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# PERCEIVED LOUDNESS OF DISTANT EXPLOSIONS

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**ABSTRACT**
Available hearing threshold measurements show a rapid increase in pressure with decreased frequency down to about 4 Hz. No indications were given, however, about perceived loudness, acceptability, or startle at larger amplitudes for single impulses such as from explosions, sonic booms, thunder, etc. The explosive destruction of TWA Flight 800, in 1996, while climbing from New York en route to Paris, was heard by 100's of ear-witnesses along 40 km of Long Island, but their oral reports are difficult to translate into pressures as needed to estimate the explosion yield. A model has been prepared and will be described, for the yield-dependent wave form, its Fourier series, and air attenuation for extrapolating from 60-gram explosive charges to tonnes of yield. It appears to fit the pattern for the few available reports, but it needs more test evaluation to stand up as evidence for litigation.

***W***itnesses to the destruction of TWA Flight 800, off Long Island, New York, July 26, 1996, reported up to seven bangs, as "loud", "very loud", even "incredibly loud". Some reported that their houses shook from the blast. These reports led to an estimate that at least 1000-kg (1-tn, metric tonne) TNT equivalent was required to give around 20-Pa (120 dB) peak air-blast pressure at their minimum 15-km distance. No publicized cause for this accident, however, seems capable of causing such a large explosion. Further confirmation of this yield is necessary, dependent on interpreting loudness ***words*** of witnesses into wave ***overpressures*** for translation through known explosion overpressure-distance-yield relations [1].

The acoustics community has unresolved debates about effects of ***impulsive*** noises on neighborhood acceptability, but practically nothing has been published about loudness perceptions of single airblasts. Studies of thunder claps have been exclusively concerned with electric currents and close-in shock wave formation which could contribute to damage.

Much is known about sound and its audibility over frequency ranges from 40 kHz down to about 200 Hz [2]. Fundamental frequencies (total of positive and negative phases for even tiny fireworks explosions, however, fall below 100 Hz. We made measurements of 60-mg TNT explosions to try to define ***our*** perceptions of their loudness. At 95 dB (1.125 Pa) in a single cycle of 67 Hz, it was barely heard near 2-km distance when the exact arrival time was known. At closer ranges, one observer felt that 115 dB (11.25 Pa) was "loud". Myself, biased by many years of large explosion testing, estimated that 125 dB (35.6 Pa) was loud enough to gain attention of an unprepared witness. Thus, that previous 120 dB estimate might appear reasonable, except that a 1-ton TNT explosion wave at 15 km range from TWA-800 ***could*** have a somewhat different waveform than simple explosion yield-scaling would predict, in result of air attenuation and weather differences.

Other information on low frequency sound is shown by curves in Figure 1, where brackets show numbered references. A curve for detection threshold, 0 phons) [3], is shown along with higher-valued phon curves, but these were not accompanied by loudness perception labels. Three points [4] from 60-g shots appear to anchor these curves near 85 phons for ***minimum*** explosion wave detection, and about 110 phons loudness to get attention. A dashed curve [5] shows the trend to 4 Hz, with approximate extension to 1 Hz. Short-dashed curves [6] appear to confirm the high frequency minimum shown by phon curves [2]. A long-dashed curve [5] is paralleled, by adding 4.3 Hz, through the 95 dB point in an attempt to predict behavior for larger explosion yields with still lower frequencies. One difficulty is apparent as the phon curve family appears to ***converge*** as it approaches still lower frequencies.

