ducts of the building could create unbearable infrasonic levels at the acoustical resonances of the room-vent systems. Finally, it is noteworthy that the biological effect of infrasound proved to be not as drastic as that described in the media (Gavreau's famous experiments lack support from more recent factual evidence).

References

1. Stanton, Martin N. , "What Price Sticky Foam," *Parameters*, Autumn 1996, pp. 63-68.
2. Altmann, Jürgen, "Acoustic Weapons – A Prospective Assessment," *Science & Global Security*, 1998, Vol. 9, pp. 165-234.
3. Altmann, Jürgen, "Acoustic Weapons – Sources, Propagation and Effects of Strong Sound," ASA/EAA/DAGA Meeting, March 1999, Berlin, Germany.
4. *The Heritage of Russian Verse*, introduced and edited by Dimitri Obolensky, Indiana University Press, Bloomington, IN.
5. Information provided to the author by David Lubman, acoustical consultant, Westminster, CA.
6. Keller, W., *The Bible as History*, translated from the German by W. Neil, 2nd revised edition, Bantam Books, New York, NY 1982.
7. From ABC News Online, 9/3/04, 11:23 pm.
8. Singer, Neal, "Reusable Explosive Device Offers Help to Law Enforcement," Sandia Lab News, Vol. 54, #7, April 2002.
9. Harris, Cyril M., *Acoustical Measurements and Noise Control*, third edition, Acoustical Society of America, 1998.
10. *Noise Control in Industry: Handbook*, edited by E. Ya. Yudin, Moscow, 1985 (in Russian).
11. Belov, E. V., "Effect of Noise of Military Engineering on Psychophysiological Condition of Servicemen," Kazan Branch of Military Artillery University (Internet publication in Russian).
12. Vassiatos, G., "The Sonic Weapon of Vladimir Gavreau," (Internet publication).
13. Vinokur, R. Y., "Infrasonic Sound Pressure in Dwellings at the Helmholtz Resonance Actuated by Environmental Noise and Vibration," *Applied Acoustics*, Vol. 65, 2004, pp. 143-151.
14. Vinokur, R. Y., "The Case of the Mythical Beast," *Quantum* (USA), 1993, Vol. 4, No. 2, pp. 10-14.
15. "Infrasound – Brief Story of Toxicological Literature," *Infrasound Technological Summary*, November 2001 (Internet Publication).
16. Danielson, A. and Landstrom, U., "Blood Pressure Changes in Man During Infrasonic Exposure," An experimental study, *Acta Med. Scand.*, 1985, 217 (5), pp. 531-535.
17. Slarve, R. N. and Johnson, D. L., "Human Whole-Body Exposure to Infrasound," *Aviat. Space Environ. Med.*, 1975, 46(4), pp. 428-431.
18. Morse, Philip M., *Vibration and Sound*, Acoustical Society of America, 1991.
19. Ultrasound, Small Encyclopedia. Moscow, *Soviet Encyclopedia*, 1979. ib. 54.
20. Shukman, D., *Tomorrow's War,* Harcourt Brace & Company, New York, NY 1996.
21. Lucey, George and Jasper, Louis, "Vortex Ring Generator," U.S. Army Research Laboratory (Internet publication).

The author can be contacted at: rvinokr@aol.com.