National Academy of Medicine

# The repercussions of wind turbine operation on human health

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*Report and recommendations from a Work Group*

In a letter dated March 7, 2005 to the Minister of Health and Solidarity, APSA (Association for the Protection of Abers) requested that the possibility that wind turbines have a harmful effect on human health be studied. The Association sent a copy to the President of the National Academy of Medicine for information purposes. During its March 15, 2005 meeting, the Board of Directors of the Academy deemed it necessary to take up the issue and to entrust a Work Group[a] that was specially created for the task of examining the problem.

## 1 Introduction

Developing wind parks in France is one way to offset the country's energy dependence. However, the populations who live right next to wind turbines in some cases, complain of various functional disorders and report very peculiar noises coming from this vicinity. For roughly ten years, regulations regarding the installation of these machines have included an assessment of the environmental impact, on both flora and fauna, focusing particularly on birds. But the possibility of nuisances for humans, particularly sound nuisances, caused by the operation of these machines has been played down, and the specific way in which it is estimated has not been regulated[1].

This falsely reassuring shortcoming has likely been one reason these populations are concerned. Consequently, it has allowed questionable rumors about illnesses to spread to explain the disorders experienced, particularly rumors concerning the responsibility of infrasounds. These rumors have only intensified the prevalence of functional disorders.

It is understood that these complaints and fears were widespread at the time as they were used as additional arguments for Associations who oppose the installation of these machine for environmental, aesthetic, or economic reasons, which are a matter of public policy and not within the domain of the Academy.

In current scientific literature, there is very little data on the potential hazards for humans that are posed by wind turbines. Reviewing current knowledge and assessing the possibility of this harmfulness was the mission of this work group, and led it to propose a number of recommendations to the Board of Directors.

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[a] This Work Group, composed of Louis Auquier, Jean-Paul Bounhoure, Jean Cauchoix, Yves Chapuis, François Legent, Henri Loo, Pierre Pène, Alain Morgon, and Patrice Tran-Ba-Huy, was chaired by Claude-Henri Chouard.

# 2
# Wind turbines

Wind turbines, whether single isolated machines or a grouping of machines that is improperly referred to as a “wind farm,” are a “renewable” source of energy that is attracting attention around the world. In France, despite the controversy caused by their operation, use of this energy “resource” is starting to grow (see Appendix A) because these installations have been receiving substantial financial incentives for several years. Said incentives are an obvious pecuniary motivation for the individuals and municipalities that accommodate these machines.

But only the owners who lease the land for the installations receive these incentives, while nearby residents reap no benefit at all. When these residents are smallholders who are often retired, they have a certain sense of injustice when they see the value of their modest property plummet. This feeling intensifies the noise nuisance to which this part of the population is subjected. In addition, the private industries responsible for installing wind turbines employ marketing techniques that are sometimes aimed at down-playing the inconveniences related to the proximity of these machines in order to obtain the prior consent of the populations. But the subsequent disappointment of discovering unexpected nuisances surely increases the psychological repercussions of the annoyance experienced.

Despite article 98 concerning wind turbines in the law of July 2, 2003, these machines remain subject only to neighborhood noise regulations (articles R 1336-8 and R 1336-9 of the public health code, and the order of May 10, 1995 concerning the methods for measuring this noise level[2]). As a result, the administrative procedures which must currently be followed to obtain a wind turbine building permit impose no minimum distance from homes. In some cases, homes are less than five hundred meters from these machines.

It is paradoxical that until now, wind turbines, which are mechanical-electric business tax-generating machines for municipalities, have never been considered industrial facilities. Their installation is subject to a specific regulation intended to prevent the risks that their operation may pose, particularly the consequences of sound nuisances inflicted on the neighboring area.

Finally, let us point out that the regulations concerning the measurement of wind turbine sound nuisances vary from country to country. The European Union is beginning to take note of this disparity and recently standardized[b] the methods for measuring noise created in the area around an operating wind turbine. But currently, these European regulations do not include any measurements taken over longer periods of several weeks.

# 3
# Health complaints made by some individuals living near wind turbines.

It is difficult to create a record of these complaints since comprehensive clinical studies lacking any methodological bias are rare in the scientific literature.

[b] CEI directive 61400-11: <http://www.awea.org/standards/iec_stds.html#WG5>

Noise is the most frequent complaint. It is described as tormenting, disconcerting, and consistently surprising because its intensity varies and it is also characterized by strange creaking sounds that are distracting and disrupt rest. When these sounds unexpectedly occur at night, they disrupt sleep by suddenly waking people when the wind picks up, or prevent them from falling back asleep.