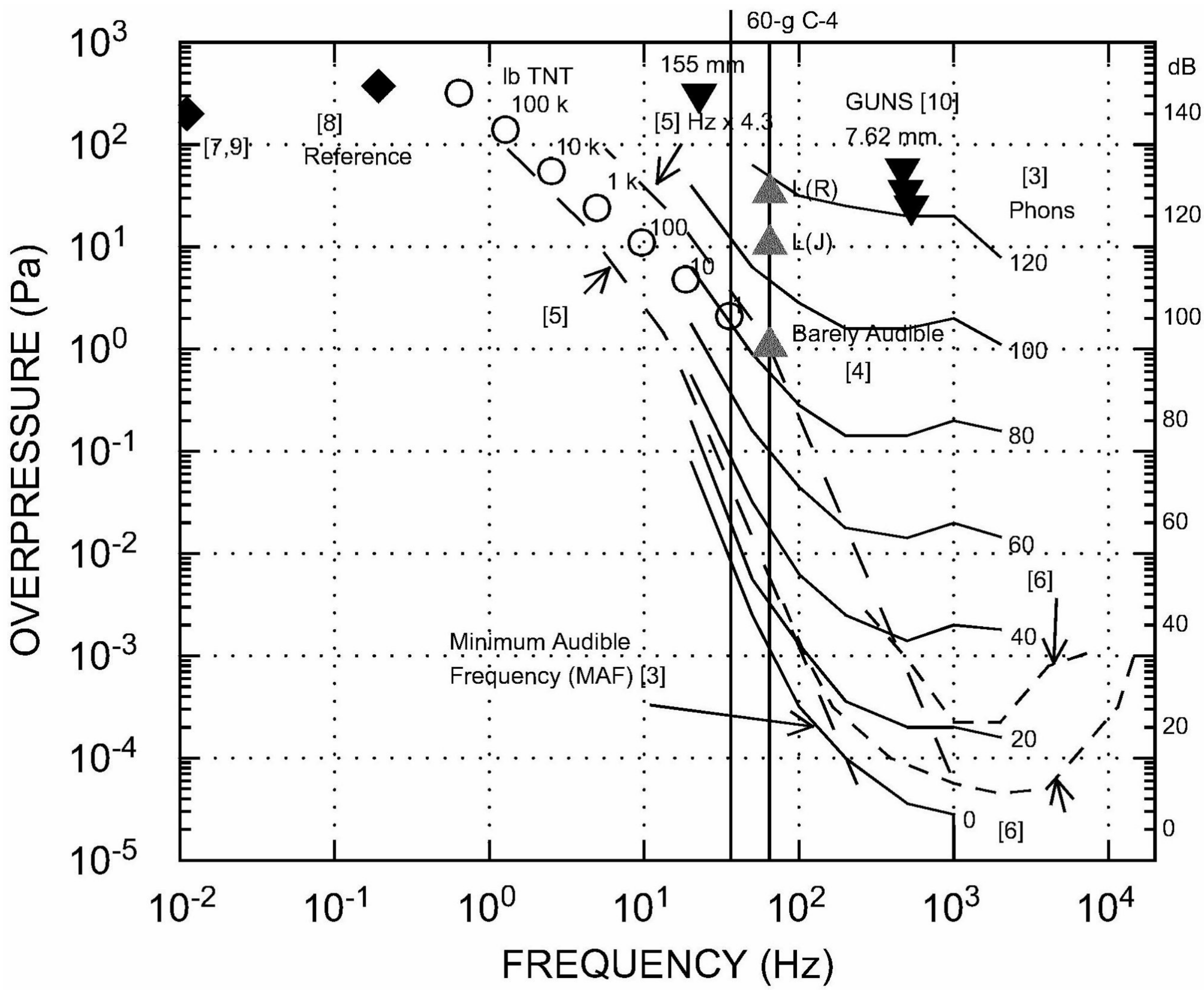


**Figure 1:** Low frequency noise perceptions, based on total wave lengths; updated Jan. 2000.

Estimates were calculated for air-attenuated overpressure and positive phase frequency (circle symbols) for various explosion yields at 15-km distance. It is, however, impossible to ascertain the phon gradient with overpressure for even a 1-tn TNT explosion. It appears that this wave might be near the detection threshold, indicating that an attention-getting airblast from TWA-800 should from even more than 1-tn TNT.

Next, a pair of points [7-9] was included from two events that were ***not*** heard, that appear to confirm rough extensions of curves from [3] and [5]. An airwave from Mount St. Helens' eruption in 1980 was not heard [7] at Toledo, WA, where the weather station barograph recorded a 373 Pa spike (at 2.7 mm $hr^{-1}$ paper speed) that would have broken many windows with an audible compression. The source, a bow wave formed ahead of the erupted ***nue d'ardent,*** had a compression rise time of more than 1.3 s to not shock up to audibility, and less than 5.6 s to have become loud bangs in Seattle, and easily audible as far as 800 km. The USSR 56-Mt H-bomb test explosion in 1961 also was not heard as it spread a 400 Pa amplitude wave across the United States [8], with 90-sec wavelength on Sandia Laboratory microbarographs [9]. Finally, some observed points from rifle and artillery fire were added [10] in the easily heard region.

Positive phase pressure waveforms, expected at 15 km from various explosion yields, are shown in Figure 2. A dashed curve shows the hearing threshold [3] with frequency transformed to half wavelength (positive phase) duration. A second dashed curve follows a path defined by 4.3 times the hearing threshold frequency, as was shown in Figure 1. Alternatively, the 1 tn TNT positive phase duration (PPD), 83 ms, with a sinusoidal waveform would have an audible threshold at 8.5-Pa (112.6 dB) overpressure. To raise this to "loud", and following the most conservative perception [4], adding 20 dB to the minimal detection of 60-g TNT tests, brings the over-pressure to 85 Pa and more than three times the expected overpressure from 1-tn TNT at 15- km range.