Wind turbines have been blamed for other disorders experienced by individuals living near them. These disorders are less specific and not as well described, and they consist of subjective events (headaches, fatigue, passing sensations of inebriation, nausea) and sometimes of objective ones (vomiting, insomnia, palpitations).

It should be noted that the movements of the shadows of rotating blades have been blamed for distracting individuals, thereby posing the risk of causing car accidents and even epileptic seizures.

## 4
## Physical changes caused to the environment by wind turbine operation.

A - The **size of wind turbines**, whose height often reaches over one hundred meters today, and their location on sites that are frequently windy, that is, open and/or elevated sites, may make them visible from distances of several kilometers.

B - This change to the environment is even more obvious when **blade rotation** is taken into account as well. The diameter of a blade alone is nearly one hundred meters. This blade rotation, which has been accused of being hazardous for humans, can injure birds. Current regulations have accounted for this risk so that nesting and migration areas are not disrupted by the installation of these machines.

C - But the biggest change to the environment, as with any industrial facility, is doubtless the creation of **ambient vibrations**.

Whether airborne or structure-borne, when these vibrations are audible they create a **noise** whose physical characteristics have no distinctive feature other than the variability of its parameters, particularly the audibility threshold for humans.

This noise[3] is due to the rotation of the gears of the machinery which brings the blade axis in line with the wind, and of the generator which produces the electricity. It is also due to the friction of the wind on the blades and frame of the wind turbine. This noise is variable and intermittent. In calm weather, wind turbines are still and therefore make little noise. But if the wind picks up or is moderate, the noise created by the installation is always irregular. This noise variability explains the controversies related to the intensity of the noise. It increases its impact on humans by alarming them in a repetitive and unforeseeable manner.

The features of wind turbine noise have just begun to be studied, perhaps due to the complaints voiced by Associations. This noise has been analyzed in the immediate air space of these machines, and further away in the water[4] in offshore wind parks. Likewise, the methods for remote propagation are now well known[5]. Remote propagation depends on the climatic conditions (temperature, humidity, wind speed and wind direction, etc.), but is equally influenced by the topography and environment specific to each site. Rolling topography, for example, may intensify the noise and make it echo (or block it out) in certain places in very localized ways. Conversely, residents living on the seashore do not hear wind turbines despite close proximity because these residents are subjected to, although not bothered by, the constant sound of the waves, the surf, and the wind from the sea.

This variability is illustrated by the recent noise measurements taken in Saint Crépin[6] (Charentes Maritimes department) with modern instrumentation near homes. The readings were taken at 9 different sites. They registered 3 values outside the standard that exceed the authorized noise levels, and in these three cases the wind turbines responsible were over one kilometer from the home where the measurement instrument was placed. However, of the 6 measurements that did not register a value exceeding the standard, 3 corresponded to machines located less than 500 meters from the homes. These differences were due only to the topography of the sites.

For future projects, it would be advisable that for each site considered, acoustic simulations be conducted and readings be taken at the homes in question before construction begins. These simulations therefore now need to be included in the impact assessment for these wind parks.

In France, neighborhood noise measurement, particularly measurement of the noise produced by wind turbines, has been subject to the NF S 31-110 standard since 1995. This standard requires that sound measurements be taken with winds under 20 km/h[7], because for higher speeds, “sound meters may register unwanted sounds”…! This regulatory situation was even more shocking since, on the one hand, it was already easy at that time to overcome this difficulty, and on the other hand, it is much higher wind speeds that tend to set these machines in motion. The application of this standard probably explains most complaints voiced about wind turbines today.

It has been announced that this standard will be changed. But according to the Ministerial[8] documents describing this change, nuisances will be foreseen using software modeling more so than with measurements in the field that account for the variability of the noise spectrum over a long period of time and seasonal variations of wind speed and wind direction. The change may therefore be ineffective.

All this makes it all the more deplorable that when article 98 on wind turbines was written into the law of July 2, 2003, these obviously noisy, electromechanical machines were not immediately considered industrial facilities. Admittedly, a building permit must be obtained for buildings exceeding a certain height and an "impact assessment" must be conducted for buildings exceeding a certain power. But this impact assessment does not take into account the unique nature of the noise generated by these machines, which continues to be regulated by the regulations for ordinary homes. In fact, a minimum sound safety distance must be specified for wind turbines, even if this distance is specific to each installation. This measure alone can prevent sound nuisance. This common sense parameter has until now been ignored to the point that, currently, neither installers nor public authorities can provide any statistics, for each private and public wind turbine (or wind park), on the distance separating each machine from the nearest home.