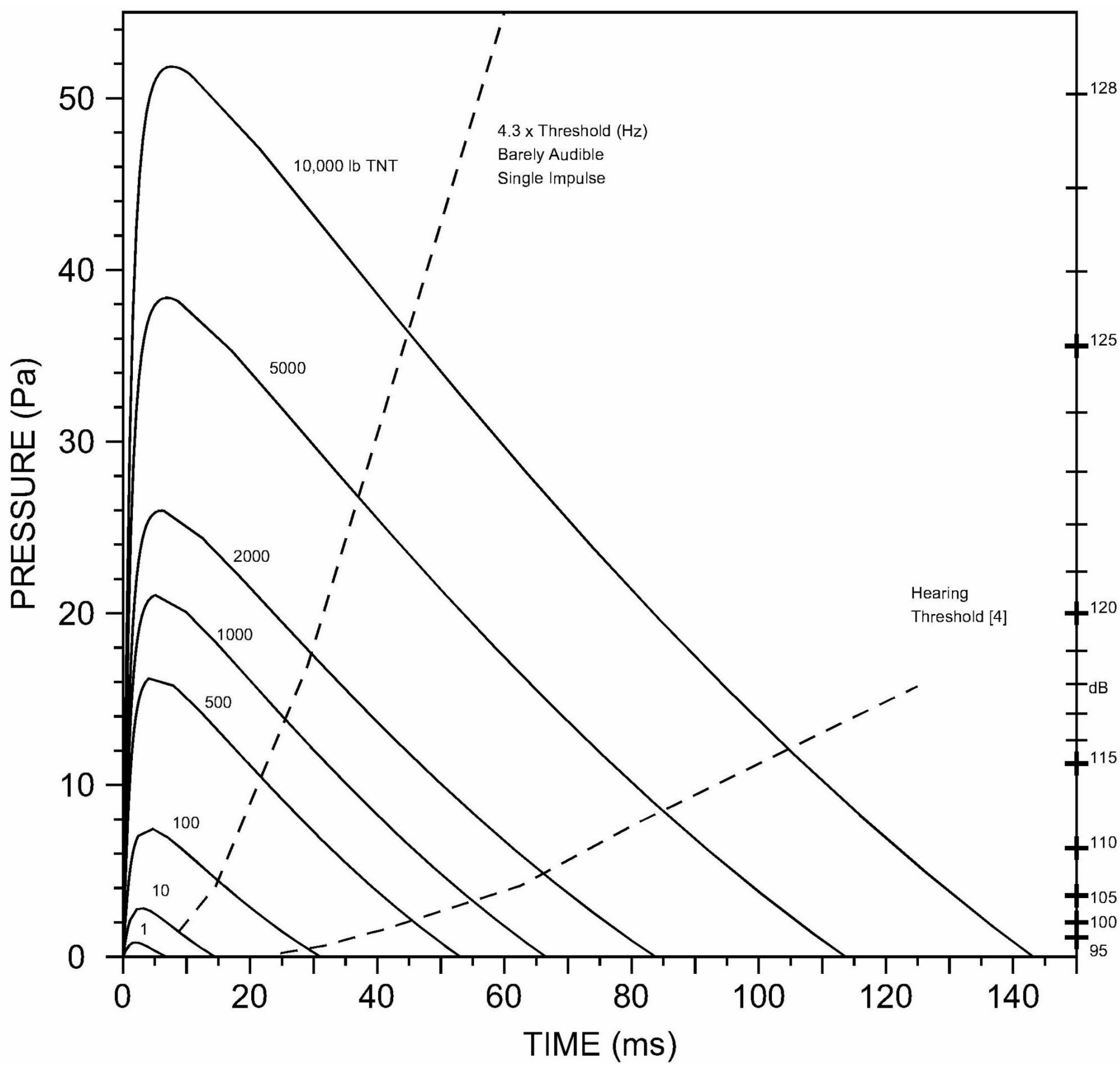


**Figure 2:** Explosion airblast waves at 15 km distance, attenuated by empirical model.

Loudness perception depends, however, on compression rise time that is not approximated by such a sinusoidal assumption. Compression is not, however, practically instantaneous as it is at close ranges and high overpressures. Instead, frequency-dependent atmospheric attenuation smooths the sharp shock peaks as was shown in Figure 2. Two approaches, one empirical [11] and one based on molecular relaxation theory and dependent on humidity [12], were taken to show the difference in results calculated [11] for a 1-tn TNT explosion at 15 km, in Figure 3. Two extremes of humidity, 10% and 100%, are shown as "dry" and "wet" calculations. It turns out that the much earlier-derived empirical model gives close to a mean attenuation, so that was used for calculating the various waveforms in Figure 2.
Rise times to peak overpressure range from 4.5 ms for "wet" air, to 6 ms for the empirical waveform, to 10 ms for "dry" air. The 6 ms value represents one-quarter wavelength of a 42 Hz sinusoidal wave. From Figure 1 this frequency would require 3- Pa (104 dB) overpressure to be barely heard. Adding 20 dB, to reach the lower perception of loud, brings it to 32-Pa overpressure and somewhat above the 26 Pa expectation for 1-tn TNT at 15 km. Adding 30 dB to get the higher reaction raises the overpressure requirement to 100 Pa, requiring many tonnes yield at the distance from Long Island to the TWA Flight 800 disaster.
In summary, it appears that ***at least*** 1tn TNT was necessary to cause the airblast reported along 40 km of coastline. That is likely more than the capability of the several explanations that have been put forward by various factions at various times during investigations of this accident. They have included explosives in carry-on luggage, checked baggage, air-freight canisters, or clandestine caches, but these

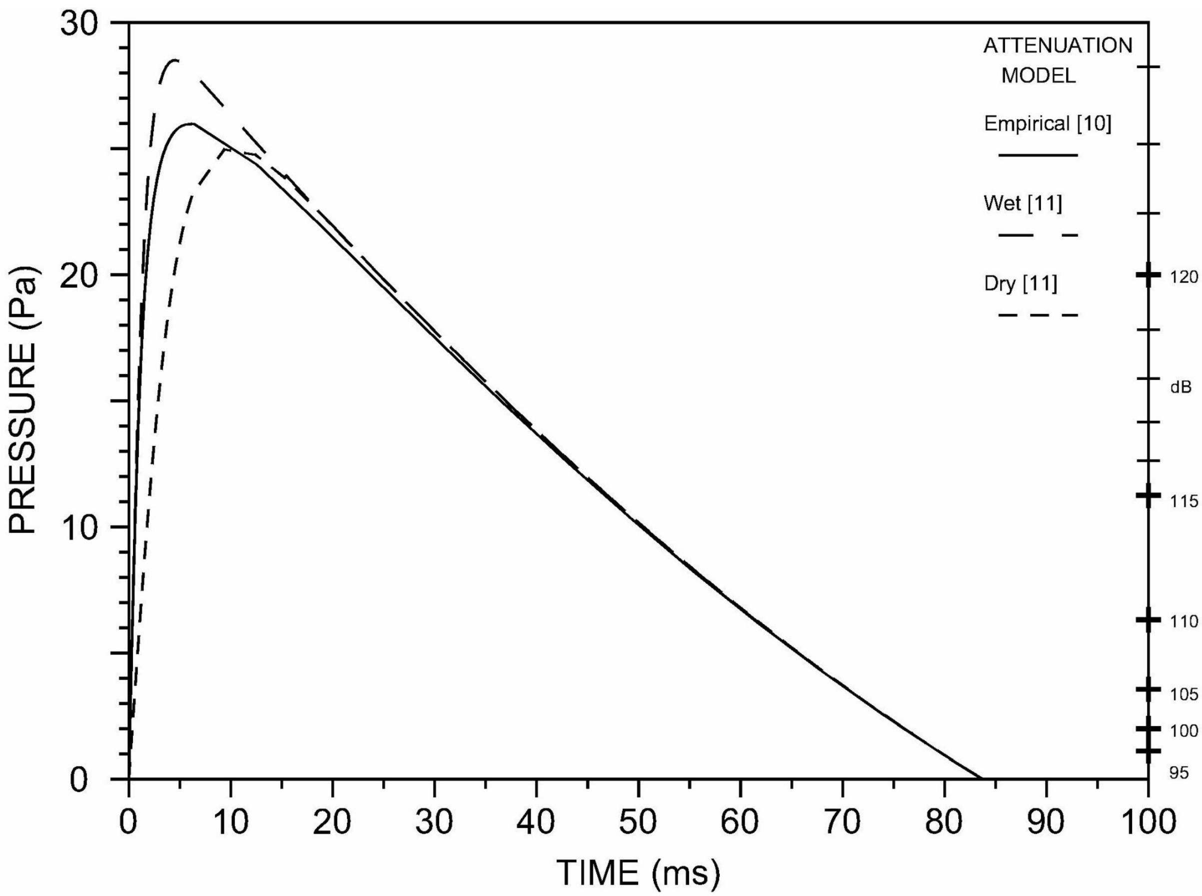


**Figure 3:** Explosion airblast waves signatures 1-ton TNT airburst at 15 km distance.

were eliminated when no signs of an adjacent chemical explosion were found on the wreckage. Only large missiles, from inadvertent friendly fire by naval training exercises or by terrorist attack, could carry such a payload. Such missiles would require a large launch platform that has never been discovered on land or on a large ship with many potential whistle-blowers. Meteorite strikes or their sonic booms, or nearby bolide explosions, all of extremely low probability, did not leave their typical footprints.

There also remains the problem that witnesses reported up to ***seven*** bangs. There were no large reflecting structures in the neighborhood to give such echoes, and a nearby radiosonde weather balloon report showed no possibilities for multipath propagation from a refracting atmosphere. Finally, in what will likely be the "official" explanation for this disaster, spark-ignited fumes in the nearly empty central fuel tank blew the aircraft apart. It would take nearly 200 l of this Jet-A fuel, exactly carbureted to a detonable mixing ratio, to make the necessary noise in a scenario that appears to be refuted by some of the flight data recorder information.

One highly speculative cause remains to be discredited: the earth ***belched*** a cloud of ***methane*** up from extensive methane hydrate deposits far below the seabed. Such an invisible mushroom cloud, and adjacent bubbles, ***could*** have been detonated by either the entering aircraft or by an atmospheric electric charge traveling up an ionized, trailing cloud stem from the earth.

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