**Infrasounds** are defined as the lowest area of the noise environment (air, liquid, or solid), which may or may not be audible to humans, and whose somewhat imprecise upper limit is around 20 Hz. They must be very intense to be heard. Consequently, for fear of confusion, they must not be included in the widest range of low-frequency sounds most often given for the vowels and music the human ear can perceive.

Although inaudible, infrasounds are present in our most common environments (see Appendix B). They exist in every industrial environment. At extreme intensities, they are also found in explosions, thunder, and earthquakes. The experimental study of their audibility and their effects on humans and animals requires highly sophisticated laboratories because of their large wavelength and the enormity of the intensities that must be generated in order for them to be perceptible.

### D - The physiopathological effects of noise

The type of effects is a function of intensity[9].

All audible noises, when they are **very intense,** can eventually lead to functional disorders and to subsequent, well-known, lesions of the ear.

But such intensities are only found a few meters from an operating wind turbine, and no one permanently lives or works in such close proximity.

At **moderate intensities**, chronic noises do not lead to lesions of the ear. Perceiving them may, however, cause stress responses to the extent that they are irregular and, above all, poorly tolerated. This induced stress may be responsible for various well-known conditions that are detailed below. In theory, they are prevented by the precautions taken, for example, in the construction of freeways and airports. The pathogeny of the nuisances caused by the noise that is generated in audible frequencies by the intermittent operation of wind turbines is of the same kind.

**Infrasounds**

At the intensities at which they are found at the noisiest industrial sites, infrasounds, which are hardly audible, have no proven pathological effect on humans, unlike frequencies that are higher in the audible spectrum. Only during natural or man-made explosions can they be in any way responsible for the often lethal lesions observed.

Beyond a few meters from these machines, the infrasounds from wind turbine noise quickly become inaudible. They have no impact on human health.

The fallacy of the so-called scientific origin of the rumors spread about infrasounds is detailed[10] in Appendix B.

## 4
## Are wind turbines dangerous for humans?

Some dangers and risks are well known and have already been accounted for through effective preventative measures. Others are less well defined, inconsistent, variable in form, and their assessment in the clinical setting suffers from methodological biases.

**A - The primary dangers include:**

- All accidents involving people due to the preparation of sites, the installation (or disassembly) of wind turbine parks, and their maintenance. These are industrial accidents for which current regulations, if enforced, are sufficient for prevention.
- The operation of wind turbines that involves the risk of trauma caused by the projection of various-sized parts that have accidentally detached from these machines following equipment failure. Preventing such projections requires creating a sufficiently large *no man's land* estimated based on the size of the machines. Said area is not specified in the current regulations, however. Note that this precautionary measure, when taken, is often disregarded or contested by the landowners.
- The same dangers that have been present for decades in some cemeteries of old wind turbines that became obsolete and were abandoned without disassembly because of financial reasons.

The prevention of all these dangers is explicitly provided for in recent regulations, particularly those concerning abandoned sites.

**B - The hypothetical risks of wind turbines**

The psychological and even neurological repercussions of the **shadow flicker effect** caused by the continued observation of blade rotation, particularly in the direction of the sun if it is low on the horizon, are often cited complaints. The fear that wind turbines may have an epileptogenic effect has often been raised. However, although the epileptogenic role of light stimulation has been conclusively demonstrated in other circumstances, we have found no observation in the literature that incriminates wind turbines in this way. This fear is not substantiated by any convincing cases. Moreover, it should be noted that the subject's eyes must be unusually stationary for a period of time long enough for them to send to the brain systems the variations of a light beam that is as narrow and far away as that provided by the rotation of a wind turbine.

**C - The real risk of wind turbines: noise**

Whether very intense or more moderate, noise pollution is the complaint most often cited against wind turbines[11]. It can have a real effect on human health that has been disregarded until now. (see Appendix B)

Recall that acoustic trauma is dangerous in two ways. It can cause lesions of the inner ear if the intensity of noise exposure is high and sustained over a long period. But this intensity has never been observed for homes near wind turbines.

At moderate intensities, noise may cause stress responses, disrupt sleep, and impact general health. It has been demonstrated that a permanent or intermittent acoustic assault, like that experienced in some workshops or near airports and freeways, increases the risk of high blood pressure[12] and heart attack[13]. Likewise, neuroendocrine disorders[14] have been described, with an increase in the secretion of noradrenaline, ACTH, and growth hormones. Finally, sleep disorders are especially frequent in residential areas near large communication routes, with airports being the most difficult to live near due to the intermittent nature of the noise they create. The European Community considers sleep to be disrupted[15] if ambient noise exceeds 45 dB. Ambient noise must only exceed 35 dB to be deemed disruptive to sleep by the World Health Organization.

Some Associations found it acceptable to extrapolate to wind turbines these risks observed near some airports, although no comparable study has been conducted on populations living near wind parks. But, despite the methodological difficulties such an investigation must overcome, a reliable epidemiological study is essential because wind turbines and airports are two very different acoustic sources.

Acoustic assault is increased when noise is highly irregular and therefore distracts individuals. On the other hand, this noise is better tolerated if it is continuous[16]. However, even if acclimatization can reduce the effect of the irregular noise, the subject will have greater difficulty acclimatizing if he or she feels victimized by this noise. Stress and its consequences are a function of how the noise is experienced. In the case of wind turbines, the impact of this nuisance may depend on how it is inflicted on the subject. If he/she has a direct interest, which is most often a material interest, the risks of being bothered are likely much lower.

In any case, preventing these risks is simply a matter of distance from the acoustic source. As long as an epistemological study of these sound nuisances has not been conducted, and considering the results of the recent noise measurements taken with modern means, it would be desirable, for precautionary purposes, to suspend the construction of wind turbines whose parks have power over 2.5 MW if these machines are located too close to homes.

But what would this minimum distance be? In principle, it is difficult to specify a minimum distance that would apply to all parks because, as we have seen, sound propagation, that is, the extent of this nuisance area, depends on topographical and environmental elements specific to each site. A range has, however, been proposed in the ADEME (Agency for Environment and Energy Management) ministerial document cited above[2]. On page 76 thereof, it is estimated that "within 500 m, the project is very unlikely to comply with regulations, and beyond 2,000 m, the risks of non-compliance are very low."

The validity of this approximation is confirmed by the values registered in the Saint-Crépin example cited above.

That is why, within this ADEME range, a distance of 1,500 m may now be proposed as a conservative estimate.

## 5
## Discussion of the mechanisms that can be used to explain the disorders experienced

1- Most functional disorders reported can be interpreted as the general consequences of the aforementioned **chronic noise**.

2 - But others have been blamed on **infrasounds,** arguing that they may be generated by wind turbines at a great enough intensity to cause vestibular-type symptoms

(fatigability, nausea, headaches). This interpretation must be discussed with the following in mind:

- The very low levels of infrasound intensity measured near wind turbines
- The intensity levels over one thousand times higher that these infrasounds would require to be audible, and those over one thousand times higher again for the appearance of mild and temporary vestibular responses sometimes observed in experimental cases.

This fear of infrasounds produced by wind turbines is therefore unfounded.

## 6
## Conclusions

Of the reservations regarding the installation of wind turbines, the Work Group organized for this purpose has studied those concerning human health.

It is of the opinion:

- that the production of infrasounds by wind turbines in their immediate vicinity has been thoroughly analyzed and is very moderate. It poses no danger to humans;
- that there are no proven risks of visual stroboscopic stimulation posed by the rotation of wind turbine blades;
- that the risks of trauma related to the installation, operation, and disassembly of these machines have been provided for and prevented by the regulations in force for industrial sites and which apply to the installation phase as well as the demolition phase for wind turbine sites that have become obsolete.

It recognizes:

- that the real risks of wind turbines operation are related to the possibility of a chronic acoustic trauma whose physiopathological parameters for occurrence are well known and whose impact depends directly on the distance separating the wind turbine from the places where nearby populations live and work.

It notes:

- that current regulations on the impact of the noise created by these machines[17] on human health does not take into consideration:
  - their industrial nature
  - the great irregularity of the audible signals transmitted by these machines
  - the technical progress made in the simulation and recording of acoustic impact over the long term.

- that wind turbine installers, public authorities, and Associations have not compiled any statistics indicating, for each private or public wind turbine (or wind park), the distance separating each machine from the nearest home;

# 7
# Work Group recommendations

To demonstrate the possible harmfulness of wind turbine noise on humans, the Academy considers is essential that two types of studies be conducted involving:

- the development of a procedure for recording, over a period of several weeks, the noise created by wind turbines in homes, then analyzing this noise at different times in order to apply this expertise to the populations in question.
- an epidemiological investigation into the possible health consequences of this wind turbine noise on the populations, which will be correlated with the installation distance of these machines and the results of the measurements proposed above.

Pending the results of these studies, the Academy recommends that the public authorities take the following measures immediately:

- as a cautionary measure, suspend the construction of wind turbines whose parks have over 2.5 MW of power when they are located less than 1,500 m from homes
- modify article 98 of the law of July 2, 2003 as appropriate so that these wind turbines are considered industrial facilities if they exceed a certain power and so that their installation be henceforth subject to specific regulations that account for the highly distinctive sound nuisances that they create.

# 8
# Appendices
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## Appendix 1

## Wind turbines: technical and economic aspects

### Wind energy production around the world

The production of renewable energy is growing all over the world (+1.4% per year), but its share in electricity generation is decreasing (18.1% in 2002 versus 20.5% in 1993) because consumption is increasing every year.

Hydraulic power remains the leading source (90.4%), but it has very low growth (around 1% per year). On the other hand, although wind energy represents only 0.33% of electricity generation in the world, its has begun to experience high growth. In the European Union, where it has increased 37.8% since 1993, 1.5% of electricity today is generated by wind turbines.

### Wind energy production in France

In France, 14% of all electricity is "renewable." Although it is experiencing very fast growth (+59% per year) due to very attractive financial incentives, wind power production as a whole remains limited with just over 200 MW installed[c].

In theory, the possibilities in France are great. It has the second greatest wind resource in Europe after the United Kingdom. It is located on the west coast (on the North Sea in La Rochelle), in the Rhodanian corridor and in Languedoc-Roussillon. The three wind parks constructed in 2004 have a combined power of 43 MW.

France has said it hopes to reach 10,000 MW of wind power by 2010[d].

The power of wind turbines in France varies. Among the largest and most recent examples are the 8 wind turbines of the Bouin Park in Vendée, installed in 2003, which have 2.5 MW of power each. They are 102 m high (including 40 m blades), making them as tall as a 30-story building. Their overall production is estimated at 40 GWh (40 million kilowatt hours), for an “availability” of around 25%. This production represents the electricity consumption, excluding heating, of 20,000 homes, and brings in 200,000 euros in business taxes each year for the municipality of Bouin.

[c] - In comparison, each of the 58 nuclear reactors has between 900 and 1,300 MW of power.
[d] - Considering local opposition which wind farm projects meet, this objective, which would require the installation of nearly 4,000 wind turbines, seems very optimistic.

**Advantages of wind energy**

Wind power is naturally renewable, non-polluting, and does not generate greenhouse gases (excluding the construction process).

In France, for example, wind energy is used to reduce the need for nuclear power plants and therefore to decrease the volume of nuclear waste[e].

It is used to delocalize electricity generation that is well suited to areas without electricity transportation infrastructure, particularly in developing countries.

**Drawbacks of wind energy**

Compared to other forms of electricity generation (hydraulic, conventional fossil fuels, or nuclear), wind energy is much more expensive. The "fuel" is free, but a 2.5 MW wind turbine costs approximately 3 million euro for 0.6 MW of actual average electric power.

Production is hit or miss and highly correlated between wind turbines. Drops in wind speed affect all installations in the same area[f]. This leads to instabilities in the transportation network, which can be thrown out of balance and even break down if the proportion of wind turbines is too high. France is limited to 10,000 MW of wind turbine capacity.

The financial incentives for installing them also fuels discussions on the current actual cost of energy produced in this manner, the reality of the decrease in greenhouse effect it would be responsible for, and even the industrial pollution of some old abandoned installations that were not disassembled.

Wind turbine installation is generally looked upon with disfavor by neighbors and nature protection associations who accuse them of aesthetic and noise pollution.

These nuisances would be mitigated if the turbines were installed offshore. Such installations would, however, be considerably more expensive.

[e] - If 10,000 MW of wind energy were installed, waste would be decreased by approximately 5%.
[f] - During the August 2003 heat wave, wind turbine availability dropped, on average, to 8% of maximum capacity due to lack of wind.

# Appendix B
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# Noise and infrasounds

**Noise**

A noise, which is a set of aperiodic vibrations, is defined by its frequency spectrum and the range of intensities of each of these frequencies. Recall that the anatomy of the human ear makes it very sensitive to the 500 - 4,000 Hz frequency range, and that it is precisely in this range that humans place the most significant frequencies of their speech. At the source, most industrial noises have spectra that are rather close and that differ, above all, in their relative intensities[18], but in which the intensities of the infrasounds are often below that of their audibility.

It must be emphasized that the frequency spectrum of wind turbines is, at the source, comparable to that of any industrial machine.

Distribution of acoustic energy from the source depends on the kind of medium in which it is propagated and the wavelength transmitted. Low frequency distribution is virtually spherical, while that of ultrasounds is practically unidirectional. Energy loss as a function of distance is enormous for high frequencies, low for low frequencies, and varies in about an inverse ratio of the square of the distance for medium frequencies. Thus, several hundred meters away from a source of intense noise, there are hardly any high frequencies and only medium and low frequencies remain. Infrasounds are among those that remain.

**Infrasounds**

The speed at which infrasounds propagate in air is close to that of audible waves, or about 330 m/s. As the wavelength of a sound is inversely proportional to its frequency, the wavelength of a 20 Hz infrasound is about 16 meters, which is much higher than the height of most living organisms, particularly humans.

When a body, whether an object or a living organism, is subjected to infrasounds propagated through the air, this body is immersed in a sound field in which the phase is identical at every moment. Under such conditions, over 90% of the mechanical energy received is reflected by the body. This is not the case if this body contains air-filled organs that do not communicate with the outside (that is, in humans, the tympanic cavity, the digestive tract, and the respiratory tract when the glottis is closed). When propagating through a structure, resulting in the vibration of the walls of an air-filled cavity, for example, the energy absorbed by the body when it touches one of these walls may be much greater.

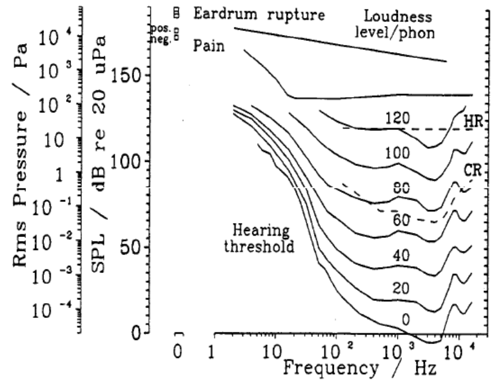


FIGURE 1 (from J. Dancer)

Equal noise contours from Fechner and Munson. Each point corresponds to a pure sound (frequency on the x-axis and sound intensity on the y-axis, in logarithmic coordinates). Each contour line, called an "equal noise contour line," connects points that correspond to sounds that give the same subjective impression of intensity. The lowest area of each contour corresponds to the maximum sensitivity of the ear (500 – 4,000 Hz). The 0 phone contour line corresponds to the lowest audible sounds; the 120 phones contour line corresponds to the pain threshold.

To conduct physiological studies, these features require the use of closed chambers of which two opposite panels have a window filled in with a speaker-type diaphragm. In this way, local pressure variations can be obtained rather easily for small bodies. These variations can be transmitted effectively to small animals. But applying these signals to humans requires much more complex installations. In addition, detecting and measuring infrasounds requires the use of different devices than those used for acoustic waves. Transducers comparable to barometers must be used depending on the frequencies.

Moreover, the directivity of the acoustic waves decreases with frequency. An ultrasonic transmitter radiates in practically a single direction. On the other hand, the waves transmitted by an infrasound generator are practically spherical and radiate in all directions. Above 150 dB, that is, just above their liminal audibility threshold, it quickly becomes impossible to produce, in a controlled and repetitive manner, infrasonic wave levels propagating in free space.

Infrasounds can therefore propagate over considerable distances, provided the energy from their source is great enough. After they are reflected on the high layers of the atmosphere, air infrasounds emitted by a nuclear explosion can travel around the terrestrial globe several times, thereby making it possible to detect these explosions from very far away. In addition, low frequencies propagate better through structures than in the air. Structure-borne infrasounds are less damped than airborne infrasounds.

Natural infrasounds (wind, thunder, etc.) are part of man's natural environment. Although they are inaudible because their intensity is too low, they are produced during many daily activities:

• jogging = 90 dB at 2 H [sic];

- swimming = 140 dB at 0.5 Hz;
- driving in a car with windows down = 115 dB at 15 Hz;
- when the external acoustic canal is scratched in certain ways = 160 dB at 2 Hz;
- machine room (of a passenger ship, for example) = 130-140 dB at 5-20 Hz.

| **Type of source** | **8 Hz** | **16 Hz** | **32 Hz** | **63 Hz** | **125 Hz** |
|---|---|---|---|---|---|
| Light vehicle at 100 km/h | 95 | 90 | 88 | 82 | 78 |
| Truck at 80 km/h | 103 | 105 | 102 | 92 | 88 |
| Train, windows open at 80 km/h | 97 | 101 | 101 | | |
| 1 MW wind turbine at a distance of 100 m | 58 | | 74 | 83 | 90 |
| **Audibility threshold** | **105** | **95** | **66** | **45** | **29** |

TABLE I (from J. Rolland)
Audibility threshold in dBA of low frequencies and some infrasounds that can be detected with instruments in everyday conditions.

As the frequency of a sound drops below the area of speech frequencies, the energy needed for the human ear to perceive it increases rapidly. In addition, although the ear can recognize a tone at high frequencies up to 20 Hz, in the low frequency ranges below this area it can only perceive distinct phenomena described as beats. This distinctive feature is part of the definition of infrasounds. But 20 Hz is an imprecise limit because the non-linearity of the average ear causes distortions that are responsible for the variable perception of unwanted noise.

At intensities under 160 dB, the physiopathological effects of infrasounds are well recorded, even if their study in humans involves large facilities that only exist in highly specialized laboratories.

The infrasound audibility threshold in humans is 105 dB for 8 Hz, 95 dB for 16 Hz, 66 dB for 32 Hz, 45 dB for 63 Hz, and 29 dB for 29 Hz. The pain threshold is between 140 db at 20 Hz and 162 dB at 3 Hz. No auditory fatigue is observed for neither 140 dB at 14 Hz for 30 minutes nor for 170 dB between 1 and 10 Hz for 30 seconds.

But these are huge amounts of energy that are only found (outside the laboratory) in explosions.

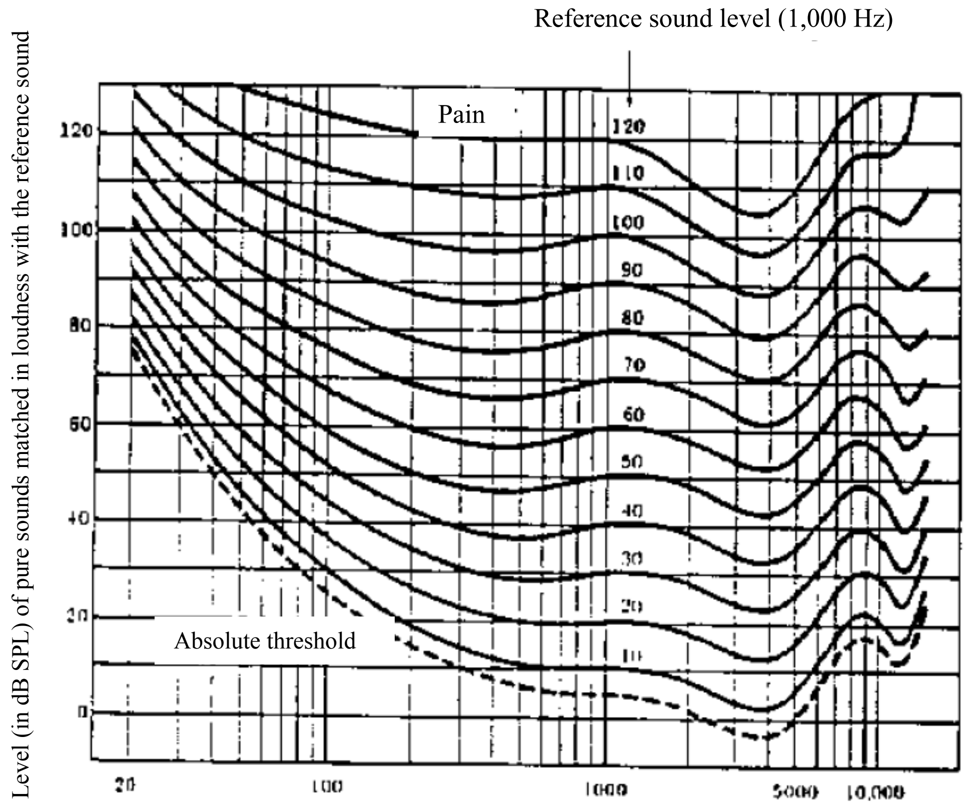


FIGURE 2 (from A. Dancer)

Energy needed (on the x-axis) to obtain the liminal threshold and the equivalent intensity sensation thresholds compared to a 1,000 Hz reference sound for different frequencies (on the y-axis). Infrasounds (at the top left of the figure) require a very high intensity in order to be perceived and an intensity which is completely outside the norm in order to approach the pain threshold.

Infrasounds, like audible sounds, can also give rise to **resonance phenomena**; the chest resonates between 40 and 60 Hz, and the abdomen resonates slightly between 4 and 8 Hz. The opening of the glottis allows the thoracic air content to resonate at 1 Hz, so that around 165 dB, passive breathing modulated by the infrasound can be observed.

The middle ear is the first to show adverse effects as infrasound intensity increases because the elastic membrane of the eardrum is sensitive to pressure variations and absorbs energy better than the rest of the body. Beginning at 130 dB, temporary eardrum hyperaemia can therefore be observed when stimulation stops.

Levels over 160 dB, which could cause cochlear lesions, would require generators with power and dimensions that are totally unrealistic in free space.

Vestibular illnesses are the most common phenomena triggered in the inner ear by infrasounds. These disorders are a reflection of the distribution to the vestibule of the energy delivered to the labyrinthine fluids by the stapes. During tympanometry, a routine clinical audiometry procedure, static pressure is applied in the external auditory canal, which exerts monaural pressure and can cause slight vertigo. And yet, in animals, exposure to 169 dB at 10 Hz or to 158 dB at 30 Hz does not lead to nystagmus. In humans subjected to levels varying between 142 and 150 dB, nystagmus is not observed either, whether the stimulation is monaural or bilateral and whether it is in phase or out of phase. However, tone bursts and modulated amplitude sounds may, during monaural or dissymmetrical application of 125 dB at a rate of three per second, produce rapid eye movements or temporary lack of balance.

Moreover, when approaching speech frequencies, coughing and a "smothering sensation" were reported during exposure to siren noises between 150 and 154 dB in the 50 to 100 Hz range. Discomfort is only observed with certain stimuli, including those in a sound spectrum having steep slopes at low frequencies (8 dB/oct.) and at an intensity greater than that of the sound perception threshold. “Psychological” effects, along with lack of concentration, may appear at over 110 dB in healthy subjects experimentally subjected to infrasounds.

In the special case of wind turbines, it should be noted that:

- at a distance of 100 meters from a 1 MW wind turbine, one records 58 dB at a frequency of 8 Hz, 74 dB at a frequency of 32 Hz, 83 dB at a frequency of 63 Hz, and 90 dB at a frequency of 125 Hz;
- the low frequencies measured 100 meters from wind turbines are therefore at least 40 dB below the audibility threshold.

At this distance, the intensity of the infrasounds is so weak[19] that these machines cannot create the discomfort or drowsiness related to infrasound activity on the vestibular part of the inner ear, which can only be observed at the highest intensities than can be created under experimental conditions.

## Fantasies brought about by infrasounds

For some of the population, and unlike sound waves that everyone can perceive, low frequencies are part of a mysterious world that frightens people. The reasons cited for this are the following:

- they accompany destructive events: thunder, explosions (especially nuclear), etc.
- these waves propagate over great distances
- it is very difficult to protect oneself from infrasonic waves which penetrate buildings very easily from the outside
- the physiological phenomena that they can cause at very high intensities are feared.

It should be noted that the general public is unaware that these high intensities, for which man's ingenuity may be responsible (explosions of various kinds, supersonic bang, etc.), have nothing to do with the intensity of the infrasounds produced by the rest of human industrial activity, particularly the intensity created by wind turbines.

This fear of infrasounds is perpetuated, particularly on the Internet, by references to a publication[20] dating back to 1966. This old paper was just analyzed by G. Leventhall[21]. He summarized all the points of this paper and methodically evaluated each one. He was able to show that, with respect to current requirements for a scientific paper, the methodology employed was unacceptable as well as its conclusions.

# Appendix C
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# Bibliography

The scientific bibliography concerning human pathologies caused by wind turbines is limited.

This scarcity is even more marked when only **impact assessments of infrasounds on humans** are taken into account. In 2005, Medline only found 179 articles on this topic. Most often, the activity of infrasounds on humans was only mentioned within the context of a more general study of the effects of acoustic stimulation. Therefore, our investigation focused primarily on current knowledge of infrasounds by inviting two specialists of these physical phenomena to speak during our hearings:

- Mr. Jacques Rolland, Director of the Centre Scientifique et Technique du Bâtiment (Scientific and Technical Center for Construction) in Grenoble[g]
- Dr. Armand Dancer, Director of Research at the Institut de Recherches Franco-Allemand (French-German Research Institute) in Saint-Louis[h].

Because they are so recent, the original publications of the **First International Conference on Wind Turbine Noise: Perspectives for Control** should also be emphasized**.** They have not yet been published and are not yet available on the Internet, but can be consulted at the Academy Library.

Despite the lack of scientific rigor of most websites that deal with the relationships between infrasounds and wind turbines, they cannot be ignored as their influence on the populations in question can be considerable. To this effect, we would like to mention the 2002 paper which can be read at http://crrm.u-3mrs.fr/ile-

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[h] French-German Research Institute – ISL – 68301 Saint-Louis, France.

rousse/2002/IleRousse2002.pdf entitled « Les infrasons entre science et mythe: la bibliométrie peut-elle contribuer à clarifier une vérité scientifique controversée ? » (“Infrasounds, between science and myth: can bibliometrics help clarify a controversial scientific truth?”). The author, engineer Bertrand Goujard, discusses his study of the bibliography on the Internet that deals with infrasounds, and which is worth reading.

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## Bibliographic references cited in the body of the Report.

[see source document for bibliography]